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Shengzhao Long
Balbir S. Dhillon
Editors

Man-Machine-Environment System Engineering

Proceedings of the 16th International Conference on MMESE

MMESE

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Man-Machine-Environment System Engineering

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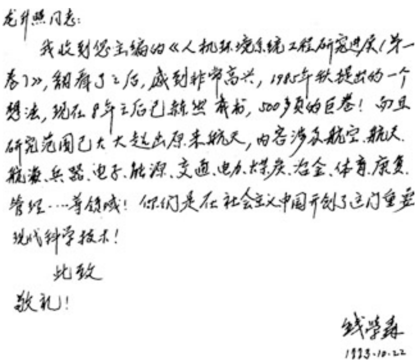
Xuesen Qian's Sky-high Estimation

Grandness Scientist Xuesen Qian's Sky-high Estimation for the Man-Machine-Environment System Engineering



龙升照同志：

我收到您主编的《人机环境系统工程研究进展（第一卷）》，翻看了之后，感到非常高兴，1985年秋提出的一个想法，现在8年之后已蔚然成书，500多页的巨卷！而且研究范围已大大超出原来航天，内容涉及航空、航天、航海、兵器、电子、能源、交通、电力、煤炭、冶金、体育、康复、管理……等领域！你们是在社会主义中国开创了这门重要现代科学技术！

此致

敬礼！

钱学森

1993.10.22

Xuesen Qian's Congratulatory Letter

Grandness Scientist Xuesen Qian's Congratulatory Letter to the 20th Anniversary Commemorative Conference of Man-Machine-Environment System Engineering Foundation

龙升照同志：

你的来信已收到。欣悉人-机-环境系统工程创立 20 周年纪念大会暨第五届全国人-机-环境系统工程学术会议即将召开，我向你们表示最热烈的祝贺！

20 年来，你们在人-机-环境系统工程这一新兴科学领域进行了积极的开拓和探索，并取得了非常可喜的成绩，我感到由衷的高兴。

希望你们今后再接再励，大力推动人-机-环境系统工程理论及应用的蓬勃发展，为中国乃至世界科学技术的进步作出积极贡献！

祝

工作顺利！

钱学森

2001年6月26日

Preface

In 1981, under the directing of the great scientist Xuesen Qian, an integrated frontier science—Man-Machine-Environment System Engineering (MMESE)—came into being in China. Xuesen Qian gave high praise to this emerging science. In the letter to Shengzhao Long, he pointed out, “You are creating this very important modern science and technology in China!” in October 22, 1993.

In the congratulation letter to the commemoration meeting of 20th anniversary of establishing the Man-Machine-Environment System Engineering, the great scientist Xuesen Qian stated, “You have made active development and exploration in this new emerging science of MMESE, and obtained encouraging achievements. I am sincerely pleased and hope you can do even more to make prosper development in the theory and application of MMESE, and *make positive contribution to the progress of science and technology in China, and even in the whole world*” in June 26, 2001.

October 22, which is the day that the great scientist Xuesen Qian gave high praise to MMESE, was determined to be Foundation Commemoration Day of MMESE by the 2nd conference of the 5th MMESE Committee on October 22, 2010. On this very special day, the great scientist Xuesen Qian pointed out in the letter to Shengzhao Long, “You are creating this very important modern science and technology in China!” and the conference also determined that the annual conference on MMESE would be held from October 21–23 to cherish the memory of the great contributions that the great scientist Xuesen Qian had made to the MMESE!

The 16th International Conference on MMESE will be held in Xi’an, China on October 21–23 of this year; hence, we will dedicate *Man-Machine-Environment System Engineering: Proceedings of the 16th International Conference on MMESE* to our readers.

Man-Machine-Environment System Engineering: Proceedings of the 16th International Conference on MMESE is the academic showcase of the 16th International Conference on MMESE jointly held by MMESE Committee of China and Beijing KeCui Academe of MMESE in Xi'an, China. The *Man-Machine-Environment System Engineering: Proceedings of the 16th International Conference on MMESE* is consisted of 70 more excellent papers selected from more than 400 papers. Due to limitations on space, some excellent papers have been left out, we feel deeply sorry for that. Crudeness in contents and possible incorrectness are inevitable due to the somewhat pressing editing time and we hope you kindly point them out promptly, and your valuable comments and suggestions are also welcomed.

Man-Machine-Environment System Engineering: Proceedings of the 16th International Conference on MMESE will be published by Springer-Verlag, German. Springer-Verlag is also responsible for the related matters on index of Index to EI, so that the world can know the research quality and development trend of MMESE theory and application. Therefore, the publication of *Man-Machine-Environment System Engineering: Proceedings of the 16th International Conference on MMESE* will greatly promote the vigorous development of MMESE in the world, and realize the grand object of "making positive contribution to the progress of science and technology in China, and even in the whole world" proposed by Xuesen Qian.

We would like to express our sincere thanks to Springer-Verlag, German, for their full support and help during the publishing process.

Beijing, China
July 2016

Prof. Shengzhao Long

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Part VII Research on the Overall Performance of Man-Machine-Environment System

About the Editors

Prof. Shengzhao Long is the founder of the Man-Machine-Environment System Engineering (MMESE), the chairman of the Man-Machine-Environment System Engineering (MMESE) Committee of China, the chairman of the Beijing KeCui Academy of Man-Machine-Environment System Engineering (MMESE), and the former director of Ergonomics Lab of Astronuat Rearch and Training Center of China. In October 1992, he is honored by the National Government Specific Allowance.

He is graduated from the Shanghai Science and Technology University in 1965, China. In 1981, directing under famous Scientist Xuesen Qian, he founded MMESE theory. In 1982, he proposed and developed Human Fuzzy Control Model using fuzzy mathematics. From August of 1986 to August of 1987, he conducted research in Man-Machine System as a visiting scholar at Tufts University, Massachusetts, USA. In 1993, he organized Man-Machine-Environment System Engineering (MMESE) Committee of China. He published "Foundation of theory and application of Man-Machine-Environment System Engineering" (2004) and "Man-Machine-Environment System Engineering" (1987). Edited "Proceedings of the 1st–15th Conference on Man-Machine-Environment System Engineering" (1993–2015). E-mail: shzhlong@sina.com

Dr. Balbir S. Dhillon is a Professor of Engineering Management in the Department of Mechanical Engineering at the University of Ottawa, Canada. He has served as a Chairman/Director of Mechanical Engineering Department/ Engineering Management Program for over 10 years at the same institution. He has published over 345 (i.e., 201 journal + 144 conference proceedings) articles on reliability, safety, engineering management, etc. He is or has been on the editorial boards of nine international scientific journals. In addition, Dr. Dhillon has written 34 books on various aspects of reliability, design, safety, quality, and engineering management published by Wiley (1981), Van Nostrand (1982), Butterworth (1983), Marcel Dekker (1984), Pergamon (1986), etc. His books are being used in over 85 countries and many of them are translated into languages such as German, Russian, and Chinese. He has served as general chairman of two international conferences on reliability and quality control held in Los Angeles and Paris in 1987.

Professor Dhillon has served as a consultant to various organizations and bodies and has many years of experience in the industrial sector. At the University of Ottawa, he has been teaching reliability, quality, engineering management, design, and related areas for over 29 years, and he has also lectured in over 50 countries, including keynote addresses at various international scientific conferences held in North America, Europe, Asia, and Africa. In March 2004, Dr. Dhillon was a distinguished speaker at the Conference/Workshop on Surgical Errors (sponsored by White House Health and Safety Committee and Pentagon), held at the Capitol Hill (One Constitution Avenue, Washington, DC).

Professor Dhillon attended the University of Wales where he received a BS in electrical and electronic engineering and an MS in mechanical engineering. He received a Ph.D. in industrial engineering from the University of Windsor. E-mail: dhillon@genie.uottawa.ca

Part I
Research on the Man Character

Head-Related Transfer Function Database of Chinese Male Pilots

Xiaochao Guo, Duanqin Xiong, Yanyan Wang, Yiping Ma, Dongdong Lu and Qingfeng Liu

Abstract A head-related transfer function (HRTF) measurement was conducted to explore the 3-D audio displays with 58 male pilot participants in free field of acoustics in hemi-anechoic room. 50 items of head-related anthropometric parameters were measure by 3D probe. 13 elevations (φ) from −40° to +80° and 723 azimuths (θ) were selected to position 3-D sound in test, and head-related impulse responses (HRIR) were collected by omnidirectional microphones inserted bi-ears of pilots. The first HRTF database of Chinese male pilots was built with more than 6.86 hundred millions digital data. It suggested that some asymmetries were found in HRIR and anthropometry of right–left ears by analysis.

Keywords Head-related transfer function (HRTF) · Head-related impulse response (HRIR) · Male pilots · Head · Anthropometry · 3-D audio

1 Introduction

The head-related transfer function (HRTF) database is the key fundamental to 3-D audio displays in virtual reality and directional signal representation by hearing. There are two famous databanks in the area of HRTF measurements. The CIPIC HRTF Database included head-related impulse responses for 45 subjects at 25 different azimuths and 50 different elevations (1250 directions) at approximately 5 angular increments in addition to 27 items of anthropometric parameters [1]. In the MIT HRTF Library, 710 different directions were sampled at elevations from −40° to +90° to obtain the HRTF impulse responses at a sampling rate of 44.1 kHz with a

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KEMAR dummy-head microphone [2]. In China, a HRTF database based on the measurements of 26 males and 26 females in university was established with 9 different elevations (493 directions) and 4 items of anthropometric parameters [3]. To explore the nature of HRTF and 3-D audio displays, 58 pilots were measured and a HRTF database of Chinese male pilots was built in the present paper.

2 Method

2.1 *Head-Related Anthropometric Parameters*

93 mark points were defined in 3-D coordinate based on OAE or Frankfurt plane in anthropometry on human head above torso, and 50 items of anthropometric parameters were first derived from the 3D probe with ROMER Absolute Arm in which there were 17 pairs of parameters for right–left measurements.

2.2 *Head-Related Impulse Response (HRIR) to 3D Sound*

2.2.1 Free Field of Acoustics in Hemi-anechoic Room

A hemi-anechoic room was built according to GB/T 6882-2008 which is identical to ISO7345:2003 [4]. The free field radius of acoustics is more than 2.2 m for frequency range of 80 Hz–16 kHz, and 2.8 m for frequency band of 200 Hz–16 kHz, with background noise less than 10 dB(A) [5].

2.2.2 Maned HRTF Measurement Device

A manned HRTF measurement turntable was designed and set in the free field of acoustics in the hemi-anechoic room mentioned above to orient the sound source to human listener as shown in Fig. 1 [6]. The MLS signal was generated by PC and presented as stimulus by a loudspeaker while head-related impulse responses were collected by two DPA 4060-BM microphones put into external acoustics meatus of human bi-ears with 44.1 kHz A/D sampling rate.

2.2.3 Positions of the Sound Source on the Spherical Space

Sound source location was specified by the elevation angle (φ) and azimuth angle (θ) listed in Table 1. The (φ, 0°) and (φ, 180°) were used to check the head position of human subject by test–retest procedure as same as the (φ, 180°) and (φ, 360°) to

Table 1 The numbers of HRTF measurement N in different elevation (φ) and azimuth (θ)

φ	−40°	−30°	−20°	−10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
$\Delta\theta$	6°/7°	6°	5°	5°	5°	5°	5°	6°	6°/7°	8°	10°	15°	30°
N	57	61	73	73	73	73	73	61	57	47[a]	37	25	13

[a](50°, 180°) was inserted between (50°, 176°) and (50°, 184°) for test–retest checking

control the human error because of head moving during test. So there were 723 spatial sampling points on the spherical space with a 1.2 m radius.

2.3 Participants of Pilots

There were 58 male pilots aged 34.02 ± 3.14 in years with total flight time of 1985.89 ± 976.41 h taking part in the HRTF measurement.

3 Results

In total, 3886 (67 × 58) head-related anthropometric parameters and 83,868 (723 × 2×58) head-related impulse responses to 3D sound in format of .wav were measured. There were more than 6.86 hundred millions digital data in the HRTF database of Chinese Male Pilots. Some anthropometric parameters were listed in Table 2. The HRTF trends were shown as in Figs. 1 and 2.

4 Discussions

4.1 Asymmetry of Head-Related Anthropometric Parameters

The ears of human are collectors and sensors of sound waves, and play important roles in 3-D spatial orientation by hearing. It is very interesting that 10 of 17 anthropometric parameters were significantly different in statistics in Table 2. It was also found that the included angle of auricula and side of skull was 30°–60°, the angle of auricular concha and side of skull was about 90° in coronal plane, auricle length was averaged in 59.3 mm (46.2–74.4 mm) for the right and 60.0 mm

Table 2 Some anthropometric parameters of pilots in HRTF database (mm)

Items of anthropometry		Mean	Std. deviation	Percentiles			*T*-test	*P*
				5th	50th	95th		
Ear implantation	R	57.88	4.27	49.03	58.11	63.72	−1.03	0.307
	L	58.26	4.21	49.44	58.51	64.10		
Physiognomic ear length	R	65.90	3.87	59.70	65.26	72.32	2.82	0.007
	L	64.34	4.89	57.32	64.59	71.50		
Cavum concha height	R	21.12	2.28	18.40	20.99	24.95	2.21	0.031
	L	20.65	2.11	17.68	20.75	23.69		
Cymba concha height	R	12.85	1.76	10.25	12.68	16.02	1.00	0.324
	L	12.47	3.08	8.64	12.23	15.61		
Cavum concha width	R	21.51	3.48	15.98	21.20	29.17	−2.30	0.025
	L	23.12	4.26	16.79	22.85	30.44		
Fossa height	R	11.71	1.71	8.94	11.50	14.87	−1.77	0.083
	L	12.28	1.93	9.38	12.19	15.43		
Pinna width	R	24.22	3.87	17.20	24.33	29.38	−4.19	0.000
	L	26.59	3.22	21.86	26.11	34.43		
Intertragal incisure width	R	8.40	3.51	4.40	7.71	11.84	−2.32	0.024
	L	9.23	5.58	5.26	8.31	12.71		
Cavum concha depth I	R	15.23	2.48	11.35	15.10	19.02	2.62	0.011
	L	14.43	2.36	11.45	14.15	18.14		
Cavum concha depth II	R	13.39	1.88	10.88	13.33	16.43	−0.01	0.991
	L	13.40	2.62	10.13	13.12	17.36		
Cavum concha depth III	R	20.62	2.12	16.57	20.65	24.41	−2.43	0.018
	L	21.34	2.41	17.18	21.36	25.86		
Cymba concha depth I	R	7.57	1.32	5.43	7.53	10.42	−1.21	0.231
	L	7.83	1.30	6.04	7.70	10.36		
Cymba concha depth II	R	20.43	2.42	16.37	20.65	24.39	−3.24	0.002
	L	21.47	2.52	17.56	21.36	26.31		
Cymba concha depth III	R	14.87	1.84	11.37	15.29	17.21	−3.11	0.003
	L	15.90	2.66	10.05	16.40	20.21		
Fossa depth	R	15.01	3.79	8.84	14.45	23.01	1.05	0.298
	L	14.29	4.77	9.34	13.70	21.81		
Pinna rotation angle (°)	R	13.38	5.22	5.11	13.32	25.16	−1.26	0.211
	L	14.21	5.80	4.15	14.54	24.94		
Pinna flare angle (°)	R	56.19	15.77	36.71	52.34	88.66	0.61	0.542
	L	55.27	13.29	36.07	52.08	84.99		

(48.0–71.0 mm) for the left, and auricle breadth was averagely in 30.0 mm (24.0–37.5 mm) for the right and 31.0 mm (20.6–40.0 mm) for the left [7]. All this meant that some asymmetry of external ears exist and maybe influence HRTF.

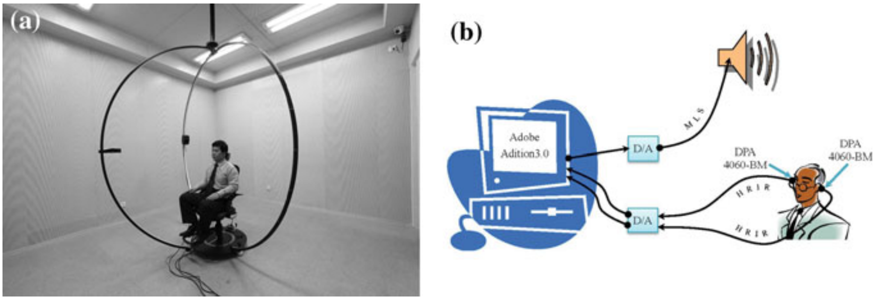

Fig. 1 The test sketch of HRTF measurement of male pilots. **a** HRTF test in hemi-anechoic room, **b** stimulus-response flow in HRTF test

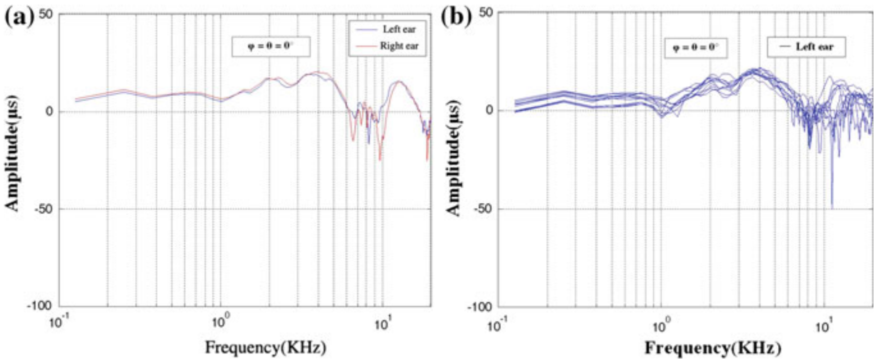

Fig. 2 The HRTF magnitudes of pilots in database at different frequencies. **a** one pilot, **b** 20 pilots

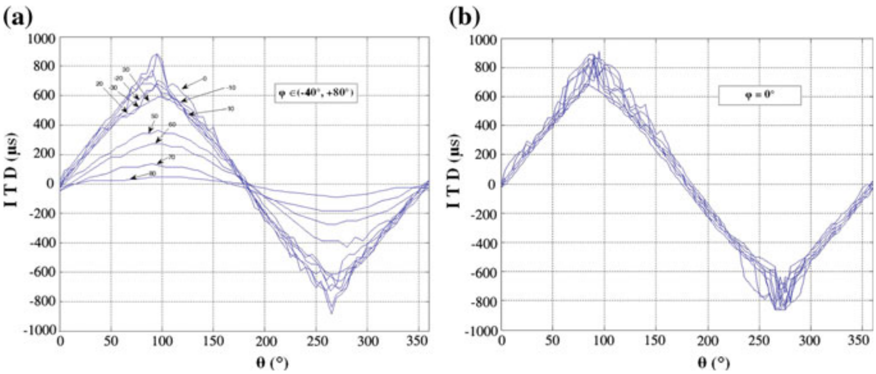

Fig. 3 The interaural time difference (ITD) of pilots in database at different azimuths. **a** one pilot, **b** 10 pilots

Table 3 Head-related anthropometric factors extracted by Principal Component Analysis for 67 items (partial)

	Items	Components in rotated component matrix																						
		c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12	c13	c14	c15	c16	c17	c18	c19	c20	c21	c22	c23
[a]	Physiognomic ear length (R)				0.62																			
	Physiognomic ear length (L)	0.51			0.51																			
[b]	Cavum concha height (R)	0.60																						
	Cavum concha height (L)	0.60																						
[b]	Cymba concha height (R)																					−0.73		
	Cymba concha height (L)	−0.74																						
[b]	Cavum concha width (R)												0.91											
	Cavum concha width (L)	−0.54																						
[b]	Fossa height (R)									0.87														
	Fossa height (L)										0.85													
[b]	Pinna width (R)															−0.90								
	Pinna width (L)																				0.87			
[b]	Intertragal incisure width (R)	−0.83																						

(continued)

Table 3 (continued)

	Items	Components in rotated component matrix																						
		c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12	c13	c14	c15	c16	c17	c18	c19	c20	c21	c22	c23
	Intertragal incisure width (L)	−0.91																						
[b]	Cavum concha depth I (R)																						0.54	
	Cavum concha depth I (L)	−0.55										0.72												
	Cavum concha depth II (R)																							0.61
	Cavum concha depth II (L)	−0.72																						
	Cymba concha depth I (R)																		0.85					
	Cymba concha depth I (L)	−0.59																						
	Cymba concha depth II (R)						0.58																	
	Cymba concha depth II (L)						0.81																	
[b]	Pinna rotation angle (R)								0.87															
[b]	Pinna flare angle (R)							0.74																
	Total for ears	11/28	0/5	0/5	4/4	0/3	3/3	2/2	2/2	1/1	1/1	1/1	1/1	0/3	0/1	1/1	0/1	0/1	1/1	1/1	1/1	1/1	1/1	1/1

[a]GJB4856-2003
[b]CIPIC HRTF Database

4.2 Characteristics of HRIR to 3D Sound

The HRIRs of right–left ears were different in band of 6.0+ KHz in addition to individual differences in frequency domain among pilots as shown in Fig. 2 that maybe related to the asymmetry of bi-ear anthropometry. The interaural time differences (ITD) were smallest when the loudspeaker was set in the midsagittal plane (front/back) and biggest when 3-D sound source was positioned in the coronal plane (left/right) with variety in elevations (φ), although the maximum of absolute ITD were averaged 680–900 μs (in Fig. 3), which may reflected the interaction of sound distances to ears and head-related anthropometry.

4.3 Factor Analysis of Head-Related Anthropometric Parameters

All 67 items of anthropometry were defined in accordance with GJB4856 [8] or the CIPIC HRTF Database [1]. There were 23 principal components extracted after Varimax rotation with Kaiser Normalization converged in 23 iterations and 91.46 % of total variance explained by factor analysis (Table 3). It is found that 14 of the 23 components were out of Chinese GJB4856, which could explain 31.61 % of total variance in the present study. It suggested that morphological characteristics and differences of human ears should get more attention from HRTF researchers.

5 Conclusions

58 male pilots were measured for anthropometry in 3-D probe as well as for HRIR to 3-D sound with 13 elevation angles and 723 azimuth angles in free field of acoustics in hemi-anechoic room. The HRTF database of Chinese male pilots was built of more than 6.86 hundred millions digital data. It suggested that the asymmetry of head-related anthropometric parameters may deserve more attention as well as the HRIR of 6.0+ KHz in further research of HRTF by analysis.

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Q–Q Test for Pilot Evaluation of Ergonomics in Aircraft Cockpit

Xiaochao Guo, Yanyan Wang, Qingfeng Liu and Duanqin Xiong

Abstract The Q–Q test (Qualitative and Quantitative test) was set up in the context of pilot evaluation of ergonomics in an iterative process of aircraft cockpit design to facilitate and optimize human-centred design with quantitative data of pilot use in simulated flight. First, a subjective rating scale was built on degrees of acceptability and satisfaction referring to Cooper–Harper Scale. Second, the quantitative measurements of user performances were simultaneously introduced, and the difference between the optimal design and the tested design on the basis of user performances and parameters of designs would support iterative design or redesign. Third, the consensus of pilot sample or subgroups was integrated by the Delphi technique to determine which problems should be solved on time after communication with stakeholders. One example was also discussed.

Keywords Q–Q test (Qualitative and quantitative test) · Pilot evaluation · Aircraft cockpit · Ergonomics · Human factors · Cooper–harper scale · Delphi technique

1 Introduction

The Cooper–Harper scale is a popular tool for pilot evaluation in handling qualities of piloted aircraft [1–3], in which pilot ratings determined the handling characteristics of the aircraft in terms of qualitative degrees of suitability and Levels (1-Satisfactory, 2-Acceptable, or 3-Controllable) with comments indicating what deficiencies had been discovered. However, quantitative data may be desired by designers in pilot evaluation of ergonomics because results of user performance test (UPT) will be very helpful to improve in human-centred design [4, 5]. So the Q–Q

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test (Qualitative and Quantitative test) method was established in the context of pilot evaluation of ergonomics in an iterative process of aircraft cockpit design.

2 Method

2.1 Pilot Ratings as Qualitative Probe in Q–Q Test

A subjective rating scale was built on degrees of acceptability and satisfaction with 10 points in 4 levels similar to Cooper–Harper scale. In Q–Q test, pilot must judge according to acceptability or satisfaction and give his comments about What and How aiming at the points within levels with deficiencies (Fig. 1).

It is noted that scored 6 or 10 was not allowed if pilot rated a design in Level 2 which means "moderate acceptable" and vice versa (Fig. 1a), for instance.

2.2 Quantitative Measurement of User Performance in Q–Q Test

User performances were measured in two conditions, i.e., the optimal design versus the tested design in the context of flight use. The difference of $X_{optimal} - X_{tested}$ will indicate the deviation in the tested design and the range of improvement in the iterative design based on the user requirements or pilot needs of flight use.

2.3 Participants of Pilots in Q–Q Test

Pilot sampling is closely related to the purposes of pilot evaluation in Q–Q test and the stages of production design on the basis of anthropometric factors, flight

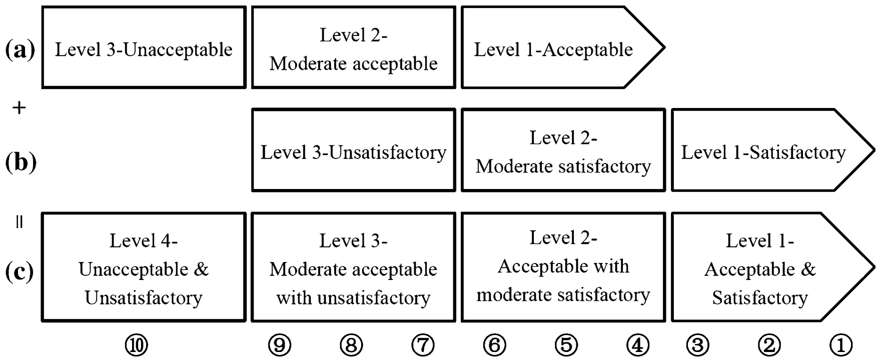

Fig. 1 Pilot rating scales in Q–Q test

experiences, and the like. Pilots could be selected referring to GJB4856 and GB/T12985 or ISO7250-3 [6–8] if design range was specified as smallest to largest 5th–95th percentile or 1st–99th value in stature (body height) and body mass (weight) according to anthropometric requirements. The size of pilot sample could be confirmed by GB/T23699 [9] at least 3 persons in screening test or 7 persons in detailed test for each subgroup.

2.4 Integration of Data in Q–Q Test

For qualitative data, integration of pilot evaluations was accomplished by the Delphi technique [10]. The quantitative data were analysed in statistics.

3 Results

An example was presented in Table 1, in which there were 5 pilots in each subgroup of smallest or largest percentile, i.e., 5th (P_5) or 95th (P_{95}) percentile of pilot stature according to GJB4856 during screening test of cockpit design mentioned by GB/T23699/ISO15537 above.

The meanings of levels in Table 1 were shown as in Fig. 1a for acceptability.

4 Discussions

4.1 Pilot Sampling as User Representatives

Participants of pilots took a key role in Q–Q test because the pilot sample was representative of user population such as that in GJB4856. So pilot sampling should be either from the intended users or as similar as possible to the population. In stratified sample, participants may be representatives of 5th, 50th, 95th subgroups in GJB4856, the valid cases of sample were generally not less than 5 persons in user performance test (UPT) for statistical power (Table 1), and the differences of gross sample, i.e., whole of 5th, 50th, 95th subgroups to user population should be analysed statistically.

Considering that the overweight trends of pilots show an obvious rise with time and age [11] and some human dimensions seemed to augment generally in view of body growth [12], the analysis of participant characteristics of pilot sample (Table 2) could help the designers of aircraft cockpit to make correct decision in the iterative process of design.

Table 1 Results of Q–Q test as an exemplar in screening test of cockpit design

Pilot subgroup	Index	Vote in the 1st round of Delphi			Vote in the 3rd round of Delphi			Pilot comments in consensus	Value to change from UPT
		Level 1	Level 2	Level 3	Level 1	Level 2	Level 3		
P_5	1	5			5				
	2	3	2			5		More retrusive	66 mm
	3	4	1		5				
	4	4	1		5				
	5	1	3	1		5		Much higher	
	6			5			5	More retrusive	80 mm
	7	1	3	1		5		Much higher	
	8		1	4			5	More retrusive	188 mm
	9	5			5				
	10	1	1	3		5		More spacious	
P_{95}	1	5			5				
	2	2	2	1		5		More retrusive	52 mm
	3	4	1		5				
	4	4	1		5				
	5	4	1		5				
	6		2	3			5	More retrusive	35 mm
	7	5			5				
	8		2	3			5	More retrusive	159 mm
	9	5			5				
	10	1	1	3			5	More spacious	

Table 2 Participant characteristics of pilot sample in a Q–Q test (in mm)

Anthropometric codes and items in GJB4586		Users in GJB4856		Pilots in Table 1		*T*-test
		$\bar{X}$	s	$\bar{X}$	s	
2.1	Stature (body height)	1705.0	36.6	1703.4	64.1	
2.88	Length of upper extremity	727.5	22.7	753.3	30.6	$P < 0.05$
3.1	Sitting height	924.3	21.9	909.5	27.0	
3.3	Eye height II, sitting	810.0	21.4	750.9	176.1	
3.25	Lower extremity length, sitting	979.5	28.5	997.3	47.7	
3.15	Forearm-plus-hand length	453.1	14.4	459.7	32.2	
5.1	Body mass (weight) Kg	68.0	7.6	76.7	10.0	$P < 0.05$

4.2 *The Consensus by the Delphi Technique*

4.2.1 Personal Judgement by Individual Pilot

Participants of pilots must have been trained prior to the Q–Q test to be familiar with the tested design and its requirement of use in simulated flight. Each of pilots must first manipulate prototype of the design independently, then give pilot rating on one's own.

Pilot ratings were given by two steps. The gross judgement was made at first such as Acceptable, Moderate acceptable, or Unacceptable (Fig. 1), a rating score was marked in succession within the Level.

It suggested that the tested design had some deficiencies if a pilot judged the design as "not acceptable" or "not satisfactory," the pilot must point out what deficiencies to be discovered and how to improve. Discount without cause should not be allowed by testers in principle.

4.2.2 Group Judgement by Pilot Sample

In stratified sample, each of subgroup such as P_5, P_{50}, P_{95} pilots in Table 1 should make their group decision after round by round with the Delphi technique. The consensus perhaps emerged or few exceptions probably stuck to which is no matter for Q–Q test. The group comments of pilots must also present as in Table 1 if pilot sample judge the tested design as "not acceptable" or "not satisfactory" mentioned above.

4.3 *Communication Within Stakeholders*

The conclusions in Q–Q test were classified into "improvement suggested," "improvement warranted," "improvement required," and "improvement mandatory" on the basis of group judgement by pilots after communication of ergonomics specialists (the tester group as an example), participants of pilots (user representatives) to the designers of aircraft cockpit while product managers attended the conference both from users and manufacturers.

The communication should validate the group judgement of pilot sample or clarify further about some exceptions, and facilitate the improvement of the tested design after trade-off with an eye to technology, cost, and timing.

4.4 UPT Supporting the Design Improvement

It should be said that the degraded pilot ratings and user performances could be derived from the tested design in Q–Q test such as some parameters unsuitable for users or some of indexes mismatch to use requirement. To improve the tested design therefore aimed to correct the distinct departure.

A perfect design, i.e., an optimal design for users may be rated as grade 1, 2, or 3 in Level 1 as shown in Fig. 2, and participants of pilots could suggest few of improvement, although deficiencies in design were negligible or mildly unpleasant. A deviation from grade 1–3 was ignorable.

For example, if the tested design was graded as 5 in Level 2 by group judgement of pilot sample with comments of improvement warranted (Table 1), the parameters of the iterative design were warranted to adjust backwards about 52–66 mm. The value to change from UPT equated to the difference between the optimal design and the tested design on the basis of law of causation relative to parameters of designs and user performances.

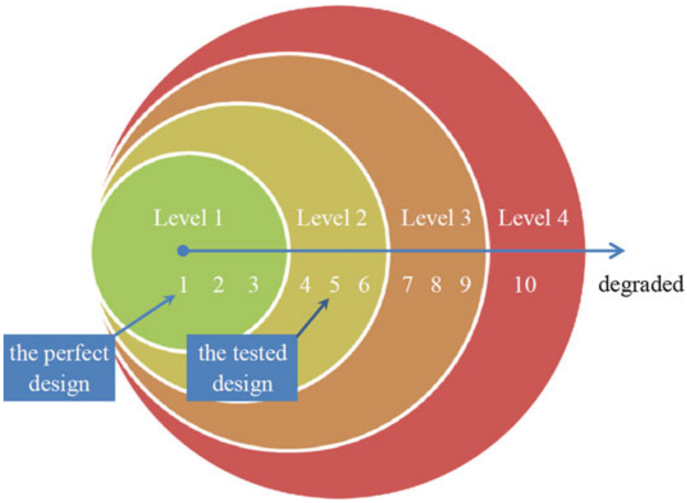

Fig. 2 To improve the tested design into Level 1

The values listed in Table 1 just were the differences of $X_{optimal} - X_{tested}$ as mentioned above, which could be reported in mean, range, or percentile as a result of data analysis in UPT.

5 Conclusions

The Q–Q test had been used in several types of aircraft for pilot evaluation of ergonomics, made better in facilitating human-centred design and supporting iterative design by scientific and quantitative data from users.

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Drivers' Lane-Changing Maneuvers Detection in Highway

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Abstract Three algorithms to detect driver's lane-changing maneuvers are put forward there. Feature sets in different dimensions, several time windows and classifiers based on different theories are analyzed. Simulation result shows that the parameters including land departure amount, vehicle acceleration, steering angle, steering angle velocity, and steering torque can validly reflect the vehicle running status. The Random Forest (RF) Classifier based on decision-making tree theory presents the best detection result, where the lane-changing detection result reaches 94.92 % and the lane-changing maneuver can be detected 0.04 s after the onset of steering and 2.37 s before the vehicle totally crosses the desired lane line.

Keywords Automotive engineering · Lane-changing maneuver detection · Driving simulation · Support vector machine · Random forest · K nearest neighbor

1 Introduction

Lane-changing in highway is a most common but dangerous behavior. According to National Highway Traffic Safety Administration (NHTSA), ratio of traffic accidents happened in lane-changing is up to 27 % [1]. Advanced Driver Assistance Systems (ADAS), such as lane-changing assistance system aiming at detecting drivers' lane-changing behavior as early as possible, could diminish about 7.3 % [2] traffic accidents, which play important roles in today's traffic safety. Data of rear-end accidents in highway from NHTSA indicate that almost 60 % traffic accidents could be reduced if drivers could be alerted 0.5 s earlier while 90 % traffic accidents could be reduced if drivers could be alerted 1.0 s earlier [3]. Therefore, algorithms that can realize great detection rate as well as earlier detection moment are significant in the development of ADAS.

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Some researches about drivers' lane-changing maneuvers are already completed. Salvucci and Liu [4] observed that the time course of steering angle of lane-changing is a sin-sinusoid and regarded the start point of sin-sinusoid as the onset of lane-changing maneuver. Pentland and Liu [5] put forward Hidden Markov Model, which can detect the drivers' lane-changing maneuvers 1.5 s after the onset of steering and the total detection rate of lane-changing (LC) and lane keeping (LK) can reach 95 %. Salvucci [6] established the Mind Tracking Model, and can detect drivers' LC maneuvers 0.5 s after the onset of steering and reached a detection rate of 80 %. Mandalia and Salvucci [7] applied Support Vector Machine (SVM) to detect drivers' LC maneuvers, reaching a detection rate of 87 % as to LC and a total detection rate of 97.9 %, detecting drivers' LC maneuvers 0.3 s after the onset of steering. As most of today's classifiers as to LC detection are based on dynamic sequence like HMM or classification surface like SVM, algorithms based on decision-making trees or non-parameter learning method are hardly seen. In addition, the moment of lane-changing to be detected in all classifiers above is still a little late, and the continuous detection performance of the classifiers above is not so clear. In this paper, some statistic features of vehicle's operation parameters from a driving simulator will be selected to form feature sets in different dimensions, and several sample windows as well as three classifiers will be discussed, which may provide reference to the development of ADAS as to feature selecting, sample window selecting, and the design of classifier.

2 Experiment Design and Data Preprocessing

2.1 Experimentation

Experiment was carried on an automatic BMW 3 of a driving simulator in a bidirectional and four lane highway scene. Seventeen female drivers (with mean driving experience of 7 years and mean travel distance of 64.4 thousand kilometers) between 20 and 40 years old took part in this experiment. Subjects are required to drive following a car or a track and find the appropriate opportunity to overtake the leading car after the overtaking instruction was given.

2.2 Samples Selecting and Sample Windows

After kicking out the abnormal data, vehicle operation parameters of 144 LC maneuvers (including left-LC and right-LC) and LK maneuvers from 17 drivers are used to establish the 60,000 training samples. Vehicle operation parameters of 40 LK to LC maneuvers are selected randomly to be the test samples. The sample window series are set as 0.6 s, 0.8 s, 1.0 s, 1.2 s, and 1.4 s in this paper. The test samples are scanned by a sliding window and the step size is 1 s.

2.3 Feature Selecting

In this paper, the mean value, standard deviation, and variable coefficient of lane departure amount, acceleration, steering angle, steering velocity, and steering torque are selected as the features. Considering the time series of the parameters, the same feature in different dimensions is compared in this paper (shown in Table 1).

3 Model

3.1 Support Vector Machine

Support Vector Machine (SVM) classifier is based on modeling the classification interface and can perform well in the situation of not enough samples supplied.

When modeling the SVM model, first, selecting the mean value, standard deviation, and variable coefficient of lane departure amount, acceleration, steering angle, steering velocity, and steering torque as the features of training samples x:

$$x = \begin{bmatrix} f_u & a_u & d_u & r_u & g_u \\ f_c & a_c & d_c & r_c & g_c \\ f_\sigma & a_\sigma & d_\sigma & r_\sigma & g_\sigma \end{bmatrix}, \quad (1)$$

where f is the lane departure amount, a is the acceleration, d is the steering angle, r is the steering velocity, and g is the steering torque. Subscript u means the mean value of this parameter in the sample window, subscript c means the variable coefficient of this parameter in the sample window, and subscript σ means the standard deviation.

Then, normalizing the x to $[-1 \quad 1]$. And the 60,000 training samples form the training set X.

Table 1 The feature sets

Feature set	Feature dimension	Features				
		Lane departure amount f (m)	Acceleration a ($\mathrm{m \cdot s^{-2}}$)	Steering angle d (°)	Steering velocity r ($^\circ \cdot \mathrm{s}^{-1}$)	Steering torque g (N·m)
1	18	f_u, f_c, f_σ	a_u, a_c, a_σ	d_u, d_c, d_σ	r_u, r_c, r_σ	g_u, g_c, g_σ
2	*	f_u^i, f_c^i, f_σ^i	a_u^i, a_c^i, a_σ^i	d_u^i, d_c^i, d_σ^i	r_u^i, r_c^i, r_σ^i	g_u^i, g_c^i, g_σ^i

Subscript u means the mean value of this parameter in the sample window, subscript c means the variable coefficient of this parameter in the sample window, subscript σ means the standard deviation of this parameter in the sample window, and superscript i means that there are i features in the sample window

*Stands for the feature dimension by calculating each parameters in half of the sample window step by step, considering the time series of parameters (shown in Fig. 1) of this parameter in the sample window

The training set X is needed to be transferred to a high-dimensional space through a kernel function, and work out the optimal parameters to model the optimal interface in the high-dimensional space. Radial basis function is selected as the kernel function in this paper

$$K(x_i, x_j) = \exp[-\gamma(x_i - x_j)]^2, \tag{2}$$

where x_i, x_j, respectively, stands for two vectors from training set X.

In this nonlinear separable situation, introducing the penalty factor c to this model, and working out the optimal kernel parameter γ and the penalty factor c through Grid Search (GS)

$$l(x) = \sum_{i=1}^{n} cK(x_i, x_j), \tag{3}$$

where γ is the kernel parameter and c is the penalty factor.

3.2 Random Forest

Random forest (RF) is a classifier that contains plenty of decision-making trees and output the final decision judging by these decision-making trees.

After selecting the features and normalizing through formula (1) and formula (2), boostraping samples from the training set X randomly and repeatedly to get several boostraping training set X^n. Then building the decision-making tree in each boostraping training set by the iteration of x to the two categories and calculating the coefficient G in each node:

$$G^n = \sum_{i=1}^{n} p_i^j(1 - p_i^j), \quad i = 0, 1 \tag{4}$$

where p_i^j stands for the probability of feature j in category i. $i = 0$ stands for LK and $i = 1$ stands for LC. G^n is the coefficient G of the boostraping training set X^n.

When input test sample x, calculating the coefficient G of each node from the bottom of each tree, deciding its category in each node until the coefficient G reaches the minimum and outputting the predicted category

$$g_i^n(x) = \min(G^n), \quad i = 0, 1 \tag{5}$$

where $g_i^k(x)$ is the predicted category of the test sample x.

For all the trees, if marked the total amount of trees whose predicted category is LK as k_0, and that of LC as k_1, then the final decided category will be:

$$g_i = \max_i k_i, \quad i = 0, 1 \tag{6}$$

where g_i is the final decision.

3.3 K Nearest Neighbor

K Nearest Neighbor (KNN) is a non-parameter learning method. Different from SVM and RF, KNN outputs the decision not relied on the trained model, but by the distance measurement to all training samples and taking the nearest training sample's category as the decision.

For the training set X and the input test sample, calculating the distance from x to the training set X by Euclidean Distance:

$$d_{ij} = \sqrt{\sum_{k=1}^{n} (x_{ik} - x_j)}, \tag{7}$$

where x_j is one of the input test sample and x_{ik} is the training sample k whose category belongs to i.

If marked the amount closed to the input test sample x_j in LK as k_0, while that of LC as k_1, in all training samples. The classification rule is defined as

$$g_i(x) = \max k_i, \quad i = 0, 1 \tag{8}$$

where k_0 is the amount closed to the input test sample x_j in LK and k_1 is the amount closed to the input test sample x_j in LC. If $k_0 > k_1$, the decided category will be LK and if $k_0 < k_1$, the decided category will be LC.

4 Detection Results

4.1 Detection Accuracy

Detection accuracy can be observed in Tables 2 and 3.

Table 2 lists out the total detection rates of two feature sets in different dimensions, from which we can draw a conclusion that feature's effectiveness cannot be improved only by enhancing the feature dimension but not selecting out the optimized features. Both Tables 2 and 3 indicate that sample window of 1.0 s is the best sample window within these features. Table 3 compares three classifiers' total detection accuracy and finds out that classifier RF can reach the best detection accuracy in all sample windows.

Table 2 The KNN's total detection rate of each feature set in different sample windows

Feature set	0.6 s (%)	0.8 s (%)	1.0 s (%)	1.2 s (%)	1.4 s (%)
1	84.94	84.14	86.17	85.52	85.12
2	79.36	79.78	79.90	78.71	74.88

Table 3 Total detection rate of each classifier in feature set 1 within different sample windows

Classifier	0.6 s (%)	0.8 s (%)	1.0 s (%)	1.2 s (%)	1.4 s (%)
SVM	81.02	83.22	84.99	84.44	84.219
RF	**88.76**	**89.32**	**89.75**	**89.57**	**89.69**
KNN	84.94	84.14	86.17	85.52	85.12

The bold is to emphasize the best detection accuracy of RF model regarding total detection rate

Table 4 The detection rate of each classifier in feature set 1 and sample window of 1.0 s

Classifier	Total detection rate (%)	Detection rate of LK (%)	Detection rate of LC (%)
SVM	84.21	81.25	86.65
RF	**89.75**	**82.14**	**94.92**
KNN	86.17	90.00	84.61

The bold is to emphasize the best detection accuracy of RF model

Table 4 lists out the total detection rate, detection rate of LK, and detection rate of LC. Classifier RF gets the best detection result not only in total detection rate but also in detection rate of LK and detection rate of LC, and the total detection rate can reach 89.75 % while the detection rate of LC can reach 94.92 %, which can also prove that lane departure amount, acceleration, steering angle, steering velocity and steering torque can validly reflect the driving status.

4.2 ROC

Receiver Operating Characteristic Curve (ROC) is an aggregative indicator to reflect the relationship between True Positive Rate (TPR) and False Positive Rate (FPR), by assigning several critical values to the continuous variable and calculating several TPR and FPR. This curve assigns TPR as ordinate and FPR as abscissa. Larger Area Under Curve (AUC) means higher detection accuracy and better model. As for better model, the knee of ROC should be as closed to the top left corner in the unit square as possible. It is one of the most welcome indicators to the performance evaluation of classifiers because the uneven distribution samples have little effect on it.

$$\mathrm{TPR} = \mathrm{TP}/(\mathrm{TP} + \mathrm{FN}) \tag{9}$$

$$\text{FPR} = \text{FP}/(\text{FP} + \text{TN}), \tag{10}$$

where TP is the amount of correctly classified LC samples, FN is the amount of incorrectly classified LK samples, FP is the amount of incorrectly classified LC samples and TN is the amount of correctly classified LC samples.

Figure 2 is the ROC of each classifier in situation of feature set 1 and sample window of 1.0 s, which indicates that RF performs better than SVM, as the curve of RF is above that of SVM always.

Table 5 lists out the AUC of each classifier, indicating that RF will get the best detection rate among these three classifiers while KNN may get the poorest detection rate. The AUC of RF is above 0.9, which indicates that RF model is reliable.

4.3 Continuous Detection Result and Detected Time Sequence

Each test sample consists of the LK and LC phase. Continuous detection result of one test sample is shown in Fig. 3, where RF and SVM perform well in continuous detection result.

In this paper, detected time sequence (listed in Table 6) means the retardation time of the first detected moment of LC to the onset of steering. As detected time sequence is the key in alerting system, it is important to detect drivers' maneuver of LC as soon as possible.

In statistic, the mean value of during time in LC is 7.86 s and the time from onset of steering to the moment when vehicle cross the desired lane is 2.99 s. In the situation of feature set 1 and sample window of 1.0 s, classifier RF can detect the LC maneuver 0.04 s after the onset of steering and 2.27 s before the vehicle crosses the desired lane (Table 6).

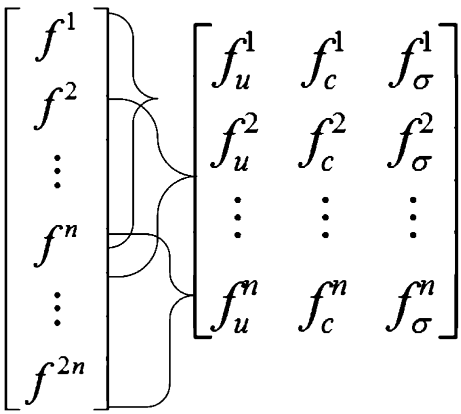

Fig. 1 The sketch map of selecting features considering time series

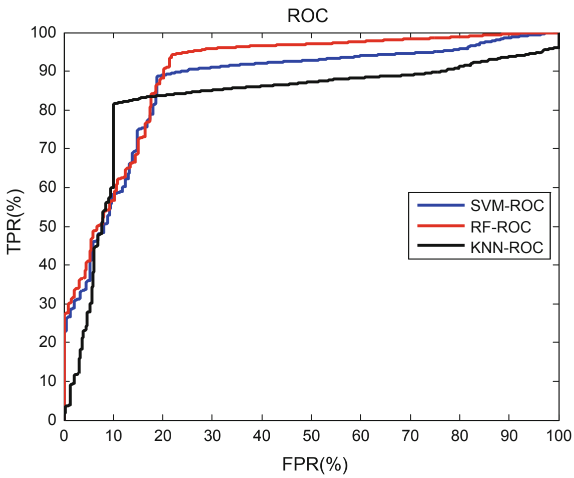

Fig. 2 The ROC of each classifier in feature set 1 and sample window of 1.0 s

Table 5 The AUC of each classifier in feature set 0.1 and sample window of 1.0 s

SVM	RF	KNN
0.86	**0.90**	0.82

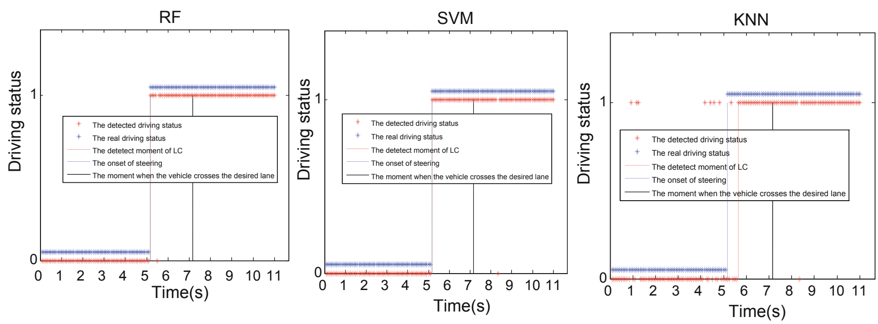

Fig. 3 The continuous detection result from each classifier

Table 6 The detected time sequence of each classifier in feature set 1 and sample window of 1.0 s

Classifiers	T_d		T_a	
	Section (s)	Mean value (s)	Section (s)	Mean value (s)
SVM	[−2.67, 1.92]	0.14	[−7.17, −0.75]	−2.14
RF	[**−3.92**, **1.75**]	**0.04**	[**−5.08**, **−1.00**]	**−2.37**
KNN	[−1.00, 1.92]	0.65	[−4.42, −0.75]	−1.61

The bold is to emphasize that the RF model can detect the lane-changing maneuver earlier than the other two classifiers

5 Conclusion

This paper provides three algorithms for LC maneuvers detection, by comparing different feature dimensions and sample windows in each algorithm, find out that the sample window of 1.0 s is the best sample window and the features like lane departure amount, acceleration, steering angle, steering velocity, and steering torque can reflect LC maneuvers well. The classifier RF gets the highest detection accuracy among the three classifiers, not only in total detection rate but also in detection rate of LK and detection rate of LC. In addition, RF model can detect the LC maneuver 0.04 s after the onset of steering, which can detect LC maneuvers earlier than the other two classifiers, and performs well in continuous detection result. RF model for LC maneuvers detection may be a way to enhance detection accuracy. In the future research, visual characteristic of drivers and environment variable should be included.

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A Model Research for Evaluation of Community Workers' Comprehensive Quality Based on BP Neural Network

Haiwei Peng, Xiaohui Peng and Xiaogao Wang

Abstract This paper takes the evaluation of comprehensive quality of community workers as the research purpose, the research methods are gathering data and establishing mathematical model and so on. First of all, it analyses the definition and current situation of community workers; second, it explains the necessity and importance of the comprehensive quality evaluation of the community workers; finally, we establish the comprehensive quality evaluation model of community workers based on BP neural network which takes an evaluating index system including five Level-1 index and thirteen Level-2 index as the base to get a comprehensive quality evaluation model based on BP neural network. We have proved that this model is functional by data results, and it shows that the model's calculation results are consistent with experts'. This model owns advantages like self-learning ability and high intelligent. Model research can provide a theoretical basis for the evaluation of community workers when it comes to evaluation and selection.

Keywords BP neural network · Community workers · Comprehensive quality evaluation

1 Introduction

Community workers are workers who are engaged in providing service and management for community party organizations, committees, and service stations, and have signed a service agreement with the residential district (villages and towns) [1]. In developed countries, community workers have a reputation of "social engineer," which represents a high degree of social orientation and professional

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prestige, we can see that the public has a high recognition of community workers. However, in China's mainland, the development of community work education is relatively late, and the development of social work agencies is still in the initial stage. Staffs quality of these agencies is uneven, some of them are new trained professional social workers, also, and some of them have not been specially trained but had obtained the professional qualification. Phenomenon like irrational personnel structure, low professional level, and unclear responsibilities division are widespread [2].

China has not listed community workers in the occupational classification which results in lack of corresponding professional standards in introducing system, approving qualification, apprising professional title, and promoting. We could set up a unified standard comprehensive quality evaluation for community workers so that they can have a clear understanding of their own. This will not only improve the qualities of the community workers, but also offer an objective evidence for the manage works of community works like training, promotion, salary distribution [2].

2 Selection of Comprehensive Quality Evaluation Index of Community Workers

As shown in Fig. 1, we have selected five kinds of Level-1 index to evaluate the comprehensive quality of community workers through consulting literature and questionnaire survey [3].

We divide Level-1 index into some specific Level-2 index in order to improve the index's measurability and evaluation's accuracy, as shown in Table 1.

1. Knowledge quality: it refers to community workers' cultural knowledge level including professional knowledge and knowledge in various fields. Community workers should not only own professional knowledge skill, but also should have a wide range of knowledge, this is the basic foundation that the community workers can complete community work correctly and improve the work efficiency.

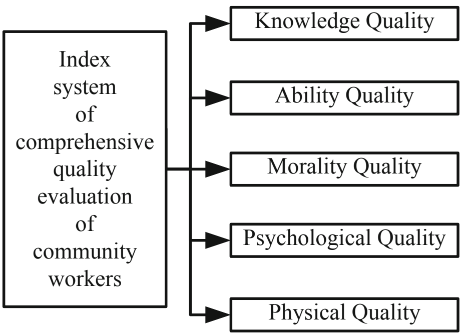

Fig. 1 Level-1 index of comprehensive quality evaluation for community workers

Table 1 Index system of comprehensive quality evaluation for community workers

Level-1 index	Level-2 index
Knowledge quality A_1	Professional knowledge B_1, knowledge in all fields B_2
Ability quality A_2	Coordination and organizing abilities B_3, professional skill B_4, social research B_5, innovation B_6 and interpersonal skills B_7
Morality quality A_3	Political consciousness B_8, professional ethics B_9 and dedication B_{10}
Psychological quality A_4	Self-cognition B_{11} and environmental adaptation B_{12}
Physical quality A_5	Strength B_{13}

2. Ability quality: it refers to the community workers who should own these basic skills including the coordination and organizing ability, professional skill, social investigation, interpersonal communication ability, and innovation to finish their work correctly. These skills are guarantees for community workers to provide service and promote community construction.
3. Morality quality: it refers to the professional moral and political calibre that community workers should have, including political consciousness, professional ethics, and dedication. Community workers are required to hold a firm and correct political direction, take solving residents' actual demand as the starting point, for community workers, these are the premise to participate in community construction and create a harmonious society.
4. Psychological quality: it refers to the character, cognitive ability and adaptive ability of community workers, including self-cognitive ability and environmental adaptability. With the development of society, the psychological quality index is more and more valued by the employing unit, and it is an important index to measure the overall development.
5. Physical quality: due to the heavy load of community work, a strong and healthy body is the foundation to do the community works. According to the Civil Affairs Bureau of statistics, community need to undertake 16 major terms, 152 minor terms and the report forms they need to finish can reach 14 kinds including 159 terms, and sometimes community workers also need to be engaged in physical labour.

We can only divide the degree of comprehensive quality evaluation of community workers into three grades represented by excellent, good, and poor since the development of community workers in China is late, few workers have known this field and the quality is uneven. It is not good for us to evaluate if the evaluation grade is too assorted.

3 Establishment and Solution of the Comprehensive Quality Evaluation Model Based on Neural Network

3.1 Basic Theory and Calculation Steps of BP Neural Network

BP neural network is a complex information transmission process which imitates the process of organism neuron, it is composed of a large number of simple processing units which will be connected to form a network of complex nonlinear system, and it is used to solve the nonlinear approximation problem between multiple factors [4].

Figure 2 is a typical three-layer neural network, which has n neurons in input layer, m neurons in middle layer, and $l(l = 1)$ neuron in output layer.

The realization process of BP neural network can be divided into five steps:

Step 1: Decide the network structure. According to the amount of input and output index, neurons amount of input and output layer can be settled and neurons amount of middle layer can be counted using empirical formula.

Step 2: Initialize the network. Initializing network Weight Value W_{ij}, threshold θ, step size η, and the calculation accuracy E to make the input and output data normalized.

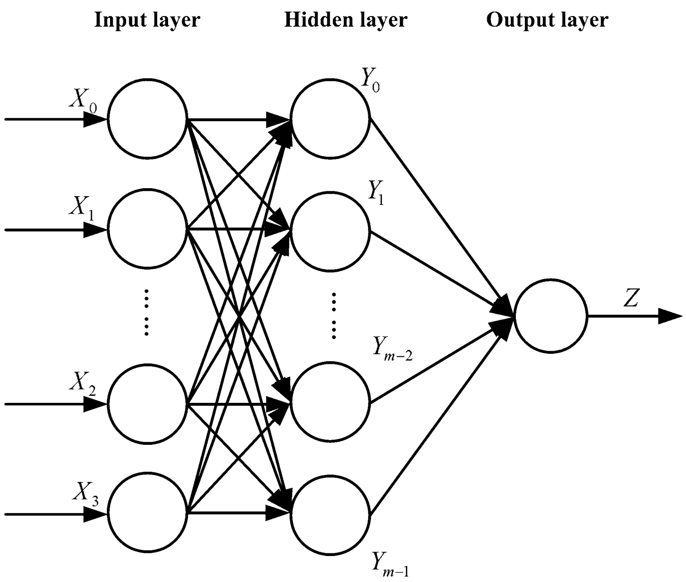

Fig. 2 The basic structure of BP neural network

Step 3: Train the network. Calculating each output of the middle layer and output layer.

$$
\begin{aligned}
&f\left(\sum_{i=1}^{n-1} W_{ij}X_i\right) \to Y_j \quad j = 0, 1, \ldots, m-1 \\
&f\left(\sum_{j=0}^{m-1} W_{jk}Y_j\right) \to Z_k \quad k = 0, 1, \ldots, l-1
\end{aligned} \tag{1}
$$

The nonlinear activation function can be shown as follows:

$$f(u) = \frac{1}{1 + \mathrm{e}^{-u}} \tag{2}$$

Step 4: Adjust the network. If the training accuracy cannot reach the requirement, then the network weighting should be adjusted, error calculation is as follows:

$$E = 1/2 \sum_{k=0}^{l-1} (d_k - Z_k)^2 \tag{3}$$

The adjustment formula of weighting is as follows:

$$
\begin{aligned}
&W_{jk} + \eta\delta_k Y_j \to W_{jk} \\
&W_{ij} + \eta\delta_j Y_i \to W_{ij}
\end{aligned} \tag{4}
$$

In the formula $\delta_k = (d_k - Z_k)Z_k(1 - Z_k)$, $\delta_j = Y_j\left(1 - Y_j\right) \cdot \sum_{k=0}^{l-1} \delta_k \cdot W_{jk}$.

Step 5: Evaluate the staff. If the training accuracy can meet the requirement, then the network training is over, input evaluation samples to process community workers overall quality evaluation.

3.2 Sample Collection

The amount of Level-2 comprehensive quality evaluation index of community workers is 13. When we are collecting these data, we will take an integer between 0 and 100 in order to compare and calculate the index more simple and convenient. The larger the index is, the higher the quality is. We will use computer to randomly generate 100 groups of sample data which will be divided into two parts, the selected randomly 80 groups of sample data will be used for training, see Table 2, the rest groups will be used to assess, see Table 3, the evaluation grade will be settled by expects.

Table 2 A part data of the training sample

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	Comprehensive evaluation
035	97	83	87	65	99	69	61	Good
040	87	61	70	83	70	89	82	Poor
073	98	75	75	99	99	92	76	Excellent
089	89	89	65	90	67	63	90	Excellent
093	62	89	93	65	90	74	61	Good

Table 3 A part of the test sample data

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	Comprehensive evaluation
001	64	70	72	86	93	93	92	Excellent
020	81	83	63	99	88	98	72	Good
067	71	80	95	73	85	94	77	Excellent
084	86	72	97	85	80	82	77	Poor
093	73	91	89	74	78	97	96	Good

Table 3 is a part of the test sample data. The test process is to input the test sample into the trained neural network and then compare the result with experts' to verify the model's accuracy.

3.3 Parameter Setting

According to the law of Kolmogorov [5], if the neural network structure is reasonable and weight setting is appropriate, three-layers BP neural network can approximate approach any continuous function, so here we adopt three layers of network structure to construct the neural network. The amount of Level-2 comprehensive quality evaluation index of community workers is 13. So the neurons number n of input layer of the network is 13 and the evaluation grades will be excellent, good, and bad. We will use 100, 010, 001 to represent, so the neurons number m of the output layer of the network is 3, and the number s of hidden layer of the network is 8 which is calculated by the empirical formula.

Network's frequency is 50, the learning efficiency is 0.5, step length $\eta = 0.05$, calculation accuracy $E = 0.0001$, the maximum number of iterations is 100,000 times, the network weights and thresholds are random number.

3.4 Sample Training

Input the training samples to network training, end the training after iterating 71,944 times. As shown in Fig. 3, it is the network training error change trend figure, it can be seen that the accuracy can reach 9.99984e-005 after 71,944 times' network training which meets the requirement.

Table 4 is the training result of 10 groups of the test samples, it is hard to tell the evaluation grade from the original data. We will set the largest data as 1, the rest will be 0. The standard of the evaluation grade will be divided into [1 0 0] excellent, [0 1 0] good, [0 0 1] bad. Through the data, we can see that four groups are excellent, five groups are good, and one group is bad. This result is consistent with the expert's, which means this model can be an effective way to assess.

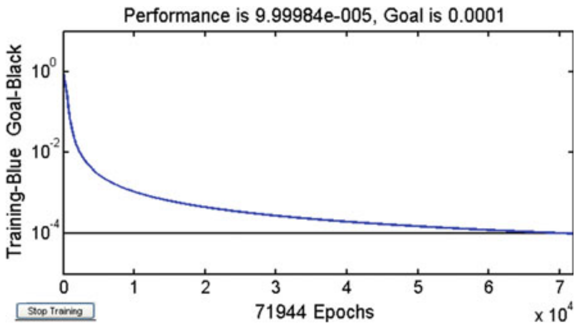

Fig. 3 Neurons network training error change trend figure

Table 4 The result of the test samples

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Evaluation level	0.92042	3.52E-08	0.9354	0.88247	8.98E-04
	0.60932	0.99999	0.008612	1.15E-03	0.99964
	1.13E-05	0.22932	0.04335	0.26868	8.69E-05
	Excellent	Good	Excellent	Excellent	Good
	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
Evaluation level	0.53457	2.19E-03	8.07E-09	0.081713	2.95E-06
	0.041528	0.9495	1	6.21E-03	0.98389
	0.000404	0.017573	4.07E-02	0.82848	0.93727
	Excellent	Good	Good	Poor	Good

4 Conclusions

This model which is based on BP neural network owns advantages like high accurate evaluation result, self-learning and adaptive ability, it can simulate artificial thinking way with intelligence by constructing neural network. This can create a good environment, promote workers' enthusiasm and establish a right career guide.

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Predicting Navigation Performance in a Multi-module Space Station Through Spatial Abilities

Junpeng Guo, Guohua Jiang, Yuqing Liu and Ming An

Abstract Astronauts often experience disorientation when navigating inside the multi-module space station due to the lack of gravity and the complex structure. Their sense of direction is an important indicator of the navigation performance. This research aims to identify the spatial abilities that are vital for keeping good orientation judgments during the navigation process. Sixteen male participants were recruited for the experiment. Their spatial abilities in 2D&3D perspective-taking and mental rotation, and the navigation performance in a simulated multi-module space station developed by virtual reality technique were tested respectively. Participants' performance in the spatial ability tests was found to be significantly correlated with their navigation performance, which indicated that good spatial ability was crucial in achieving good navigation performance. This finding can be applied in the astronaut selection and custom training in the future.

Keywords Spatial orientation · Virtual reality · Spatial ability · Navigation performance

1 Introduction

Disorientation is one of the major problems that astronauts met when living inside the complexly structured spacecraft, such as the Mir Space Station, Apollo Spaceship and the International Space Station [1, 2]. This is due to the lack of gravity there and the multi-module structure. Without gravitational cues, astronauts

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could float freely in the three-dimensional space using various body orientations and view the interior environment from different viewpoints, most of which were seldom experienced in the gravitational environment. As there were also no gravity acting on the vestibular or proprioceptive receptors, astronauts could not easily distinguish the “up” and “down”.

Instead, astronauts had to rely on the visual verticals to tell which way is “up”. The visual vertical vectors inside the spacecraft were always defined by the visual cues, and usually the lights were set on one interior surface and that surface would be the ceiling and the opposite interior would be the floor. These artificial visual verticals could provide astronauts the reference for orientation tasks and as proved by NASA, the adaptation time needed in the spatial orientation in the local module could be reduced by establishing a stable visual vertical [3]. However, the space station usually consisted of multiple modules and the visual verticals may present in different orientations when astronauts navigating inside the space station [4]. This inconsistency could lead to orientation difficulty when astronauts navigated in the different modules. Because after entering into each module, astronauts should adjust their body orientation to align with the visual vertical so that they could normally work or live in that module. And in order to achieve this alignment, astronaut might need to pitch forward or backward first and roll 90° afterwards when they entered into a new module. After these rotations, astronauts might got confused about other modules’ locations as it was indeed not an easy job to keep a clear mental map of the overall complexly structured architecture in arbitrary body orientations. But it was crucial for astronauts to keep good judgments about spatial orientation during the navigation process because they needed to keep an efficient and safety working state. Theoretically, these spatial orientation tasks inside the multi-module space station might require some basic spatial abilities that resembled the abilities needed in some psychometric spatial tests as they all needed people to transform spatial relationships in the egocentric or allocentric coordination. It was necessary to investigate the relationship between the intra-vehicular navigation performance and the individual spatial abilities as it might benefit the selection and training for astronauts.

On the earth, it was impractical to make use of the physical mockups for the orientation study because of the gravitational restriction. Virtual reality technique could provide a good alternative method for this propose, as it could build a high-fidelity simulated environment and made people depend mainly on the visual cues for orientation, analogous to the situation where astronauts faced inside the space station. In this research, we utilized a simulated space station developed by the virtual reality technique to study the relationships between the navigation performance and individual spatial abilities.

2 Methods

2.1 Participants

Sixteen male adults (mean age = 25.17, SD = 1.36, ranging from 22 to 27) with college-level education participated the present study. None of the participants had operated the similar navigational task before the experiment. The study was approved by the IRB and all participants signed the informed consent prior to the experiment.

2.2 Apparatus and Experimental Environment

The navigation task inside the simulated space station was conducted using a desktop virtual reality system. Participants could navigate in the simulated environment through a 3D space mouse in all the six degrees of freedom. The simulated space station was generally developed according to the imaginary expanded configuration of the space station planned by China and consisted of nine rectangular modules and two spherical nodes with abundant interior decoration that could provide visual verticals, as shown in Fig. 1.

Prior to the navigation task, the participants were tested for their spatial abilities using the computerized psychometric tests including 2D&3D perspective-taking ability (PTA in short) tests and mental rotation ability (MRA in short) tests. The 2D and 3D PTA test was the computerized adaptation of the paper-and-pencil PTA tests developed by Kozhevnikov and Hegarty [5] and Guay and Mc Daniels [6], respectively. The 2D and 3D MRA tests were the computerized adaptation of the paper-and-pencil MRA tests developed by Shepard and Metzler [7] and Cooper [8] respectively.

Fig. 1 Configuration of the virtual space station used in the experiment

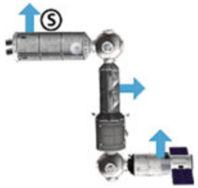
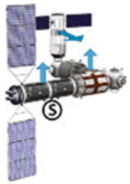
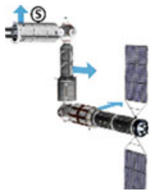
2.3 Procedure

Each participant was firstly tested for their spatial abilities using perspective-taking and mental rotation tests, both in 2D and 3D versions. Each spatial ability test was conducted within a limited and fixed time same to all the participants and their accuracy (the percent correct) in the tests were recorded to indicate their spatial abilities. After this, they took part in the navigation test. The navigation test consisted of six trials. And before the formal test, two practice trials were provided. Participants could learn the control methods and the procedure of the navigation test through the practice trials.

In each trial, the participants needed to navigate from a starting module to a target module using the first-person viewpoint. In the full configuration of the space station there were more than one entrances that could get into in each node, which could confuse the participants because they could not know which way they should go, so during each trial only the modules that would be navigated through were made visible while the rest could not be seen by the participants and they just needed to get into the only visible entrance when they needed to choose the way to go. One specific configuration of the route was used in each trial and there were six configurations of routes in total as shown successively in Table 1. The arrow beside each module indicated the orientation of the visual vertical and the symbol "*S*" indicated the starting module while the other end of the route was the target module.

In this experiment, we mainly consider participants' performance in keeping good sense of direction when navigating through multiple modules, so we adopted participants' performance in spatial orientation judgments as the navigation performance. Thus, in each trial the participants completed the route navigation firstly and then their sense of direction was tested in the Pointing Back Task and Modeling Task. To complete the route navigation, the participants needed to make translation and rotation movements, such as yaw, roll and pitch forward or backward, using the 3D space mouse (the movement methods in each route were also shown in Table 1). The rotation methods in each intersection were defined by the experimenter, e.g. they should pitch backward when entering into a module upside and pitch forward when entering into a module downside. And when arriving at the target module, the participants needed to adjust their body orientation to align with the visual vertical of the module by roll. And this adjustment should be finished within a limited time that predefined by the experimenter according to the angle needed to roll. Right after the adjustment, the participants needed to Pointing Back towards the starting module using the 3D space mouse. To do this, they first rotated the 3D space mouse towards the desire orientation and then click one button to confirm their choice. This process was called the Pointing Back Task. After this, the participants needed to reproduce the configuration of the experienced route by pressing the specific keys at the keyboard. The configuration would present immediately after the corresponding key was pressed. And this process was called the Modeling Task. The deviation angle (in degrees) and latency (in seconds) in the Pointing Back Task, and the accuracy (the percent correct) and latency (in seconds)

Table 1 The configurations of routes used in the intra-vehicular navigation test

Route umber	Configuration	Movements	Route number	Configuration	Movements
1		Pitch forward—pitch backward	4		Pitch forward—roll 90°
2		Pitch backward—roll 180°	5		Yaw—pitch backward
3		Pitch forward—yaw	6		Pitch backward—roll 90°

in the Modeling Task were recorded to evaluate the participants' performance in the navigation test.

3 Result and Discussion

3.1 Results of the Spatial Ability Tests

All the participants obtained an accuracy within the three standard deviations of the mean on the four spatial tests, so no spatial test result was omitted in the data analysis.

3.2 Performance of the Intra-vehicular Navigation Test

After the navigation process was finished in each trial, the participants needed to complete the Pointing Back Task and Modeling Task to test their sense of direction. The deviation angle in the Pointing Back Task represented the error made by the participants in identifying the starting point, so smaller deviation represented better orientation judgments. And the accuracy in the Modeling Task could represent participants' knowledge about the route in an allocentric coordination. And we considered that the latency in the Pointing Back Task and Modeling Task could reflect the difficulty felt by the participants in completing the tasks.

The navigation performance was evaluated by the four indices recorded in the Pointing Back Task and Modeling Task as discussed above, and their descriptive statistic was shown in Table 2, categorized by the sequence number of the route shown in Table 1.

Table 2 Descriptive statistics of the four indices evaluating the navigation performance

Sequence number of the route	Pointing back task		Modeling task	
	Deviation angle (°)	Latency (s)	Accuracy	Latency (s)
1	48.68	18.21	0.69	25.72
2	62.03	19.87	0.75	19.76
3	76.77	21.56	0.94	17.64
4	46.88	18.60	0.88	7.44
5	69.74	20.64	1	13.04
6	54.38	19.15	0.94	9.27

Table 3 Pearson correlation coefficients for spatial ability test results and navigation performance indices

Test type	Deviation angle in pointing back task	Latency in pointing back task	Accuracy in modeling task	Latency in modeling task
2D PTA	−0.39*	−0.35**	0.38	−0.41**
3D PTA	−0.47**	−0.46**	0.42	−0.58**
2D MRA	−0.31*	−0.29	0.25	−0.34*
3D MRA	−0.40*	−0.37*	0.36	−0.43**

*$p < 0.05$
**$p < 0.01$

3.3 Correlations Between Spatial Ability and Navigation Performance

The Pearson correlation coefficients between the spatial ability measures and the navigation performance indices are listed in Table 3. One thing needed to be noticed was that the higher values in the spatial ability tests represented better performance while the lower values in the navigation performance indices represented better performance except the accuracy in the modeling task, so the coefficients between the spatial ability test results and the navigation performance indices were negative other than the accuracy in modeling task.

And from Table 3 we could see that, the spatial ability test results correlated with the navigation performance indices significantly except that the accuracy index in the Modeling Task. The insignificant correlation between the accuracy in the Modeling Task and the spatial ability test results may be due to the relative low variability in the accuracy index as most of these route reproduction results reached a relative high level as show in Table 2, but these coefficients also showed a trend of positive correlation, although not significant. For the other three navigation performance indices, the 2D&3D perspective-taking ability showed better significant correlation than the 2D&3D mental rotation ability. This may explained by the difference cognitive mechanism needed in these two spatial ability factors. The PTA mainly showed individual ability in self-based spatial knowledge representations, which coded for the spatial relations of objects with respect to one's own body axes. While the MRA mainly showed individual ability in object-based spatial knowledge representations, which coded for the spatial relations of objects with respect to other objects, although usually still having an orientation consistent with either the viewer's encoding perspective or along a salient scene axes. Thus, as navigation tasks in our experiment also required self-based representations when various rotations occurred during the navigation, the PTA might show more significant correlation with the navigation performance indices. Also, the 3D PTA showed better correlation than the 2D PTA and this indicated that in the simulated weightless environment people needed to process the spatial information from a 3D space instead of a 2D plane.

4 Conclusions

The goals of this research were to study whether spatial abilities could predict navigation performance inside a multi-module space station and to identify the spatial abilities that were important in accomplishing the spatial orientation during the navigation. Theoretical analysis indicated that in order to keep a good sense of direction during the navigation process in weightlessness, participants needed to correctly transform the spatial relationships between self and the environment or between two different objects after successive rotations during the navigation. These spatial transformations involved in the intra-vehicular navigation process cause the demand on the spatial ability such as perspective-taking and mental rotation. Present study shows that the perspective-taking ability and mental rotation ability can predict the navigation performance as the results of the spatial ability tests is significantly correlated with most of the navigation performance indices (three out of four as shown in Table 3). This finding can be applied to several areas in the space missions, especially in the astronaut selection as well as the custom training. For astronaut or crew selection for the space station mission, the spatial ability should be taken into consideration. And for the preflight orientation training, more attention should be given to the individuals with lower spatial abilities. Besides, the present finding can also help in the inflight task arrangement as the more complex navigation tasks might need to be assigned to crew members with better spatial ability.

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Comparative Analysis of the Psychological Health Education Condition of College Students

Yu Luo, Haiyan Dai, Qian Shen, Jialiang Li, Yunde Sun and Peijun Zheng

Abstract The aim of the paper is to research the psychological health condition of college students who are involved in psychological health course fore-and-aft, and to provide a scientific basis for psychological education of college students. Method: the Symptom Checklist (SCL-90) (Zhang in Psychiatry checklist. Hunan science & technology Press, Changsha, pp 17–20, 2003 [1]) will be adopted to make questionnaire survey for Grade 2011 students in one vocational and technical college, and compare the differences of psychological health condition of students who are involved in psychological health course fore-and-aft, and make comparison with national youth group. Conclusion: the psychological health condition of Grade 2011 students has been improved obviously from enrolment to finishing psychological health course when they graduated, and are superior to national youth group. Therefore, the college students' psychological health education should be enhanced.

Keywords College students · Psychological health education · Comparative analysis

For the good growth of college students, they should not only be provided a harmonious and nice exterior environment, but also help is needed for them to establish a peaceful and positive state of mind, and which is the basis for them to go forward in the society and get the whole life happiness [2]. In order to enhance the psychological health condition and ability to withstand risks at school and after graduation, more than 1200 college students have been used for making comparative analysis of psychological health education condition, which can provide basic data for college students' psychological health education, analysis report are shown as follows.

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1 Research Object and Method

1.1 Research Object

By the Cluster random sampling method, 630 students in Grade 2011 who are freshmen have been taken, and 600 graduation students in Grade 2011 who are not involved in psychological health course have been taken, 610 graduation students in Grade 2011 who are involved in psychological health course have been taken, and they have been made questionnaire in batches, unmatched questionnaire have been removed, and then questionnaire recovery rate, respectively, were 99.36, 97.67, and 99.34 %.

1.2 Research Method

The Symptom Checklist (SCL-90) will be adopted to make questionnaire survey for Grade 2011 students in one vocational and technical college, and the differences in psychological health condition of students who are involved in psychological health course fore-and-aft will be compared, and comparisons with national youth group will be made. The testees need to finish the test on their own in accordance with their realities under the general instruction and filling method. The SCL-90 consists of 90 items, 10 categories of factors: somatization, obsessive-compulsive, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation, psychoticism, and other factors. For each item, scores from 1 to 5 shows the evaluation standard. Score 1 means Not at all; score 2 means A little bit; score 3 means Moderately; score 4 means Quite a bit; score 5 means Extremely. The higher the score is, the more serious the symptom is, and the lower the psychological health condition is.

1.3 Statistic Analysis

All data will be treated by SPSS 17.0 software package; t-test will be shown in comparison among groups, and the result will take $P < 0.05$ as the difference to reveal the statistic significance.

2 Result

2.1 Comparison Between SCL-90 Test Result of Grade 2011 Students in Different Stages and National Youth Group

The SCL-90 test result comparison of Grade 2011 students in enrolment and graduation is shown in Table 1. As the result, total points and each factor score in enrolment are greater than that of in graduation, the score of students who are involved in psychological health education course completely from enrolment to graduation is superior to that who are not involved in course and national youth group [3], and the difference has shown the statistic significance ($P < 0.05$ or $P < 0.01$).

Specifically speaking, the average of total points is 139.20 ± 32.88, each factor value is between 1.24 and 1.68 when the Grade 2011 freshmen do not touch psychological education in SCL-90 test. The average of total points is 126.6 ± 35.6, each factor value is between 1.22 and 1.55 when the graduation students are involved in psychological health education four years in SCL-90 test. The same as graduation, the average of total points is 135.20 ± 30.98, each factor value is between 1.28 and 1.79 when the graduation students are not involved in psychological health education four years.

Table 1 Comparison between SCL-90 test result of Grade 2011 students in different stages and national youth group

Item	Freshmen $n = 626$ (not involved in psychological health education course)	Graduation $n = 586$ (not involved in psychological health education course)	Graduation $n = 606$ (involved in psychological health education course)	National youth group $n = 781$
Total points	139.20 ± 32.88	135.20 ± 30.98	126.6 ± 35.6**	
129.96 ± 35.76**				
Somatization	1.38 ± 0.36	1.34 ± 0.43	1.28 ± 0.31**	1.34 ± 0.45**
Obsessive-compulsive	1.79 ± 0.49	1.60 ± 0.54	1.55 ± 0.38**	1.69 ± 0.61**
Interpersonal sensitivity	1.72 ± 0.46	1.68 ± 0.49	1.54 ± 0.39**	1.76 ± 0.67**
Depression	1.54 ± 0.46	1.45 ± 0.53	1.37 ± 0.34**	1.57 ± 0.61**
Anxiety	1.52 ± 0.41	1.37 ± 0.46	1.28 ± 0.31**	1.42 ± 0.43**
Hostility	1.68 ± 0.59	1.41 ± 0.53	1.26 ± 0.44**	1.50 ± 0.57**
Phobic anxiety	1.28 ± 0.32	1.24 ± 0.42	1.20 ± 0.23**	1.33 ± 0.45**
Paranoid ideation	1.63 ± 0.50	1.50 ± 0.50	1.38 ± 0.38**	1.52 ± 0.60**
Psychoticism	1.46 ± 0.48	1.45 ± 0.38	1.22 ± 0.29**	1.36 ± 0.47**

P.S *$P < 0.05$; **$P < 0.01$

2.2 Positive Symptom Disposition of Factor Score ≥3 of Grade 2011 Students in Different Stages

As shown in Table 2, at the beginning of enrolment, the number of students in grade 2011 whose any one of nine factors score is equal or greater than 3 is 110 when they enroll, it means that there are 17.57 % students whose psychological health problem is moderate or above. The sequence of these 9 factors score from big to small is: interpersonal sensitivity, depression, obsessive-compulsive, hostility, phobic anxiety, paranoid ideation, anxiety, somatization, psychoticism. The relevance ratio of psychological health problem is 0.31–2.87 %.

The number of students in grade 2011 whose any one of nine factors score is equal or greater than 3 is 80 when they graduated and never studied psychological health course, it means that there are 13.65 % students whose psychological health problem is moderate or above. The sequence of these 9 factors score from big to small is: interpersonal sensitivity, obsessive-compulsive, hostility, paranoid ideation, depression, phobic anxiety, anxiety, somatization, psychoticism. The relevance ratio of psychological health problem is 0.34–2.73 %. There is no big difference from enrolment.

The number of students in grade 2011 whose any one of nine factors score is equal or greater than 3 is 22 when they graduated and have studied psychological health course, it means that there are 3.63 % students whose psychological health problem is moderately or above. The sequence of these 9 factors score from big to small is: hostility, obsessive-compulsive, interpersonal sensitivity, depression,

Table 2 Positive symptom disposition of SCL-90 ≥3 of Grade 2011 students in different stages

Item	Positive symptom disposition (%) (not involved in psychological health education course from enrolment)	Positive symptom disposition (%) (not involved in psychological health education course from enrolment to graduation)	Positive symptom disposition (%) (involved in psychological health education course from enrolment to graduation)
Somatization	8 (1.27)	4 (0.68)	1 (0.16)
Obsessive-compulsive	16 (2.55)	15 (2.56)	4 (0.66)
Interpersonal sensitivity	18 (2.87)	16 (2.73)	3 (0.49)
Depression	17 (2.71)	8 (1.36)	2 (0.33)
Anxiety	11 (1.75)	6 (1.02)	1 (0.16)
Hostility	13 (2.07)	13 (2.21)	8 (1.32)
Phobic anxiety	13 (2.07)	7 (1.19)	0 (0)
Paranoid ideation	12 (1.92)	10 (1.71)	2 (0.33)
Psychoticism	2 (0.31)	2 (0.34)	1 (0.16)

paranoid ideation, anxiety, somatization, psychoticism. The relevance ratio of psychological health problem is 0–1.32 %. There is obvious difference from enrolment.

3 Conclusion

From the result of study, there is no big difference between freshmen in Grade 2011 and other students in the same grade who are not involved in psychological health course. And there is obvious difference between them and those who have been involved in psychological health course for four years from enrolment and it is superior to national youth group. Young college students are in the middle or later periods of their development, the view of life of them has gradually formed and become stabilized, and psychological development will go forward maturity quickly but not fully. Up to youth development, the childhood is focused on understanding the characteristics of the outside world, and then has turned to recognize inner self-assessment, and then there are some series of contradiction of self-consciousness appearing, and which can cause psychological disorder and disease [4]. Therefore, according to different characteristics of young students growth in different stages, psychological test, and psychological health education, psychological training and psychological counseling should be conducted and inner status should be kept active and steady [5].

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An Evaluation Model of Body Force Feeling During Load Carriage

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Abstract *Objective* This study aimed to explore the relationships between body force feeling and biomechanics signal during different loads during walking simulation by analysis of their change characteristics, and establish an evaluation model of body force feeling. *Methods* Six healthy young men were selected to carry three packs under four kinds of load (25, 29, 34, and 37 kg) of 110 min simulated walking test (speed of 5 km/h) by synchronous acquisition of four kinds of load level (25, 29, 34, and 37 kg) of simulated walking test (speed of 5 km/h). *Results* Mixed effects regression model is adopted to establish the systemic stress evaluation model, and this model can relatively accurately predict body force feeling in the process of walking.

Keywords Load carriage · Biomechanics signal · Force feeling

1 Introduction

For firefighters and construction workers, rescue workers and soldiers, and many other industries, weight-bearing walking for a long time is one of the basic ability requirements [1–3]. The overweight load weight and long walking time often cause body injury. At present, many scholars abroad aim to solve ergonomics problems in the process of load carriage walking by combining the physiological and physical mechanics study. There is no systematic study of force sense evaluation model [4–6]. This paper makes a comprehensive analysis of variation characteristics of biomechanics signal and stress feeling in different weight walking process, to explore establishment method of the stress evaluation model.

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2 Method

2.1 Subjects

In total, 6 healthy participants participated in the experiments. The participants with strong ability to understand and cooperate with the experiment had a age of 18–22 years, weight of 60–66 kg, height of 170–175 cm, and no significant difference in basic physiological parameters (vo2 max heart rate, blood pressure, and quiet, etc.). Three days tests to familiar with procedures and physiological characteristics of stress feeling level description are developed before formal experiments.

2.2 Experimental Conditions

In order to ensure that the experimental data is comparable, all tests were ran in the morning on LE 600 CE large movement, using three kinds of backpack, four kinds of load level (25, 29, 34, and 37 kg) with laboratory temperature 20–23 °C, speed 5 km/h, the total time of 120 and 10 min rest every 50 min march.

2.3 Stress Feeling Classification

Body stress can be divided into four grades as light, medium, heavy, and very heavy, and gives each level scale score on the basis of the Borg.

2.4 Equipment and Measurement Parameters

2.4.1 Pressure on Shoulder, Waist, and Back

Shoulder and waist were placed two Tekscan 9081 microsensing films, while back was placed one sensor film. Each film was connected with a portable data terminal, which was connected to the PC for data by the USB cable. The real-time data can be displayed and stored using I—Scan application software.

2.4.2 Belt Tension of Packs

Both sides of the shoulder were placed SMARP-200 strain sensors. The real-time data using RS—232 bus to PC for display and storage.

2.5 Procedure

First, record the weight of participants and heart rate with no carriage for 5 min during sitting. Second, march 50 min with relevant load and rest for 10 min, and then march 50 min again till running machine is stopped. Third, rest unloaded for 10 min. Physiological and biomechanical parameters were recorded continuously and force feeling were tested every 3 min.

If there is one of the following symptoms, experiment terminated immediately [7, 8]:

1. Heart rate more than 90 % HRmax
2. Subjective complaints to stop testare unstable gait, dizziness, flustered, nausea, and other symptoms.

3 Independent Variable of Model Selection

The body force sense is a dependent variable of stress sense evaluation model of load carriage marching. The independent variables may include shoulder strain, the shoulder pressure, back pressure, the waist of time domain average spectrum and its energy, load and the march of time, etc., as shown in Table 1.

According to test data, scatterplot of WBRPE and individual variables were drawn to preliminarily determine the independent variables that can be incorporated into the regression model. Correlation with WBRPE and BMI were as shown in Fig. 1, where there is a strong correlation (r = 0.692). Scatterplot of WBRPE and Fsh, FshPSD, Prate, and PshPSDrate are shown in Fig. 2.

Table 1 Instructions of independent variable

Independent variable	Instructions	Independent variable	Instructions
Fsh	Shoulder pull	FshPSD	Shoulder pull spectrum energy
Psh	Shoulder pressure	Pba	Back pressure
Pwa	Waist pressure	Pshrate	Ratio of shoulder pressure to the total pressure
PbaPSD	Back pressure spectrum energy	PshPSD	Shoulder pressure spectrum energy
PwaPSD	Waist pressure spectrum energy	PshPSDrate	Ratio of shoulder pressure spectrum energy to the total pressure spectrum energy
L	Load	B	BMI
T	Time		

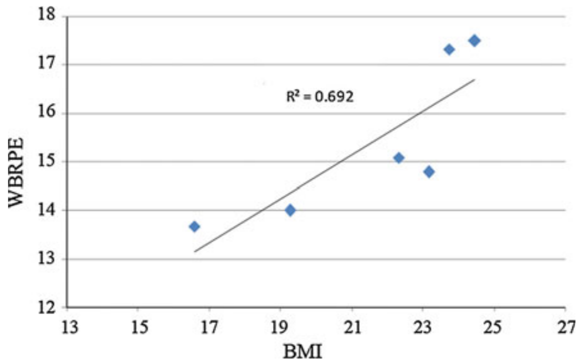

Fig. 1 scatter plot of WBRPE and BMI

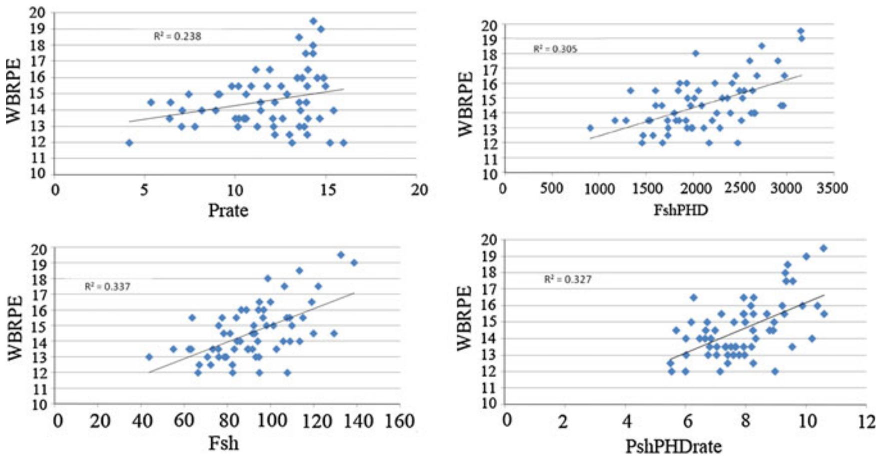

Fig. 2 scatter plot of WBRPE and Fsh, FshPSD, Pshrate, PshPSDrate

4 Force Feeling Model

The mixed test data established the force feeling evaluation model must include time series information and the typical panel data with repeated measurements, involved with pack type and load weight [3, 9]. The mixed model data means multiple hierarchies and can be called a horizontally structural model data. In this study, the first hierarchy is load: the stress feeling of the subjects must have the larger correlation in the same load experiment. The second hierarchy is pack: the ergonomics design of pack would inevitably affect subjects force feelings. In addition, this study has the characteristics of repeated measurement. The force senses valued every 3 min are necessarily associated to complete the 110 min march, because the person sense of stress will increase along with the continuous march time. Therefore, the "load effect," "pack effect," and "individual effect" error cannot satisfy the independent distribution assumption. In view of the above analysis, this study used the mixed effect regression model to set up the force felling evaluation model.

There are fixed effects and random effects in mixed effect regression model. The fixed effect model is as follows:

$$Y = X\alpha + \beta$$

or

$$y_{ij} = \beta_0 + \beta_1 X_{1ij} + \beta_2 X_{2ij} + \cdots + \beta_k X_{kij} + e_{ij}$$

The mixed effect model is as followed:

$$Y = X\alpha + Z\beta + \varepsilon$$

Y is n-dimensional matrix of different packs, different loads, and subjective stress, X is matrix composed of fixed effects parameter, α is the unknown vector corresponding to the fixed effects parameter, Z is matrix of random effects parameters, β is the unknown vector corresponding to the parameters of random effects, ε is the unknown vector corresponding to the random error vector. Typically random intercept model is used to random effects, and the mixed effects regression model are as follows:

$$y_{ij} = \beta_0 + \beta_1 X_{1ij} + \beta_2 X_{2ij} + \cdots + \beta_k X_{kij} + u_j + e_{ijt}$$

y_{ij} is subjective stress felling of load j and subjects i, $\beta_0, \beta_1 \ldots \beta_\mathrm{k}$ are fixed effects parameter, the average model parameters, which are the same for all subjects. u_j and e_{ijt} represent error of different load and different march time.

In analysis of the mixed effect regression, it was assumed that there is a difference of the stress changing trend under different loads. Because under low load stress feeling changes slowly, while changes relatively strong under high load bearing, therefore it can be judged that there are aggregation in different load tests. In order to verify this hypothesis, L is as a block factor and WBRPE as dependent variable for preliminary hybrid effect analysis shown as Table 2. A significant difference (P = 0.022) can be seen in intercept, proving that hypothesis completely correct and variable load in the hybrid model which WBRPE is the dependent variable exist clustering. The analysis results are similar to the hybrid model in which SHRPE is the dependent variable.

WBRPE is the dependent variable, L is block factors, t, Fsh, FshPSD, PshPSDrate are fixed effects, and judgment criteria is $P < 0.05$ and VIF < 5. Stepwise method is applied to regression analysis of mixed effects.

The body force felling model is set up as follows:

Table 2 The load mixed effects analysis results of clustering

Covariance parameters estimation							
Parameter		Estimation	Standard error	Wald Z	Significance	95 % confidence interval	
						Lower limit	Upper limit
Residual error		1.701259	0.073656	23.098	0.000	1.562853	1.851924
Intercept (individual = L)	Variance	1.403713	1.153702	1.217	0.022	0.280338	7.028699

Dependent variable: WBRPE

$$
\begin{aligned}
\mathrm{WBRPE}(t) = 0.022023 \times L^2 - 1.212125 \times L + 0.143309B \\
+ 0.001181 \times \int_{k=0}^{t} \mathrm{FshPSD}(k) \\
+ 0.175881 \times \int_{k=0}^{t} \left(\frac{\mathrm{PshPSD}(k)}{\mathrm{PshPSD}(k) + \mathrm{PbaPSD}(k) + \mathrm{PwaPSD}(k)} \right) \\
+ 23.11685
\end{aligned}
$$

5 Conclusions

The large group field test of different load carriage status was carried with the group. The results showed that the mixed effect regression model can more accurately represent body force sense. There is positive significance of the establishment of the model for the design and guide for the load weight selection.

6 Compliance with Ethical Standards

The study had obtained approval from the Army Key Laboratory of SEEPC Ethics Committee.

All subjects participated in experiment had signed the informed consent.

All relevant safety, health, and rights had been met in relation to subject protection.

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Research on Core Competence Training of Command Type Graduates

Rongzhi Yang, Xin Liu, Ruijie Wang, Haoran Zhu and Yun Du

Abstract This paper aims to explore the ways to train the core competence of the command type graduates. Research is done on three levels: the explanation of concepts, the research on quality models, and the exploration of training methods. From the research, we think that the core competence is the capability of commanding in battlefields, the elements of which include ideological morality quality, physical and mental quality, technological and cultural quality, fundamental military quality, command quality in combat, quality of battlefield management, and that of political work. The paper brings up corresponding conclusions regarding the core competence training policies, and provides helpful references for the training of military master students.

Keywords Graduates training · Core competence · Quality model

Command type graduates are a major area of graduates training, with key requirement of the capability of fighting and winning wars. It is becoming a focus point for military academies to cultivate the command type graduates for core competence. However, from the current condition, the research is still at early stage. It is imperative to research on this topic in order to adjust in the complicated future war circumstances.

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1 Deepening the Understanding of Command Type Graduates Core Competence Training

1.1 Relevant Concepts

1.1.1 Competence

The International Twenty-First Century Committee made a new reliable explanation for competence as follows: competence is a complex unique to individuals, combining the materials information, social behaviors, cooperative awareness, innovation capability, and adventure spirit of the individuals together through technical and vocational training. This explanation realized the real transfer from qualification concept to capability concept, signifying the new progress made toward competence. Competence has many characteristics including the connection between potential and reality, the unification of development and degradation, the coexistence of finite and infinity, the integration of disciplinary and complexity, the connection between generality and differentiation, and the combination of natural and social aspects.

1.1.2 Core Competence

Core competence was first brought up by Prahalad and Hamel in 1990 [1]. They think that the core competence of a corporation is the accumulative knowledge of the corporation, especially the knowledge about how to coordinate different production skills and combining various techniques. It is the integration of skills and techniques, rather than a single technique and skill. Generally speaking, core competence plays an essential role in competition, and is the competitiveness that keeps things for long-term stable competitive advantage and gaining extra value. It is the combination of certain key resources and key capabilities based on knowledge innovation, a complicated assembly of the integration of techniques, production base, technical talents, training, organization adjustment, rules and belief, and experience [2].

1.1.3 Command Type Graduates Core Competence

Command type graduates core competence is the sum-up of techniques and skills for future information era wars during the capabilities generation training process of command type graduates. It is a mission for military academies to train the military commanding graduates who can meet the requirements of military war preparation and future information era wars. To complete the task with high quality, it is a must to train the core competence, and its essence is to provide training of the capability of commanding, fighting, and winning wars for command type graduates.

1.2 Importance of Command Type Graduates Core Competence

1.2.1 Playing a Supporting Role During the High Level Talents Training in This Area

Core competence is the basic quality needed for the military high level talents, and is the core competitiveness for the grow-up of military command talents.

1.2.2 Playing a Supporting Role During the Usual Military Comprehensive Rehearsal and Training

Core competence is reflected in the daily military comprehensive drills and training. The troops shall be trained according to real wars and the core competence is the ability to face the battlefield.

1.2.3 Playing a Supporting Role in Future Information Era Wars

Command type graduates are the talent strategy project for future information era wars. And core competence is the ability to face the information era and future.

1.3 Importance of War-Oriented Core Competence Training of Command Type Graduates

1.3.1 Objective Requirement for Promoting Command Type Graduates to Focus on Actual Combats

The training of core competence toward battlefields for military command type graduates is the requirement for the promotion of graduates toward actual combats focus.

1.3.2 Practical Requirement to Optimize Overall Design of Command Type Graduates Training

For the training of command type graduates, the core competence toward battlefield should be considered as the most important, and taking this as the focus for the optimization of overall design of high level talents training.

1.3.3 Imperative Need for the Training of High Level Command Talents Toward Battlefields

Modern war requires high level commanding talents, and it is more and more imperative to train the core competence of high level command graduates to deal with battlefields and winning wars.

2 Constructing the Quality Model for the Core Competence Towards Battlefields of Command Type Graduates

Learning to command during war and winning wars is a great mission for military commanders. Command type graduates are the commanders for future information era wars, and their core competence toward battlefields is the capability of commanding in battlefields. Through research, we think that the elements for command type graduates should have the capability of commanding in wars include: (1) Ideological morality quality. (2) Physical and mental quality. (3) Technological and cultural quality. (4) Fundamental military quality. (5) Command quality in combat. (6) Quality of battlefield management. (7) Quality of political work. Among the elements, No. (1)–No. (4) are basic qualities, No. (5) is core competence, while No. (6) and (7) are indispensable part of the qualities. Figure 1 shows the quality model of command type graduates' core competence toward battlefields.

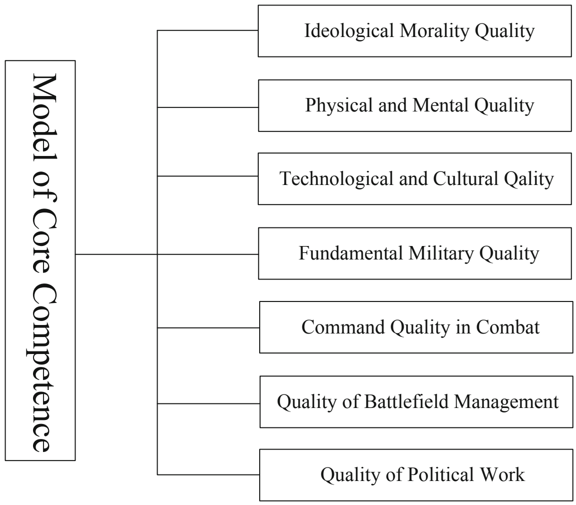

Fig. 1 Quality model of command type graduates' core competence towards battlefields

2.1 Ideological Morality Quality

Ideological morality quality, the attitude at work, belongs to a kind of soft ability which is different from one's ability or capability. The quality includes the love for one's job, the spirit of taking initiatives, the spirit of sacrifice, the charm of personality, and so on [3].

2.2 Physical and Mental Quality

Physical and mental quality is a carrier and material foundation of one's capability. The quality includes psychological endurance, physical quality, mental condition, anti-frustration ability, and so on.

2.3 Technological and Cultural Quality

Technological and cultural quality is a commander's competence and proficiency in science and knowledge, and the ability of applying science and knowledge in professional field. The quality includes structure of knowledge, computer skills, sensitivity of science and technology, imagination, and so on.

2.4 Fundamental Military Quality

Fundamental military quality is the basic military knowledge and skills that are essential for commanders. The quality includes military skills, viability, military knowledge, execution ability, and so on.

2.5 Command Quality in Combat

Command quality which is a commander's competence in combat, is the essential measure of core competence, and also the core of the completion of command missions. The quality includes the ability of comprehensive judgment, the ability of obtaining information, the ability of organization and coordination, the ability of expression and so on [4].

2.6 Quality of Battlefield Management

Battlefield management quality is the peripheral and security ability served for the completion of command missions. The quality includes the ability of personnel management, the ability of frontline management, the ability of weapons and equipment management, the ability of logistics management, and so on.

2.7 Quality of Political Work

Quality of political work, an important part of core competence, is essential for commanders. The quality includes the ability of investigation and research, the ability of policy comprehension, the ability of propaganda, the ability of applying law war, public opinion war and mentality war, the ability of spy-preventing and confidentiality practices, the ability of doing ideological work, and so on [5]. Quality model of core competence is as shown in Fig. 2.

3 Basic Training Methods of Command Type Graduates' Core Competence Training

3.1 Basic Principles

Promoting the whole process of core competence training based on the principle of making good overall design, laying solid vocational basis, focusing on key aspects of education, emphasizing on practice and exercise, and improving core competence. The basic principles are as follows.

3.1.1 Combining Teaching with Combat

The teaching-for-combat concept means the teaching for winning wars. The education of military command graduates shall fully reflect the combat-for-combat concept, combining teaching with combat. The teaching and lecturing shall be conducted around the combat process, and the cadets shall be trained according to real wars.

3.1.2 Combing Research with Combat

We believe that the research on facing battlefields shall be the major content for the combination of research and combat, emphasizing on the technical breakthrough

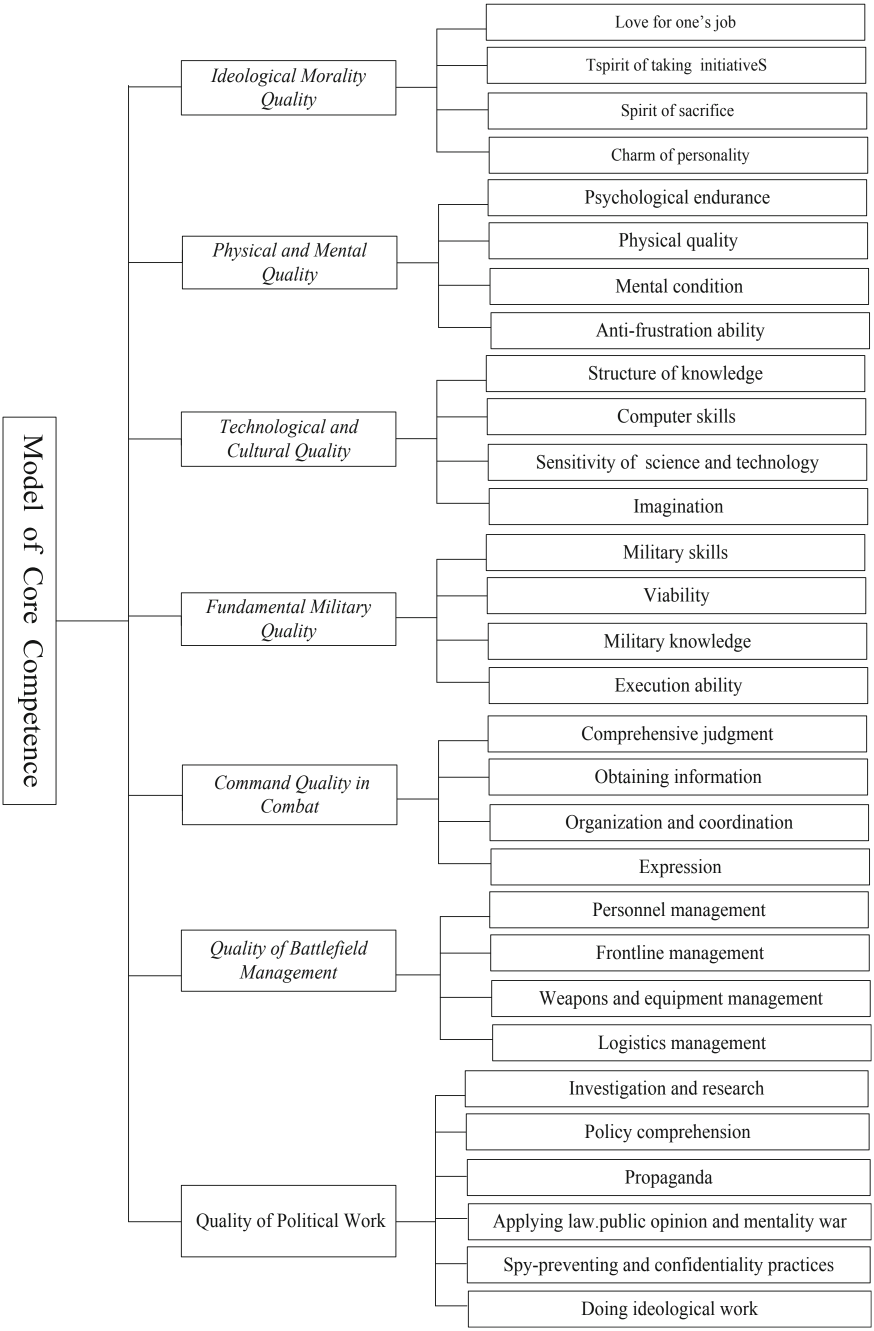

Fig. 2 Quality model of core competence

toward battlefields, the theory innovation toward battlefields, and the drill and training toward battlefields, making great efforts to solve the key problems in combat and drills, trying to realize the goal of research for combat.

3.1.3 Combining Training with Combat

During the process of daily training, strict basic training shall be conducted according to the real war scenario. The drills shall be made with the troops, and the cadets shall take the role of commanders for division or group, and organize the troops to join the drills according to exercise programs, thus improving their capability of combating and commanding, realizing the goal of training for combat.

3.2 Optimizing Conceptual Design of Core Competence Training

On basis of overall requirements, training programs should be well designed according to the training of combat capability.

3.2.1 Designing Relevant Courses Toward Battlefields

Foundation courses, for example, military strategy science, military affairs dialectics, and so on, should be optimized to cultivate cadets' strategic thinking competence. Aiming at improving core competence, specialized courses which are served for real wars should be well designed. Challenge courses should be set up in order to widen cadets' horizons, and offer help for cadets to improve their comprehensive qualities.

3.2.2 Building Criterion Adapting to Requirements of Real Wars

We should change our conventional ideas and study supposing battlefields which are important environmental factor and the basic site where troops will complete combat missions. The study of supposing battlefield is the X factor in future war which will decide the failure and success of a war. The main content of research includes the study on combat environment, the study on combat strength of two sides, the study on combat strategies for winning wars, the study on combat technical support, and the study on our political work, logistics work, and equipment security work in supposing battlefields.

3.2.3 Making Practical Teaching Plans Adapting to Battlefields and Extracurricular Innovation Activities Programs

Practice for real wars is an effective method of improving core competence. Colleges and academies should make more efforts to make practical teaching plans adapting to battlefields and extracurricular innovation activities programs, including the setting up of practical teaching plans adapting to combat cases and combat disposition, plans adapting to the military drills of academies, and plans adapting to military training, as well as extracurricular innovation activities programs adapting to combat training.

3.3 Searching for Ways and Methods of Core Competence Training

Colleges and academies should emphasize on laying solid foundation of military command, regarding the core competence training as the starting point and end-result, and the fundamental point of evaluating the educational quality.

3.3.1 Strengthening Quality Foundation of Core Competence Toward War

Upholding the combination of curricular and extracurricular activities, the combination of theory and practice, the combination of learning and research, colleges and academies should emphasize on cadets' ideological morality quality, physical and mental quality, technological and cultural quality, and fundamental military quality, and other qualities to train the cadets in order to strengthen the quality foundation of core competence facing real wars.

3.3.2 Promoting Command and Strategy Level in Supposing Assignments

Adapting to the development tendency of joint operations, colleges and academies should set up supposing circumstance of offensive and defensive combat situation, complex electromagnetic interference, and various types of reconnaissance about enemies, lead cadets to express themselves positively in the ways of group assignment and team assignment, and promote the command and strategy level, aiming at improving the ability of disposing complicated conditions.

3.3.3 Training Combat Command Capability in Net-Drilling System

Net-drilling system, which applies computer simulation training system and networks, aims to improve cadets' combat command capability according to the information command system. In order to train the combat command capability of graduates, colleges, and academies should set up a series of training courses and subjects in the drill, lead cadets to grasp the principal contradictions which will restrict the combat process, and solve the problems in wars.

3.3.4 Training Combat Command Capability in Comprehensive Drills

Comprehensive drill, which is the combined trainings of tactics and techniques according to the combat process, is an important way of improving cadets' combat command capability. Colleges and academies should set up courses and subjects according to future occupational needs, design drill plans according to the law of cognitive, design training steps according to the rules of generating capability, and according to the combat command process, carefully design all steps of combat, including combat preparation, combat implementation, combat evaluation, and combat conclusion, with the aim to train the cadets' combat command capability and in real wars.

3.4 Perfecting Teaching Appliances Construction of Core Competence Training

On basis of the core competence training of command type graduates, colleges, and academies should perfect a series of construction as follows.

3.4.1 Construction of Teaching Facilities

Teaching Facilities are mainly applied for weapons and equipment co-operation, command training, and confrontation drills.

3.4.2 Construction of Battle Labs

Focusing on teaching and training requirements of command type graduates, the construction of battle labs shall play an important role in the research and development of high-tech achievements, supporting the troops' combat training, and joint training between academies.

3.4.3 Construction of Network Information

Colleges and academies should pay special attention to build the database of professional books, journals, and documents on military, reflecting the latest development of military theories, combat command, and the training of military talents, in order to meet the needs of teaching and research, as well as the self-directed learning of cadets.

3.4.4 Construction of Tutor Team

The key point is the quality training toward war, especially the aspects of instructional design, teaching content, and teaching methods.

3.4.5 Construction of Educational System and Institution for Graduates

The construction shall safeguard the core competence training towards war of command type graduates.

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Behavioral Errors Analysis and Research on Management and Control of Troops Training Based on REASON Model

Peng Gong, Zhenguo Mei, Zaochen Liu, Leiming Yao, Yunqiang Xiang and Chang Mei

Abstract With the continuous advancement of actual combat training the intensity and difficulty of troops training is increasingly expanding, unsafe factors are gradually complicated, safety risks are frequently on the rise, and however, unsafe behavior for officers and men is the key factors which decide troops training safety. On the basis of analysis of causes of military behavioral errors which include the following factors such as military qualities, equipment and technology, training environments and organizational management the article takes three control models: control in advance, field control, and afterwards control based on REASON model of concept, and provides methods and models of management and control of military behavioral errors in troops training from the following 4 aspects: plan and training, check and guidance, reason and measures, evaluation and summary.

Keywords Troops training accidents · REASON model · Military behavioral errors · Behavioral management and control

With the continuous advancement of actual combat training the intensity and difficulty of military training is increasingly expanding, unsafe factors are gradually complicated, safety risks are frequently on the rise, however, unsafe behavior for officers and men is the key factor which decides military training safety [1]. In accordance with the analysis of the 158 training accidents in recent years, we have found that human factors reach 97.67 %, and finally show up through behavioral errors and cause accidents [2]. Therefore, it is of great significance to research inducing factors, production mechanism, management, and control issues of behavioral errors for precaution of training accidents. The article focuses on

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discussing management and control of military behavioral errors in troops training based on REASON model.

1 Brief Introduction on REASON Model

REASON Model is a kind of Model of Concept on human errors that was put forward by James Reason, Psychology professor of Manchester University in the UK. He held that Accidents occurrence follows the evolutionary rule: wrong decision of decision-makers, imperfection management, and direct prerequisite of forming unsafe behavior, the resulting unsafe behavior, and thus the failure of defensive system [3]. In 1995, Reason further deepened the path of influence of systematic safety from organizational errors, and put forwards pathological model of organizational accidents. See Fig. 1.

From Fig. 1 we can see that contributing factors include organizational errors, risk factors at working sites, and individual errors/team errors. By way of organizational errors accidents come up with influence on systematic safety and defense in depth through current and potential ineffective paths, thus trigger the following unexpected result [4].

2 Analysis of Inducing Factors on Military Behavioral Errors in Troops Training

Analyzing inducing factors of military behavioral errors is the basis and prerequisite of behavioral control for troops' officers and men. In combination with REASON model the article summarizes the following 4 aspects as to the inducing factors of military behavioral errors in troops training: qualities of officers and men, equipment and technology, training environments, and organizational management. In them qualities of officers and men are intrinsically decisive factors, equipment and technology, training environment and organizational managements are extrinsically influential factors. The formation mechanism of behavioral errors is as follows. See Fig. 2.

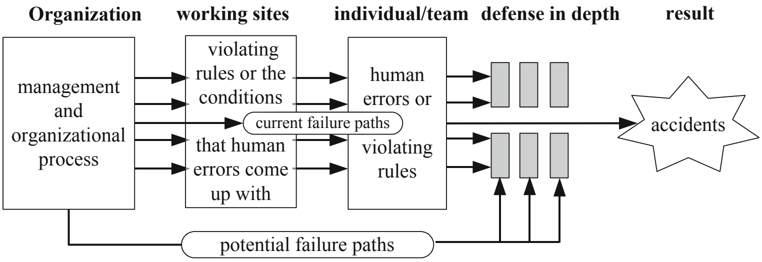

Fig. 1 Pathological model of organizational accidents

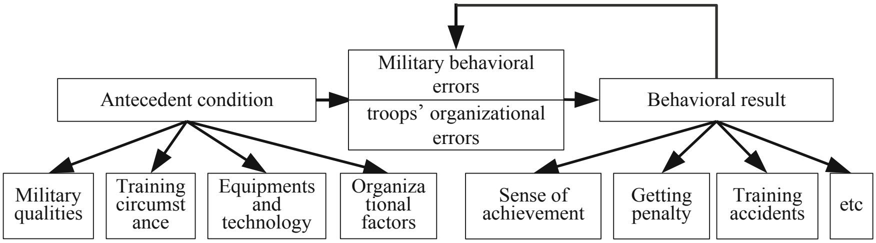

Fig. 2 Formation mechanism of behavioral errors

2.1 Qualities of Officers and Men

Qualities of officers and men include their ideological recognition level, psychological and physiological status, knowledge, and technology. Whether ideological understanding and level are right or not will play an importantly decisive role on their behavior; some individual psychology such as rudeness, carelessness, and laziness easily leads to irrational behavior for officers and men and thus trigger some unsafe behaviors. Physiological factors can lead to uncontrollably unconscious behavior for officers and men and easily causes human errors; the knowledge and technology will produce limited role for their behavior, under the situation of recognition deficiency and lower technological level their behavior will inevitably lead to blindness. Especially when risk occurs they are usually in confusion and could not deal with it reasonably.

2.2 Equipment and Technology

Equipment operation is a process of man–machine interaction, the complexity and operability of the equipment may produce an important influence on operable behavior of officers and men. If the equipment technology is complicated and ergonomic characteristics is poor that will increase operable difficulty of equipment, and lead to human errors of judgment and operation for officers and men.

2.3 Training Environments

Troops' training is a systematic engineering among man, machine, and environment. The intrinsic and extrinsic environment will play much more important influence on behavior of officers and men. A specific environment with internal disunity, the prevalence of unhealthy behavior, and disharmony between officers and men may have provocative and inducing role on their thoughts, and may produce corrosive role on their mental volition, and may come up with 'add-fuel-to-fire' role on their violating discipline and transgressing provision; Complex geographic environments and worse climate conditions such as risk degree at training sites, training difficulties, terrible weather, ambient lightning, temperature, and humidity may have terrible influence on physiology, psychology, and behavior of officers and men, subsequently trigger behavioral errors.

2.4 Organization and Management

Troops training a kind of is organizational behavior, its organization and management will have an important influence on officers and men's behavior. Some organizational and management factors which lead to behavioral errors mainly include half-baked plans, imprecise organization, incorrect command, poor communication, inadequate training, insufficient coordination, etc., these factors usually have tangible or intangible influence on thoughts and behavior of officers and men directly or indirectly, and may trigger behavioral errors under the special conditions.

3 Countermeasures of Management and Control of Behavior Errors in Troops Training

Based on researching result on organizational behavior and behavioral remedy [5], the article puts forwards the following methods and models on management and control of behavioral errors of officers and men. See Fig. 3.

3.1 Optimizing Schemes, Doing Education Well and Enhancing Control in Advance

Training plan is the basis and prerequisite which guarantee training safely and smoothly. Unreasonable training plan, contents and design, and unsuitable time allocation easily lead to training importance without distinction, excessive relaxation, improper difficulty, and unfair treatment, these phenomenon influence officers and men's psychology, cause their negative affection and trigger behavioral errors. Therefore, before training we should size up the situation, understand training level, reasonably distinguish contents, appropriately arrange time, scientifically design schemes in accordance with the steps from simplicity to complexity, from the basis to specialization, from individual to collaboration, advance gradually

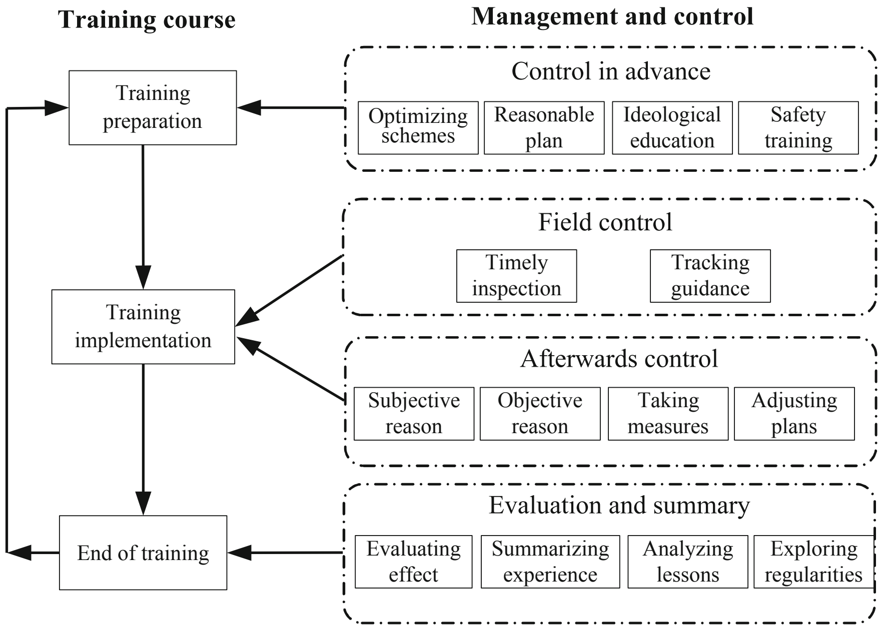

Fig. 3 Methods and models on management and control of behavioral errors in troops training

in due order to make sure that the training process have reasonable relaxation degree systematically.

Education and training is the basic work which improves safety recognition and safety qualities, and is also the important way and path which realize behavioral management and control for officers and men. Before training trainers should develop ideological mobilization to improve their understanding of training significance; organize theoretical study to reinforce their knowledge basis; develop safety education to cultivate their safety consciousness; advance safety training to progress their safety skills, and finally they reach self-discipline and control their own behavior depending on fine ideological basis and safety qualities.

3.2 Strengthening Inspection, Timely Guidance, and Doing Field Control Well

Inspection and guidance is the necessary link, and is also the important means to find and solve problems and control their behaviors. Although trainers give the necessary education and training and fortify their consciousness and safety, owing to the complicated training course and a lot of influencing factors officers and men still encounter some issues such as lack of awareness, understanding deviation, inaccurate judgment during the training activities, this will require officers in charge themselves to go to the spot, learn the situation, check the possible problems, timely tracking and guidance, help officers and men overcome the difficulties and solve the problems. If lack of awareness, they should receive further education to improve themselves; if understanding deviation they should have further research to deepen comprehension; if inaccurate judgment, they should need timely guidance and help to progress their right judgment and response capacity.

3.3 Analyzing Causes, Perfecting Measures, and Doing Afterwards Control Well

If trainers find out that there exist some errors from the performance of officers and men during the inspection, they should deeply analyze the cause, perfect the relevant measures and correct deviation to make their behavior back to the right channel. The occurrence of errors for officers and men's behavior is attributed to the following factors such as subjective factor and objective factor, governors and the governed, internal factors and external factors; by way of inquiry, communication, and retrospective analysis the trainers find out the origin, timely take the corresponding countermeasure to correct problems and solve problems. If there exist the following problems such as insufficient working staff, poor staff qualities, different opinions in understanding, inadequate resources, unsuitable organization and methods, the lower fighting morale, etc., the trainers should relevantly increase working staff, give the relevant training and adjustment, make further mobilization and unify the thoughts, enrich the resources, adjust the methods, improve the incentive measure. Sometimes the trainers should adjust the plans, and even modify the targets because there exist some possible problems such as inappropriate higher targets, underestimation on the real environments, and unreasonable task allocation concerning the original plans.

3.4 Comprehensive Evaluation, Summarizing and Improving Management and Control Level

Evaluation and summary is the last link of management course, and is the important means of improving management and control level. Evaluation is the overall judgment over measure and effect of management and control during training course and masters its effectiveness. Summary is to tease out the past situation, measures and the characteristics, analyze the experience and lessons so as to find out the regularity during the training work. Troops should do evaluation and summary well by way of the combination from the top-down approach to bottom-up approach. The two approaches are that the evaluation organization promotes organizational development in different approaches step by step. The trainers make officers and men fully understand the relationship among their behaviors, measure of management and control and training safety, deepen law of cognition, reinforce sense of safety, improve safety quality, and fortify the capacity of safety behavior through evaluation and summary.

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Research on Telegrapher Selection

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Abstract Telegraph communication plays an irreplaceable role in the field of military communication, and its quality is mainly determined by the telegrapher's skill level. Due to the reason that the generation of telegraph skills depends largely on the individual's physical and psychological qualities, selecting suitable individuals for telegraph training is the key to promoting the skill generation and improving the training efficiency. In order to solve the problems existing in telegrapher selection, such as lack of theoretical basis, great randomness, and so on, the article first analyzes the telegrapher characteristics according to the features and requirements of telegraph technology. By means of questionnaire, expert discussion, multi-level multi-target system fuzzy optimal method, etc., the article establishes the telegrapher selection appraisal system, which offers scientific and standardized guidance for the practice of telegrapher selection.

Keywords Telegrapher selection · Telegraph technology · Characteristic analysis · Appraisal system

1 Introduction

Telegraph communication, with the advantages of high reliability, fine confidentiality, rapid establishment and transmission, etc., has been an important means of military communication all along. As operator, telegrapher directly determines the quality of telegraph communication. Due to the reason that there are many specific contents and difficulties in the training of telegraph, the generation of telegraph skills depends largely on the individual's physical and psychological qualities, and it is very important to select suitable individuals for training. But there are many problems in the telegrapher selection at present, such as lack of theoretical basis, great randomness, etc., which result in long training cycle and low talent rate.

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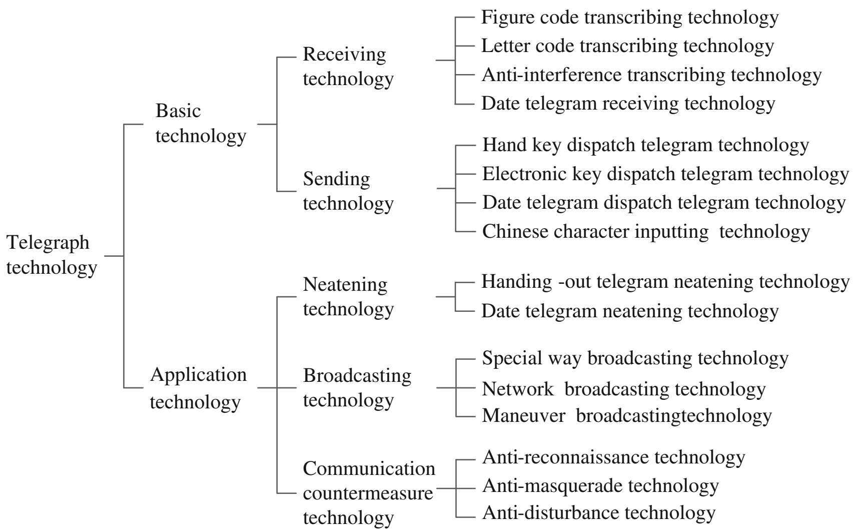

Fig. 1 Composition of telegraph technology

Therefore, it is very urgent to strengthen the research on telegrapher selection to make it more scientific, standardized and targeted.

2 Telegraph Technology [1]

Telegraph technology refers to the knowledge, experiences, methods, techniques and skills accumulated during the long-term practice of telegraph. The composition of telegraph technology is shown in Fig. 1.

Figure 1 suggests that telegraph technology is mainly composed of actions and mental activities. Actions refer to a series of explicit actions with the aid of musculoskeletal and corresponding nervous system, such as sending and receiving. Mental activities refer to the recognition activities in one's brain with the aid of thinking, such as recognition of codes. The telegraph practice is a high coordination of actions and mental activities. For example, receiving includes the actions of writing and the mental activities of recognizing codes.

3 Analysis on Telegrapher Characteristics [1]

The features of telegraph technology require that a telegrapher should have the following characteristics:

1. Skill
   - Rapidity. It means that the response speed and action speed of a telegrapher should be rapid.
   - Accuracy. It means that a telegrapher should respond and act accurately according to the changes of external environments and conditions.
   - Sensitivity. It means that the response to changes of a telegrapher should be sensitive when applying techniques and skills comprehensively.
   - Coordination. It means that a telegrapher body's physiological function and psychological function should be highly coordinate when working.
2. Comprehensiveness
   It means that telegraph is integrated by receiving, sending, neatening, etc., requiring that a telegrapher should have many corresponding skills and abilities.
3. Individual difference
   It means that different characteristics will be shown between every two telegraphers because of differences in intelligence, physiology, psychology, etc.
4. Relativity
   It means that the requirements and standards of a telegrapher should be based on the needs, and they will change with changes of needs and technologies.

4 Establishment of Appraisal System in Telegrapher Selection

The basic establishment process is as follows.

4.1 Determination of Selection Indexes

The method of questionnaire is used to determine the selection indexes.

Step 1: Prepare the questionnaire on the selection and quantization of a telegrapher's physiological and psychological indexes. Each index in questionnaire is set 5 grade scores from the "very important" to the "completely unimportant".

Step 2: Organize the surveyed staff to score every index and give modifications, supplements and improvements to the questionnaire.

Step 3: Use the improved delphi method to process the survey data to determine the telegrapher selection indexes.

4.2 Determination of Selection Index Weights

The combination of analytic hierarchy process and delphi method is adopted to determine the selection index weights [2, 3].

Step 1: Consultation forms are designed and issued to several experts, who should score the relative importance between any two indexes. The relative important degree is represented by the numbers from 1 to 9 and their inverses from 1/2 to 1/9, whose meanings are shown in Table 1.

Step 2: Calculate the weight vector.
First, normalize each column vector of judgment matrix:

$$\bar{a}_{ij} = a_{ij} / \sum_{i=1}^{m} a_{ij} \tag{1}$$

Second, calculate each row vector's sum of normalized judgment matrix:

$$\bar{\omega}_i = \sum_{j=1}^{n} \bar{a}_{ij} \tag{2}$$

Thirdly, normalize $\bar{\omega}_i$:

$$\omega_i = \bar{\omega}_i / \sum_{i=1}^{m} \bar{\omega}_i \tag{3}$$

Finally, calculate the eigenvalue:

$$\lambda = \frac{1}{m} \sum_{i=1}^{m} \frac{(A\omega)_i}{\omega_i} \tag{4}$$

Table 1 Meanings of numbers from 1 to 9 and their inverses

Number (s)	Meaning
1	The two indexes are of equal importance
3	The former index is a bit more important than the latter one
5	The former index is obviously important than the latter one
7	The former index is very important than the latter one
9	The former index is extremely important than the latter one
2, 4, 6, 8	The intermediate degree between two adjacent numbers' meanings
Inverses	Importance of the latter index than the former one, just opposite to their inverses' meanings

Table 2 Values of *RI*

m	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Step 3: Test the consistency.
First, calculate consistency test index CI:

$$CI = \frac{\lambda_{\max} - m}{m - 1} \tag{5}$$

Second, determine the random consistency index RI, shown in Table 2.
Finally, calculate consistency ratio CR:

$$CR = CI/RI \tag{6}$$

If $CR < 0.1$, it can be judged that the consistency of judgment matrix is satisfied, and the eigenvector (ω_1, ω_2, …, ω_m) is the weight of each index. If $CR \geq 0.1$, the elements should be adjusted until the consistency is satisfied.

Step 4: Use above method, the weight given by every expert can be obtained. After averaging all the weights, the final weights of index can be determined.

4.3 Appraisal of Telegraph Selection

Due to too much factors should be considered in a specific decision-making, the multi-level multi-target system fuzzy optimal method is used to make a comprehensive appraisal [4, 5].

Step 1: Divide the decision-making system to several decision-making layers according to the decision-making items and indexes.

Step 2: Calculate the decision-making optimal membership degree of the lowest layer.
First, Create the eigenvalue matrix X of index.
Suppose there is a solution set $D = (d_1, d_2, \ldots, d_n)$ composed of n candidates for a position and a appraisal set $V = (v_1, v_2, \ldots, v_m)$ composed of m indexes, then X can be created as following:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} = (x_{ij})_{m \times n} \tag{7}$$

In the above matrix, x_{ij} represents the eigenvalue of solution j's index i,

$$i = 1, 2, \ldots, m; j = 1, 2, \ldots, n.$$

Secondly, create the matrix R of relative optimal membership degree.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} = (r_{ij})_{m \times n} \tag{8}$$

In the above matrix, r_{ij} represents the relative optimal membership degree of solution j's index i, $0 \leq r_{ij} \leq 1$, i = 1, 2, …, m; j = 1, 2, …, n. Finally, make the decision.

Extract each row vector's maximum element of matrix (8) to create the best solution g:

$$g = (\max r_{1j}, \max r_{2j}, \ldots, \max r_{mj})^T = (g_1, g_2, \ldots, g_m)^T \\ j = 1, 2, \ldots, n \tag{9}$$

Extract each row vector's minimum element of matrix (8) to create the worst solution h:

$$h = (\min r_{1j}, \min r_{2j}, \ldots, \min r_{mj})^T = (h_1, h_2, \ldots, h_m)^T \\ j = 1, 2, \ldots, n \tag{10}$$

According to the best solution, suppose the relative optimal membership degree of solution j is u_j, then the weighted distance from the best D_{jg} and the weighted distance from the worst D_{jh} can be calculated by the following formulas:

$$D_{jg} = u_j \sum_{i=1}^{m} w_i (g_i - r_{ij}) \tag{11}$$

$$D_{jh} = (1 - u_j)\sum_{i=1}^{m} w_i(r_{ij} - h_i) \tag{12}$$

In the above formulas, the index weight vector W is as follows:

$$W = (w_1, w_2, \ldots, w_m)^T, \quad \sum_{i=1}^{m} w_i = 1 \tag{13}$$

According to the optimization criteria, u_j can be obtained by minimizing the objective function of the square sum of the weighted distances from the best and the worst.

$$\begin{aligned}\min\{F(u_j)\} &= (D_{jg}^2 + D_{jh}^2)\\ &= u_j^2\left[\sum_{i=1}^{m} w_i(g_i - r_{ij})\right]^2 + (1 - u_j)^2\left[\sum_{i=1}^{m} w_i(r_{ij} - h_i)\right]^2\end{aligned} \tag{14}$$

Let the derivative of $\min\{F(u_j)\}$ is 0, then u_j can be calculated:

$$u_j = \left(1 + \left[\frac{\sum_{i=1}^{m}(w_i g_i - w_i r_{ij})}{\sum_{i=1}^{m}(w_i r_{ij} - w_i h_i)}\right]^2\right)^{-1} \tag{15}$$

Step 3: Using u_j of the lowest layer as the input of the next upper layer to calculate the solution j's relative optimal membership degree of the next upper layer. Repeat the processes until reaching the top layer; then the relative optimal membership degree matrix is obtained as follows:

$$U_j = (u_1, u_2, \ldots, u_n) \tag{16}$$

Step 4: Sort the solutions according to the principle of maximum membership degree.
Finally, the telegrapher selection appraisal system is obtained shown in Table 3.

Table 3 Telegrapher selection appraisal system

Whole (1)	First-grade index (weight)	Second-grade index (weight)	Third-grade index (weight)	Optimal value
	Physiological factors (0.45)	Body size (0.13)	Height (0.03)	Interval
			Weight (0.01)	Interval
			Sitting height (0.04)	Interval
			Knee height (0.02)	Interval
			Linear distance with hands held flat (0.02)	Interval
			Distance from hip to knee (0.01)	Interval
		Vision (0.08)	Sight (0.03)	Larger
			Observation accuracy (0.03)	Smaller
			Visual ability of directional search (0.02)	Smaller
		Audition (0.04)	Hearing (0.02)	Smaller
			Auditory localization ability (0.02)	Smaller
		Strength (0.02)	Grip strength (0.01)	Larger
			Finger force (0.01)	Larger
		Response speed (0.06)	Visual response speed (0.03)	Smaller
			Auditory response speed (0.03)	Smaller
		Coordination (0.06)	Hands coordination (0.03)	Smaller
			Hand–eye coordination (0.03)	Smaller
		Adaptability (0.06)	Endurance (0.02)	Smaller
			Anti-fatigue ability (0.04)	Smaller
	Psychological factors (0.55)	Ability (0.30)	Intelligence (0.04)	Larger
			Observational ability (0.07)	Smaller
			Memory (0.04)	Larger
			Attention (0.07)	Larger
			Response time (0.08)	Smaller
		Character (0.25)	Stability (0.08)	Larger
			Boldness (0.05)	Smaller
			Fantasy (0.05)	Smaller
			Apprehension (0.07)	Smaller

5 Conclusion

The scientific telegrapher selection is of great significance to improve the talents' quality of telegraph training. The article gives full consideration to the effect of individual's physical and psychological qualities on the generation of telegraph skills. On the basis of a large amount of investigations, a relatively scientific telegraph selection appraisal system is established, which is proved in practices to have good effects on the promotion of skill generation, improvement of training efficiency, and so on.

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Experimental Research of Shoulder-Mounted Portable Equipment Operator's Foot Spacing in Standing Position

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Abstract The experimental data and their variation law of shoulder-mounted portable equipment operator's foot spacing in standing position are of great significance to determine reasonable foot spacing and effective activity duration so as to ensure scientific shoulder-mounted portable equipment standing-position operation. Footing space data in stationary operation obtained at regular intervals are quantitatively studied by means of force analysis and data value comparison. Compare the foot spacing data at different points in time and analyze their internal relations to explore effective training duration and reasonable foot spacing of shoulder-mounted portable equipment operators. In conclusion, the effective activity duration and the computing formula for shoulder-mounted portable equipment operator's foot spacing in standing position are put forward, aimed to serve as forceful support for scientific operation and training.

Keywords Training duration · Operation in standing position · Foot spacing variation

1 Significance of Research

Additional training duration is usually adopted to consolidate actions and improve the operation stability of shoulder-mounted portable equipment. It is, however, noticed that increased activity duration results in operator's overfatigue and deviated training posture, thus incurring heath damage. It is therefore purposed to find out the operator's foot spacing variation and determine reasonable operating actions while taking activity duration into account. The significances are as follows:

The article belongs to the Character of Man research scope.

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First, to ensure scientific operation posture: By measuring the standing-position foot spacing of each operator, find out the internal relations from different operator's foot spacing variation and explore the reasonable foot spacing in standing position. In this way, we expect to guarantee scientific operation posture [1, 2] through quantitative measuring and calculation.

Second, to explore the law of activity duration: Analyze the effectiveness of activity duration according to operation duration and the variation of foot spacing. Avoid further training when fatigue to improve the efficiency of training time and training effectiveness.

Third, to further advance the study on man, quantitatively analyze the changes of each operator's posture [3] to research the foot spacing variation of various operators and identify their similarities and differences to further advance the study on man.

2 Experimental Subject and Methodology

2.1 Experimental Subject

The experimental subject is 10 male cadets of some academy, whose average age is 20, 173 cm in height, 64 kg in weight, and are of good biological conditions in terms of blood pressure and heart rate (see Table 1 for specific data). Results of Cattell 16 personality factors psychological tests of the experimental subjects show normal mental quality.

2.2 Experiment Preparation

In accordance with the CPLA Outline of Military Training and Evaluation, the shoulder-mounted portable equipment operator should wear BDU with camouflage

Table 1 Experimental data

SN	Weight (kg)	Pulse	Hip width (cm)	Leg length (cm)	Foot spacing measuring			
					0 min	10 min	20 min	30 min
1	65.1	80	31	97	35	40	37	38
2	67.3	80	32	103	34	35	40	41
3	61.9	75	30	101	36	38	35	42
4	66.7	76	33	105	37	33	35	36
5	55.7	78	31	101	35	33	33	31
6	71.7	68	33	107	39	30	33	30
7	52.9	80	30	100	35	33	30	32
8	69.5	96	35	100	35	34	33	34
9	61.6	80	31	100	34	33	32	30
10	71.5	75	35	103	35	35	36	36

cap, braided outer belt and standard rubber shoes. Therefore, a full individual gear includes 1 canteen, 1 bag and 1 set of shoulder-mounted portable equipment, weighing 13 kg in total. The experimental instruments are: ACUMEN TZ-MAX100 heart-rate telemetric watch (4 pc), CENTER310 thermometer (1 pc), Cattell 16 personality factors psychological testing application (1 set), and stop-watch (1 pc). The experimental site is an indoor training area of suitable temperature and good illumination.

2.3 Experiment Design

The experiment starts with stationary training tests to measure each operator's foot spacing and observe its variation over time.

3 Data Statistics and Analysis

3.1 Experimental Statistics

Each of 10 operators conducts standing-position stationary operation for 30 min. The foot spacing values are measured at such four points in time as 0, 10, 20, and 30 min as shown in Table 1.

3.2 Human Body Model Building and Analyzing

To facilitate the research, we build the mechanical model by lowering the degree of freedom of human body shown as Fig. 1, in which the hips, legs, and the ground constitute an isosceles trapezoid [4, 5]. Its force analysis is as follows:

$$mg(l_2 \sin\alpha + 0.5l_1 - l_3) + Mg(l_2 \sin\alpha + 0.5l_1) = N_1(l_1 + 2l_2 \sin\alpha) \tag{1.1}$$

$$mg(l_2 \sin\alpha + 0.5l_1 + l_3) + Mg(l_2 \sin\alpha + 0.5l_1) = N_2(l_1 + 2l_2 \sin\alpha) \tag{1.2}$$

$$N_1 + N_2 = mg + Mg \tag{1.3}$$

$$\sin\alpha = (D - l_1)/2l_2 \tag{1.4}$$

$$F_1 = N_1/\cos\alpha \tag{1.5}$$

$$F_2 = N_2/\cos\alpha \tag{1.6}$$

In the above formulas, m stands for the Mass of the equipment with kg as its unit; M stands for the weight of the operator with kg as its unit; l_1 stands for hip

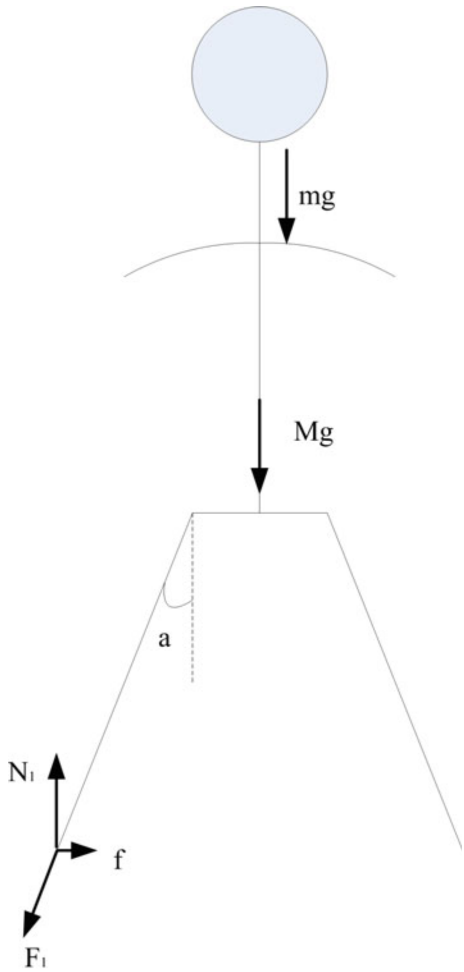

Fig. 1 Mechanical model of human body

width with *m* as its unit; l_2 stands for leg length with *m* as its unit; l_3 stands for the horizontal distance between the equipment and the center of human body with *m* as its unit; N_1 stands for the supporting force of the left foot with *N* as its unit; N_2 stands for the supporting force of the right foot with *N* as its unit; F_1 stands for the force on the left leg with *N* as its unit; F_2 stands for the force on the right leg with *N* as its unit; α stands for the angle between legs with radian as its unit.

Substitute relevant data of the formulas with a suppositional model as $m = 13$ kg, $M = 70$ kg, $l_1 = 0.3$ m, $l_2 = 1$ m, $l_3 = 0.1$ m, g = 9.8 N/kg, and α ranges from −15° to 15°, then, we obtain the variation of F_1 and F_2 as shown in Fig. 2 (the upper left line is F_1):

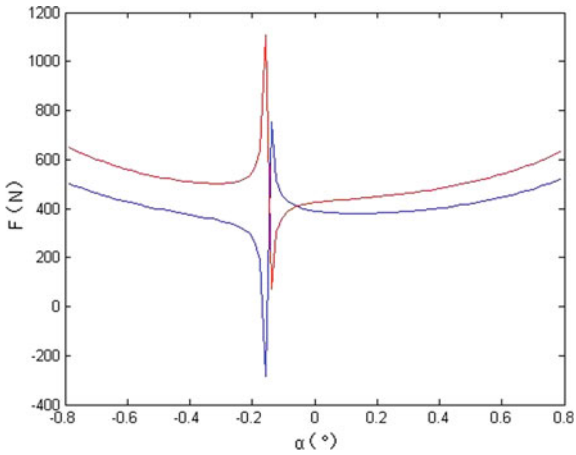

Fig. 2 Force variations under standard condition

3.3 Data Analysis

Conduct force analysis according to measured data and obtain the result as is shown in Table 2:

Seen from Table 2, the included angle between the operators' legs ranges from −1° to 4°, 3 of whom increased the angle, 3 reduced, and 4 basically remain unchanged.

Analysis of the angle variation corresponding with that of standing-position foot spacing shows its result in Table 3:

Seen from Table 3, the initial angle variance corresponding with foot spacing in standing position is at minimum; the angle variance is comparatively steady from 10 to 20 min; the angle variance decreases at 20 min; the angle variance reaches its maximum at 30 min. We could therefore tell that the activity duration of around

Table 2 Standing-position foot spacing variation

SN	Angle between feet			
	0 min	10 min	20 min	30 min
1	1.18	2.66	1.77	2.07
2	0.56	0.83	2.23	2.50
3	1.70	2.27	1.42	3.41
4	1.09	0	0.55	0.82
5	1.13	0.57	0.57	0
6	1.61	−0.80	0	−0.80
7	1.43	0.86	0	0.57
8	0	−0.29	−0.57	−0.29
9	0.86	0.57	0.29	−0.29
10	0	0	0.28	0.28

Table 3 Variation of angle corresponding with foot spacing

Time	0 min	10 min	20 min	30 min
Average value of angle	0.956	0.667	0.654	0.827
Variance of angle	0.330	1.058	0.695	1.720

20 min is scientific, while more than 30 min too long. Take angle α as 0.65°, we can calculate the foot spacing D with the following formula:

$$D = 2\sin(0.65^\circ) * l_2 + l_1 \tag{1.7}$$

Analyzing with SPSS application [6], we find no obvious relativity between foot spacing and BMI.

$$BMI = Weight/height^2 \tag{1.8}$$

4 Conclusion

Analyzed with mechanics, the supporting force on both feet shall decrease if the angle corresponding with the standing-position foot spacing exceeds −5°. Therefore, the foot spacing may increase within the suitable range for human body.

Seen from the operation of experimental subjects, the foot spacing variation of each operator is different but the corresponding angle ranges from −1° to 4°. The formula for foot spacing calculation is as follows:

$$D = 2\sin(0.65^\circ) * l_2 + l_1$$

The activity duration of around 20 min is scientific, while more than 30 min too long.

All aforementioned conclusions are derived from this very experiment, whose sample size is limited due to time and energy restraint. Further study shall focus on possible changes with sample size increase.

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Applications of Rubric in the Assessment of Cadet's Learning in Informationalized Teaching

Hai Chang, Meng Kang, Rongzhi Yang, Zhiqiang Zhang, Jie Xing and Xinpeng Chen

Abstract To attune to the informationalized teaching, a cadet-centered and process-oriented Rubric assessment method is proposed. Starting with the issue of the assessment of cadet's learning in informationalized teaching, this paper analyzes the differences between informationalized teaching assessment and traditional teaching assessment, explains the definition, function of Rubric as well as its significance in informationalized teaching, describes the designing method of Rubric, carries out a case study with research-based learning rubric as an example, and briefly states a few key points for the applications of Rubric in teaching assessment so as to provide a practical guidance for full-scale applications of Rubric in informationalized teaching assessment.

Keywords Rubric · Informationalized teaching · Designing principle · Teaching assessment

1 Comparison and Analysis of Informationalized Teaching and Traditional Teaching

Traditional teaching is instructor-centered since the instructor acts as the information source; in informationalized teaching, the instructor is no longer the knowledge initiator or indoctrinator but the facilitator who helps cadets acquire, interpret, organize, and convert information to solve practical problems [1]. Informationalized teaching is cadet-centered, in which cadets bear the responsibility of self-study as knowledge-builders other than knowledge-receivers, and are consequently expected to grow into independent and life-long learners of information-processing competencies.

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1.1 Difference in the Goal of Assessment

Traditional teaching assessment puts emphasis on learning results in order to grade cadets with judgments on what cadets have/have not learned, the result of which is formal and judgmental. In comparison, informationalized teaching assessment is based upon cadets' performance and learning process, aiming to assess the cadets' competencies to apply knowledge and focuses more on cadets' skills than knowledge, which is therefore informal and advisory.

1.2 Difference in the Maker of Assessment Criteria

The assessment criteria of traditional teaching are made in accordance with curriculum standards or the instructor's intention, resulting in fixed and unified assessment criteria of cadets' learning. However, informationalized teaching accents cadets' self-directed learning and to some extent cadets have the initiatives of what to learn and how to learn it while the instructor guides and supervises them. Therefore the informationalized teaching assessment criteria are made by the instructor and cadets in collaboration according to practical problems and cadets' knowledge, interests, and experiences.

1.3 Difference in the Attention to Learning Resources

More or less, traditional teaching ignores the assessment of learning resources which are regular textbooks and auxiliary material, while in informationalized teaching there is a wide source of learning material of varied quality thanks to the introduction of the Internet. How to select learning resources adaptable for learning objectives is an important job not only for the instructor, but for cadets for their life-long learning as well. Therefore, the assessment of learning resources in informationalized teaching is valued to a larger degree.

1.4 Difference in the Cadets' Competencies Obtained

Graded or categorized as per the instructor's assessment, cadets are passive and do not realize whether they have met the learning objectives until obtaining the instructor's feedback in traditional teaching. Whereas in information society, it is impossible to real-time evaluate the cadets' learning since knowledge is renewing constantly. Therefore self-assessment is a necessary skill for a life-long learner, which is after all one of the objectives of informationalized teaching.

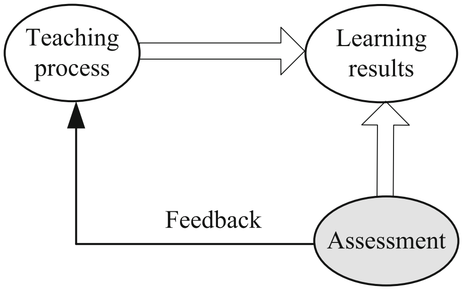

Fig. 1 Traditional teaching assessment

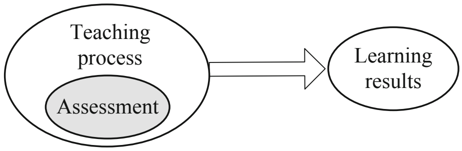

Fig. 2 Informationalized teaching assessment

1.5 Difference in the Sequence of Teaching and Assessment

In traditional teaching, the assessment, as the finish, is conducted after the teaching process aiming to make judgments on the learning results and is thus of great objectivity, as is shown in Fig. 1. Functioning to orient and stimulate cadets, the assessment is incorporated into the teaching process and is an inseparable part of learning process in informationalized teaching, as is shown in Fig. 2.

The above comparison shows that it is necessary to make practical and operable assessment criteria for various activities in different stages and periods of cadets' growth so as to make judgments on whether cadets have finally attained corresponding sub-goals of the ultimate goal, and that traditional teaching assessment is obviously not adaptive to cadets' learning in information conditions. On this basis, this paper puts forward the cadet-centered and process-oriented Rubric assessment method.

2 Function and Significance of Rubric in Informationalized Teaching Assessment

2.1 The Concept of Rubric

Heidi Goodrich defined Rubric as a grading instrument by listing a set of criteria for a job [2], while ZHU Zhiting argued that Rubric is a structured quantitative assessing instrument [3]. In this paper, Rubric is understood as a set of criteria to evaluate the cadets' action, cognition, attitude, and learning results in their learning process, integrating qualitative and quantitative assessment by specifying the assessment standards and grading levels from various aspects that are relevant with learning objectives.

2.2 The Function of Rubric

One of the most noticeable advantages of applying Rubric in teaching assessment lies in the fact that the assessing criteria come out into the open, which enables cadets to concentrate on learning the subject other than learning from their instructor. Applying Rubric shall effectively reduce the randomness in teaching assessment as assessment is conducted not only by the instructor but also amongst cadets or by cadets themselves, in the meantime, applying Rubric in teaching assessment lessens the instructor's work load and enables cadets to understand the very level of grading and how to improve it.

2.3 The Significance of Rubric in Informationalized Teaching Assessment

As an assessment instrument implying the cadet-centered teaching conception, Rubric is both the grading standard of cadets' assignment and the guide to exploring knowledge for them, and at the same time it bridges the gap between the instructor and cadets and serves as a scientific guarantee of the arts of teaching. In the first place, the application of Rubric helps the instructor to clarify the task and learning objectives, to make reliable evaluation on cadets' learning. Second, effective Rubric promotes the understanding of the learning objectives and facilitates cadets to comprehend what to pay attention to in their learning process in order to maximize their efforts to fulfill their task. Third, cadets may adopt Rubric for self-assessment and mutual assessment to control their learning progress and judge their own and fellow cadets' assignment quality; Rubric shall direct cadets to better find and solve problem and make refinement and adjustment to improve learning quality. Finally, the instructor may adopt Rubric to give accurate and timely feedbacks to cadets including their deficiencies in learning process and the anticipated quality standards, which is helpful for cadets to improve learning quality.

3 Design and Application of Cadets Learning Assessment Rubric

3.1 Principles of Rubric Design

Structural components of Rubric should change along with the variation of learning objectives, for instance, the assessment of a cadet's electronic product considers such factors as the topic, contents, structure, techniques, resource utilization and so on; the assessment of class attendance places stress on rate of attendance, Q&A interaction, assignment fulfillment, group cooperation, etc. [4].

Reasonable weight of each component is helpful for effective assessment and for well-guided learning. The weight of a Rubric component is of immediate relation with stresses of teaching objectives. Take the assessment of the electronic product again as the example: components as techniques and resources utilization should overweigh the others if the objective is primarily for cadets to master the relevant skills of electronic products making; components as topic, contents and structure ought to overweigh the others if mainly to display cadets' investigation reports.

Adopt concrete, operable, and quantified other than abstract or conceptual language to explain structural components of the Rubric. For example, a standard of *good in information collection* performs no function, but it will be clearer and more definite if changed to *collect information from various electronic and nonelectronic channels and label its origin*.

3.2 Applications of Rubric

The Rubric assessment elements of research-based learning can be determined as topic study, information collection, information categorization, information analysis and learning results, and each element is graded as 4, 3, 2, or 1 (grade 4 stands for *excellent*, 3 for *good*, 2 for *medium*, and 1 for *bad*) in order to describe the cadets' different performances as is shown in Table 1.

3.3 Key Points of Rubric Assessment

It is important to put forward anticipated requirement prior to learning in order to fully display the watchful function of Rubric on learning process. The instructor should give cadets proper reminders so that they balance their performance with Rubric on their own initiatives [5].

No assessing instrument is a panacea; expounding the advantages of Rubric does not equal to negating other assessing instruments. Each assessing instrument has its scope of application, and a reasonable combination of various instruments shall attain optimal results.

The process-oriented assessment lays particular emphasis on at-all-times assessment, which demands the instructor to give proper reminders to cadets so that they adopt Rubric to judge their performances consciously.

Cadets' self-assessment and mutual assessment shall promote their learning and improve their assessing competencies, which ought to be encouraged. Meanwhile, efforts should be made to avoid putting excessive pressure on cadets' mutual assessment, the quality of which shall otherwise be adversely influenced.

Table 1 Rubric of research-based learning

Score	Topic study	Information collection	Information categorization	Information analysis	Learning results
4	Cadets determine a matter to study by focusing on a topic	Cadets collect information from various electronic and nonelectronic channels and label its origin	Cadets categorize information and develop computer-based structure (database)	Cadets analyze information and reach their own conclusion	Cadets adopt multimedia effectively to display their findings by various means and publish them onto web
3	Cadets determine a matter to study by focusing on a given topic	Cadets collect information from various electronic and nonelectronic channels	Cadets together with the instructor find ways for computer-based categorized structure; cadets create categorized structure by themselves	Cadets analyze information and reach their conclusion under the instructor's guidance	Cadets adopt multimedia effectively to display their findings by various means
2	Cadets determine a matter to study with the instructor's assistance	Cadets collect information from limited electronic and nonelectronic channels	Cadets develop computer-based structure together with the instructor	Cadets analyze information under the instructor's guidance and reach their conclusion	Cadets adopt comprehensive media to display their findings
1	The instructor provides a matter to study	Cadets collect information merely from nonelectronic channel	Cadets use computer-based categorized structure developed by the instructor	Cadets retell collected information	Cadets adopt such limited medium to display their findings as written report

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A Structural Equation Model of Job Burnout and Stress-Related Personality Factors in Aviators

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Abstract *Objective* To develop a model of job burnout and stress related personality factors among aviators using SEM. Method Maslach Burnout Inventory-General Survey and 3 personality questionnaires were conducted in 167 pilots. *Results* Structural equation model (SEM) shows negative impact of extraversion, internal control, and hardiness on job burnout (−0.16, −0.11, −0.24), positive impact of psychoticism, neuroticism, and external control on job burnout (0.40, 0.73, 0.13). The fitness indices indicate that the structural model is proper (RMSEA = 0.060 < 0.08). *Conclusion* The findings suggest that MBI-GS is acceptable in research on pilots' job burnout. Emotion stability is the predictor of job burnout. According to ASLOC, pilots that feeling low level of control on safety maybe susceptible to job burnout, which accords with the fact that aviation is high risky.

Keywords Job burnout · Personality · Stress · Structural equation model · Pilots

1 Introduction

With the development of economy and society, the world was becoming strained more and more. A lot of studies showed that excessive job stress is always related with negative outcome in job satisfaction, organizational commitment, and employees' well-being. Thus it would do harm to morale and performance [1, 2]. In recent years, job burnout has become a hot issue in the field of job stress. More and

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more people suffer from job burnout, especially in several occupations. Aviation is high risky and stressful. Pilots must cope with many kinds of job stressors. Pilots may be susceptible to job burnout because of the impact of stressful flight training and sharp social change.

Burnout was first defined by Freudenberger [3] as a special kind of distress in workplace. He found a series of symptoms in young workers who were volunteers in a clinic. They were gradually becoming emotional exhausted, losing motivation, and commitment towards work. After series studies on social services staff Maslach [4] suggested that staff's indifference and irrespective to the clients were important problems in burnout. According to Masclach [5] burnout is "a psychological syndrome of emotional exhaustion, depersonalization and a feeling of reduced professional accomplishment that can occur among individuals working with other people in some capacity". In early phase, study on job burnout was among those who do "people work" (such as teachers, students, customers, patients). However, previous researches have shown that in almost all occupational populations the core symptoms of burnout—exhaustion, cynicism, and inefficiency existed [6–8]. And researchers developed job burnout theory for general occupation and developed a survey for general use. The categories assessed in this general survey are exhaustion (EX), cynicism (CY), and professional efficacy (PE).

Researches indicate that job and worker mismatch may lead to burnout [9]. Many studies are interested in personality factors related to burnout. Results of some longitudinal studies showed that personality factors are significantly correlated with burnout after situational variables were controlled for [10], thus, individual personality characteristics may affect burnout features. Researchers interested in which types of persons may be prone to burnout and found that some personality traits are relevant factors. Some popular personality questionnaires such as 16PF and EPQ were used in the studies and some personality variables attracted the attention. However, Alarcon et al. [11] indicated that there were few articles which were designed to structure and study the relationship between burnout and personality.

This study aimed to find the effects of personality factors on job stress and burnout among pilots. The hypothesis are:according to pilots, Extraversion can negatively predict job burnout. Neuroticism can positively predict job burnout. Psychoticism has significantly positive effect on job burnout. Hardy personality has significantly negative effect on job burnout. Internal safety LOC negatively predicts burnout and external safety LOC positively predicts burnout.

2 Method

2.1 Sample

A total of 167 male pilots from different units participated in this study from March–June 2011 when they visited Institute of Aviation Medicine for their yearly medical evaluation. The aircraft type included, helicopter, fighter, and transporter. The pilots are between 22 and 54 years old. All of them are volunteered to attend the study.

2.1.1 Aviation Safety Locus of Control Inventory, ASLOCI

ASLOCI was developed and validated by Hunter [12] based on a safety LOC scale. The items of this scale were about aviation situation. There are 20 items in the questionnaire and two subscales (internal and external). Each subscale has 10 items. The 5-point Likert scale was used to score each items. The score 1–5 means "strongly agree" to "strongly disagree". The subjects mark the point according to their first response to the items. They were told to answer the questions carefully and truthfully.

The internal and external subscale scores and the total score were calculated according to the methods developed by Hunter [12]. The questionnaire had been administered to 480 US civil pilots and results showed that they were higher internal than external. The internal consistency of two subscales were acceptable and they were negatively correlated to each other ($r = -0.419$, $p < 0.001$) [12].

2.1.2 Maslach Burnout Inventory—General Survey, MBI-GS

The MBI-GS is a 16-item questionnaire including three: exhaustion, cynicism, and professional efficacy. The subscales contain 5, 5, and 6 items, respectively. A 7-point Likert scale is used to score each items. The score 0 and 6 means never and always. Li and Shi [13] translated and adapted it into Chinese version, which retained the original structure and the three subscales. In their study, the alpha reliability coefficients of three subscales (0.88, 0.83, and 0.8, respectively) means good level of internal consistency.

2.1.3 Revised Eysenck Personality Questionnaire-Short Scale for Chinese, EPQ–RSC

EPQ-RSC was adapted by Qian et al. [14] from Eysenck Personality Questionnaire-Short Scale. It contained four subscales: Neuroticism, Extroversion, Psychoticism, and Lie. Each subscale composed of 12 items which is the same as the EPQ-R Short Scale. They adapted the EPQ-RSC in a total of 8637 participants from 56 regions of 30 provinces in the mainland, which includes 7725 Han Ethnicity persons. E, N, and L of EPQ-RSC showed satisfactory reliability and validity, and P showed relatively lower but acceptable reliability and validity according to psychological criteria.

2.1.4 Hardy Personality Questionnaire, HPQ

Kobasa and Maddi [15] developed a short version HPQ for evaluation of the hardiness level of human. It includes three subscales as commitment, control, and challenge, and each contains 12, 16, and 8 items respectively. The study showed that the full scale shows a good reliability and the coefficient alpha is 0.86.

After the establishment of good relationship with the pilots, they were told the aim and the attention of the study. Then they were asked to sign an informed consent. The questionnaire was handed out and they were told to answer the questions carefully and truthfully. Subject in the study was anonymous and confidential and each person was asked to provide a unique code by themselves through which they could acquire individual scores. All of the subjects finished all questionnaires.

2.2 Statistical Analysis

Two statistical analysis software packages including SPSS Version 12.0 and lisrel 8.7 for Windows were used to analyze the data. Bivariate correlations were adopted to analyze the relationship between three subscales of burnout. Structural equation model was established to compare the burnout and personality factors. Significance test level α is 0.05.

3 Results

Full-scale alpha coefficients of MBI-GS is 0.710. Scores of Ex and Cy are positively correlated ($r = 0.667$, $P < 0.01$) and each one is negatively correlated ($r = -0.244, -0.209$, $P < 0.01$) with PE scores. All correlation coefficients reach a significant level. Results above indicate that MBI-GS show acceptable reliability and structure validity in this study.

The results of structural equation model were showed in Fig. 1. The fitness indices ($\chi^2/\mathrm{d}f = 2891/1808 = 1.60 < 3$ RMSEA $= 0.060 < 0.08$) indicate that the structural model is proper. The results show that RMSEA is 0.60 which is less than 0.08 and the ratio of Chi-square to freedom degree is 1.60 less than 3.

According to EPQ, Extraversion can negatively predict job burnout (−0.16), Psychoticism and neuroticism can positively predict job burnout (0.40 and 0.73). According to ASLOCI, internal control can negatively predict job burnout (−0.11) and external control can positively predict job burnout (0.13). Hardiness personality can negatively predict job burnout (−0.24). So all the hypothesis that personality characters can predict job burnout in pilots is accepted, and the relation between ASLOCI and burnout are first defined in pilots.

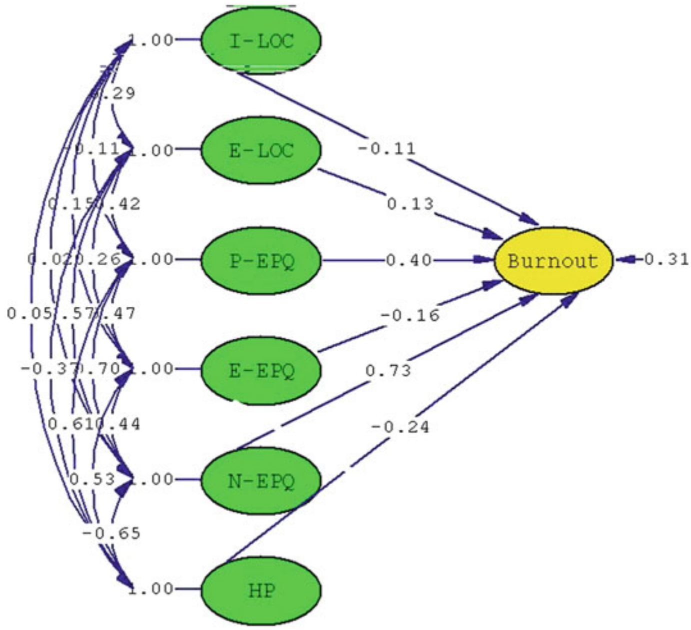

Fig. 1 Structural equation model of Burnout and personality factors. Chi-square = 2891.51, d*f* = 1808, *P*-value = 0.000, RMSEA = 0.060. I-LOC = Internal of LOC, E-LOC = External of LOC, N-EPQ = Neuroticism, E-EPQ = Extroversion, P-EPQ = Psychoticism, HP = Hardy personality

According to above findings, *t*-value of the six paths were −1.07, 0.99, 0.22, −1.38, 3.34, and −1.47, which means the selected personality factors can significantly predict job burnout respectively. The results of *t*-value model show that those who have more internal control feel less job burnout. It is the same on hardiness and extraversion. In other words, those who have more hardiness and extraversion will feel less burnout in job. Those who have more neuroticism feel more burnout in job, so as external control and Psychoticism. The findings indicate that people with higher neuroticism, psychoticism, and external control experience higher job burnout. Therefore, all of the hypothesis is supported.

4 Conclusion

The findings suggest that MBI-GS is acceptable in research on pilots' job burnout. Since the α coefficient is 0.710. Results above indicate that MBI-GS show acceptable reliability.

There are some characteristic about flying occupation which may be important factors causing job burnout. Pilots have excessive working load including high strength flying training, uncertainly working schedule, et al. [16]. Almost all of the studies show that over workload leads to job burnout especially the Exhaustion and Cynicism [17, 18]. Aviation is highly risky and flight safety is an important and special stressor which may be the cause of job burnout.

ASLOCS is used to evaluate the feeling control on flight safety. Since safety is a main stressor in aviation, we think it should impact job burnout in pilots. The results indicate that external control pilots are prone to feel high level of job burnout (exhaustion and cynicism). Studies based on internal and external LOC theory show that persons with external LOC were prone to work stress, so as to job burnout [19]. Persons with external LOC were inclined to attribute events and achievement to powerful man or good luck which made them feel more burnout than those with internal locus of control. Sunbul [20] reported that the correlation coefficient between job burnout dimensions and external locus of control were 0.278–0.289 in studies on teachers. ASLOCI based on theory above is a special tool for investigation on pilots' locus of control. Although aviation LOC may be culture and occupation depended [21], present that the result is consistent to other studies from different countries and jobs.

So far as to EPQ, the results of estimation model on extraversion and neuroticism are supported by other studies [11, 22]. Although NEO is the most popular tool in study on job burnout [23], EPQ shares the extraversion and neuroticism dimensions with it. Psychoticism of EPQ is a predictor of job burnout which had been convinced by lots of researches. So it worthwhile to study the job burnout using EPQ additional to NEO.

Among all of six personality variables, neuroticism and psychoticism can predict job burnout in higher extent (0.73, 0.40). Using these findings, army leaders and psychologists can prevent job burnout and reduce its extent through intervention according to the personality traits of pilots.

Hardy personality is a buffer of job stress and the control and challenged hardy personality show the specific contribution to burnout [24]. The result that hardiness had relatively strong negative correlation with burnout accords with many others studies. Future research should further the study on hardiness-burnout relationship in details.

This research is cross-sectional designed. Additional research is needed to explore the longitudinal effect between personality and burnout.

According to psychological intervention on job burnout and job stress, safety must be integrated in the program.

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Trend Analysis of Low Back Pain in Ergonomic Area

Xiaohong Guo, Menglu Li and Jie Li

Abstract Low back pain (LBP) continues to be the most common type of work-related musculoskeletal disorder. Since 1974, there have been 637 publications about low back pain in the ergonomic field. This study evaluates the research trends of low back pain in the ergonomic field between 1974 and 2015. Data was based on the citation indexing service, Web of Science. The analyzed parameters include authors, countries, organizations, journals, publication years, and terms. Of the 637 publications, 29 % were published in the United States (US), followed by 17 % from Canada, and 9 % from the Netherlands. Correspondingly, the University of Waterloo, Ohio State University, and the University of Amsterdam were the most productive research organizations. The results also showed that low back pain research in the ergonomics field consistently increased over the past four decades. Through term analysis, four clusters were obtained on the term map: Epidemiological Research of LBP, Biomechanics Analysis of Lifting Tasks, Association of Whole Body Vibration (WBV), and LBP at School. Most current research trends are Epidemiologic Research on LBP and Association of WBV and LBP.

Keywords Low back pain · Research trend · Ergonomics · VOSviewer

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1 Introduction

Low back pain (LBP) is one of the most common health problems that people experience and lead to disability [1]. Almost 80 % of people in their life have suffered back pain at some time. In United States, about more than 100 billion dollars are spent every year on treating back pain. The U.S. Bureau of Labor Statistics reported in 2014 that 32 % of all injury and illness cases were due to musculoskeletal disorders (MSDs) and over 55 % of MSDs affected the back. Most research on LBP focused on treatment and psychology effect of low back pain. However, ergonomic research on how to prevent back pain is increasing [2]. Studies have taken a direct research and examined the relationship between low back pain and occupation disorder [3]. In [4], Commission of the European communities published a paper in the journal of Applied Ergonomics on how to prevent LBP in workplace. Almost at the same time, David GS held a seminar on prevention of LBP in an international ergonomic conference. These early efforts opened the new era of ergonomic research in low back pain. But for a long time, the method of ergonomic research in LBP was limited to videotape, biomechanical evaluation, and physiological measurement [5]. Ergonomic research of LBP was led to a new era when electromyography (EMG) was widely used to analyze back muscle activity [6]. This tool is a technique that allows the evaluation of muscle activity. In this paper, we focus on summarizing the global research trends of ergonomic studies in LBP based on the published articles indexed by Web of Science.

2 Data and Methods

The data was retrieved from Web of Science Core Collection on 2015–11–23. The database was last updated on 2015–11–20 and the results of the topics search showed more than 30,000 publications were related to LBP research. Based on the Web of Science categories, we find that the LBP research is mainly in “Biology and Medicine” and “Psychology and Social Issues”, see Fig. 1. In our study, we just chose “Ergonomics” as our focus. The advanced search method was used in the data retrieval strategy. To that end, we set: TS = “low * back pain*”; WC = ergonomics; Timespan = all year.

In total, 637 records were obtained from the database. Even by refining the data in the ergonomics area, the publications in Web of Science were not always categorized in only one domain. This means that 637 records are all in ergonomics and, at same time, have papers categorized in other domains.

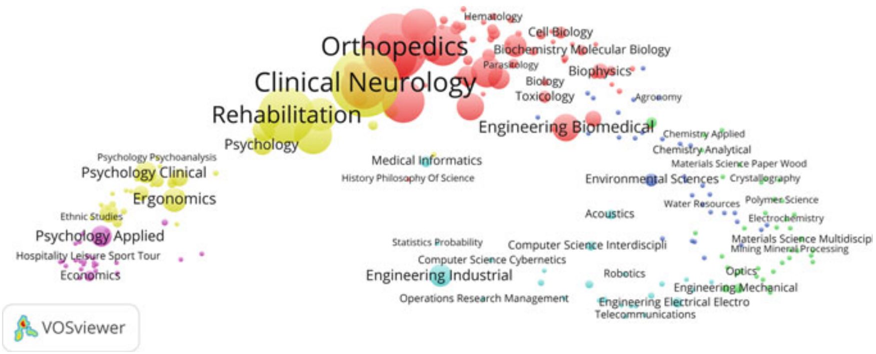

Fig. 1 Distribution of LBP research based on the Web of Science categories, the size of the nodes shown number of publications that categorized in a certain domain, colors shown different clusters (Color figure online)

The publication research trends and description analysis of the productive authors, countries/territories, organizations, categories, and source titles of LBP research in Ergonomics area were analyzed by the Web of Science "Analyze Results" function. The terms of LBP were created by VOSviewer. The software was developed to analyze the topics and bibliometric mapping network of the bibliographic data, especially for the data from Web of Science Core Collection. None of the terms were identified based on the automatic term identification technique from the title and abstract fields of documents. VOS mapping was used to give the location of the terms in two-dimensional space. This method is very close to the MDS method. The VOS clustering was used to give the color of certain nodes of a term, and the methods are similar to the Modularity cluster methods for networks.

3 Results

3.1 *Publication Trends*

Figure 2 illustrates an increasing number of articles being published in the field of low back pain in ergonomics area between 1970 and 2015. It is clear that with 29 published articles in 1998, low back pain research in ergonomic field is already an established field before a new millennium, though there is a reduction (of 50 %) in articles published in 2000. But, the research output has consistently increased between 2004 and 2015. The articles published rose by nearly 193 % from 15 in the year 2000 to 44 in 2016 within a 16 years' span.

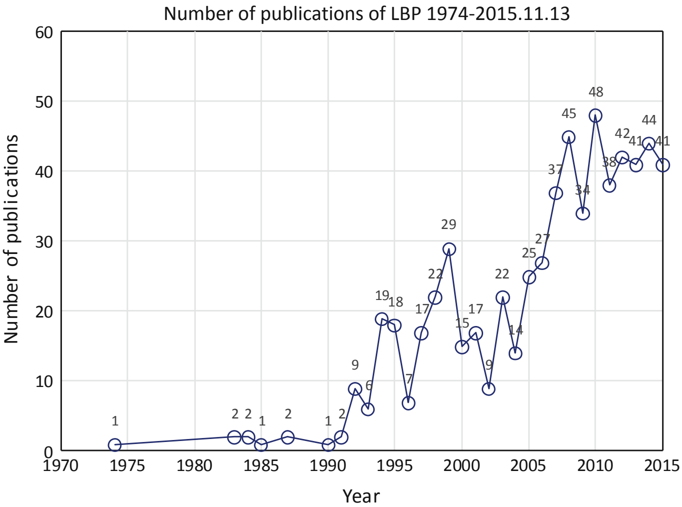

Fig. 2 Scientific outputs of LBP during 1975–2015.11.13

3.2 Publication Output

The top 10 most productive authors were displayed in Fig. 3. In all of the authors, Marras WS and Callaghan JP contributed the most with 24 papers who ranked the first place, followed by Frings-Dresen MHW, Kumar S, Van Dieen JH, Milosavlievic S, Nussbaum MA, Van Der Mollen HF, Garg A, Kingma I.

The output of different countries or territories is presented in Fig. 3. The most active country is the US followed by Canada and Netherlands. The US has published 213 articles, placing way ahead of all other countries.

The top 10 institutes with a paper quantity of more than 13 are ranked. The amount of articles published by the organization is calculated based on the author's contributions. According to Fig. 3, University of Waterloo, Ohio State University, and University of Amsterdam made up for the three most affluent institutions. University of Waterloo has published 36 articles, ranking in the first place, followed by Ohio State University with 29 articles, and third place, University of Amsterdam with 23 article published.

Among the 637 ergonomic articles in low back, 545 are under the category of industrial engineering and 394 under applied psychology. 233 articles are published in *Ergonomic*, while 138 are in *International Journal of Industrial Ergonomics.*

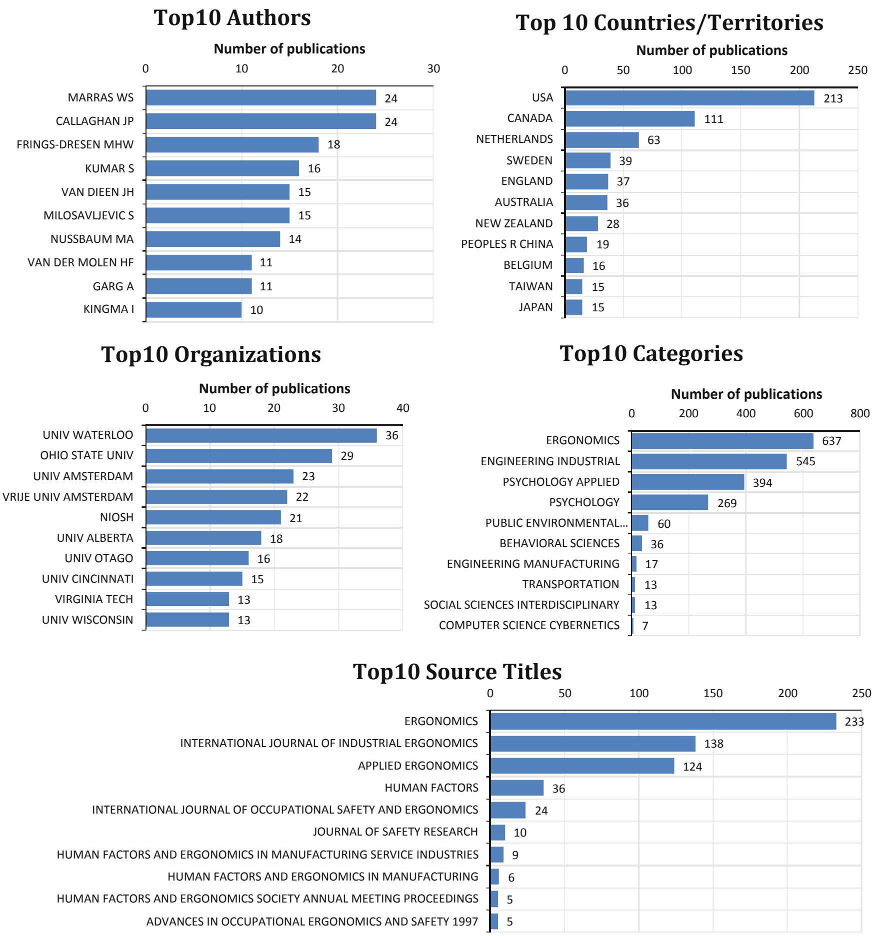

Fig. 3 Major outputs of authors, countries/territories, organizations, categories and source titles of LBP research in Ergonomics area

3.3 Topics Analysis

Terms from the titles and abstracts of the 637 documents were extracted based on the automatic term identification technique implemented in VOSviewer [7].

In all, four main clusters were obtained from the terms map, see Fig. 4. Based on the terms of each cluster, we give the name of the clusters. Cluster #1 (red) is mainly experimental research, and objective methods were applied in this domain. The cluster #2 (green) is mainly about task analysis. The force and angle of spine loading were measured in task analysis. And also including muscle activity research, EMG is the main method in this topic. Cluster #2 (green) is subjective study in LBP, and closely related to the Epidemiological research in the

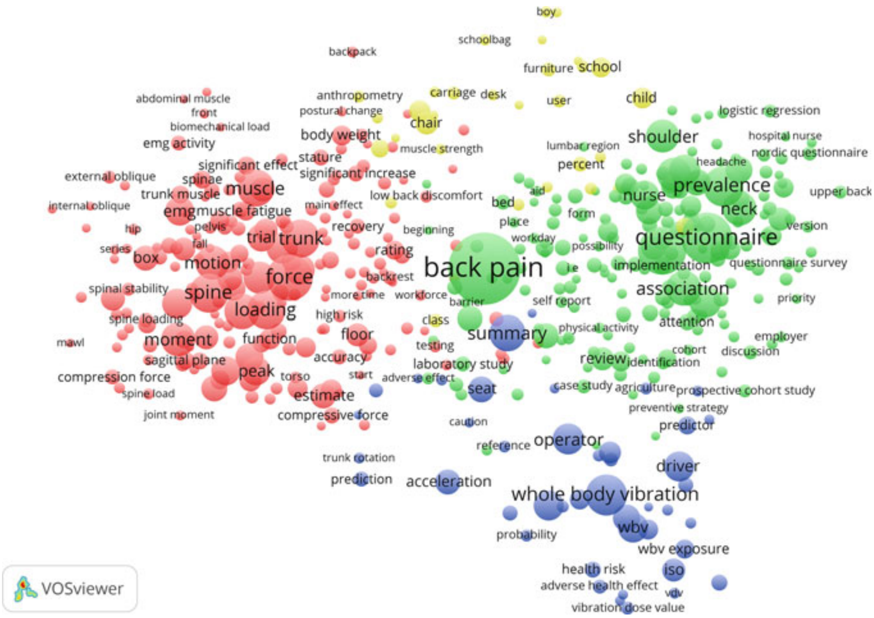

Fig. 4 Terms clusters of LBP, the size of the nodes shown the number of documents that the terms occurred, color of the node shown different clusters that the terms belongs (Color figure online)

Musculoskeletal Disorder area. Cluster #3 (blue) is mainly related to body vibration. Cluster #4 (yellow) is the LBP research in school. For the terms map and the high frequency terms of each cluster, see Fig. 5. To obtain the current research of LBP, the terms overlay analysis using the average year of terms were created, see Fig. 6. The color of terms closer to red is more recent. We can find that in the terms from cluster 2 and cluster 3. This means that subjective research is becoming a research trend as much as body vibration in LBP research.

Cluster 1#		Cluster 2#		Cluster 3#		Cluster 4#	
Terms	weight	Terms	weight	Terms	weight	Terms	weight
force	77	back pain	163	whole body vibration	64	chair	24
spine	60	questionnaire	92	summary	51	student	22
loading	57	musculoskeletal disorder	84	operator	41	child	21
trunk	56	prevalence	61	driver	38	school	19
muscle	53	association	49	vibration	38	cross sectional study	17
lift	50	neck	48	wbv	38	dimension	16
motion	48	month	46	vehicle	32	percent	12
moment	46	shoulder	44	seat	31	furniture	11
flexion	42	sample	42	acceleration	29	carriage	10
angle	41	symptom	41	iso	25	class	10
pattern	39	nurse	36	operation	23	user	10
lifting task	38	musculoskeletal symptom	32	standard	20	anthropometry	9
peak	37	survey	31	vibration exposure	19	bmi	9
emg	36	complaint	29	wbv exposure	18	potential risk factor	9
lumbar spine	36	week	29	predictor	16	schoolchild	9
trial	34	reliability	28	health risk	14	weight limit	9
experiment	34	validity	28	whole body vibration exposure	14	dependent variable	8
compression	31	program	27	exposure level	13	desk	8
velocity	29	review	25	prediction	13	accident	7
box	28	hospital	24	axis	12	boy	7
estimate	28	msd	24	accelerometer	11	break	7
spinal loading	27	employee	22	adverse health effect	11	lower limb	7
muscle activity	27	lower back	22	professional driver	11	muscle strength	7
biomechanical model	27	majority	22	vibration dose value	10	schoolbag	7
trunk flexion	26	psychosocial factor	21	agriculture	9	anthropometric	6
floor	25	article	20	probability	9	girl	6
kinematic	24	category	20	reference	9	important factor	6
distance	24	odds ratio	20	rms	9	anthropometric data	5
spinal load	23	musculoskeletal complaint	19	whole body	9	hong kong	5
stability	22	country	18	accordance	8	prolonged sitting	5
speed	22	interview	18	truck driver	8	school furniture	5

Fig. 5 Selected terms in each cluster of LBP

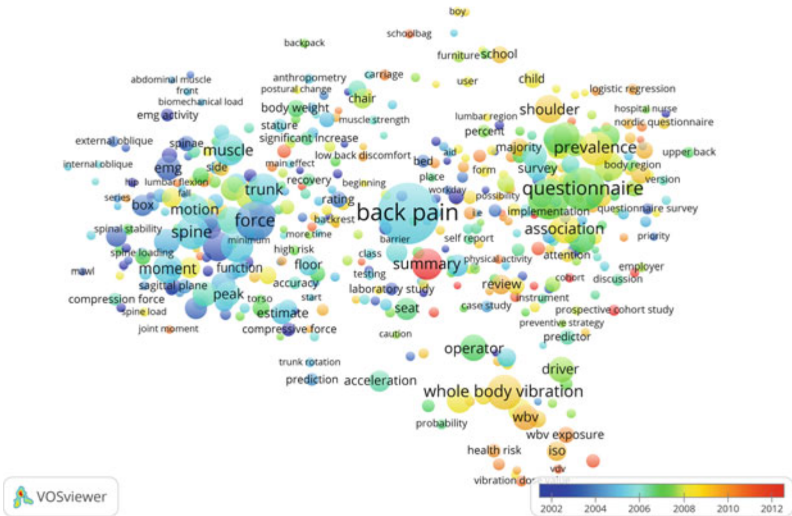

Fig. 6 Terms average year of LBP, the size of a nodes show number of documents that the terms occurred, the color of a term shows the average publication year of the publications that the term occurs (Color figure online)

4 Conclusions

In this study, we have used the bibliometric methods to analyze the performance of low back pain in Ergonomics. The results of publication output, authors, countries/territories, institutes, and terms distribution were put out in this paper. The analysis of the author shows that Frings-Dresen MHW, Kumar S, Van Dieen JH, Milosavlievic S were the most productive authors who publish articles in low back pain in ergonomic field. Articles published revealed that University of Waterloo, Ohio State University, and University of Amsterdam are key institutes that conduct ergonomic research in ergonomics. Moreover, the US, Canada, and Netherlands are the most productive countries. Finally, research trends including Epidemiological research of low back pain, Electromyography (EMG) Studies in Back Muscle, Biomechanics Analysis of Lifting Tasks, Association of Whole Body Vibration (WBV) and LBP, and LBP at School reveal the hot topic, which the Ergonomics of low back pain focus on.

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Analyzing and Modeling of Crew Team Situation Awareness

Shuang Liu, Zhen Liao, Yingwei Zhou, Xin Wang and Da Tao

Abstract Team situation awareness (TSA) is a newly emerging and important research direction in safety assessment of marine engine room system. It is increasingly recognized that a higher level of TSA will lead to better performance of teamwork as well as a safer and more efficient system in engine room. This study proposed both an innovative qualitative description model and a new framework of quantitative modeling of TSA from a teamwork perspective. Specifically, we identified the constituent elements of team mission and information sources of TSA, analyzed its consistency and influencing factors, and established a mathematical relationship between the influencing factors and consistency. Our study offered insight into the safety assessment of the engine room, the design of human–computer interface and the reduction of human error.

Keywords TSA · Crew team · Influencing factors · Consistency · Modeling

1 Introduction

With the rapid development of ship transportation, more attention has been paid on the importance of safe operation of ships. As the power resource and core place of the ship, the operation of engine room plays a vital role in ensuring the safe operation of the whole ship. As more information technology and interfaces have been integrated into the engine room, displays and controls of the information system are becoming more diversified and complicated, which is likely to cause

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negative consequences, such as high time pressure, high task complexity, high operating pressure, uncertainties in decision-making and even serious mistakes. Therefore, the team of crews should work together to ensure the operation and safety of the engine room system.

It is obvious that tasks in engine room require team cooperation, particularly in unexpected emergency situations. It is difficult for a single chief engineer, electrical engineer, mechanic, or other engineer to handle all rapidly changing information all the time, so it is essential that all the crews, as a team, can receive and understand all the information.

According to the responsibility and task allocation, each of the individual crew members can get the information that he required from the interaction with the system, and make teamwork-based decision through team communication and collaboration. Apart from their professional knowledge and technical experience, crew members should also have good perception, understanding, prediction and judgment for the situation occurred in the system when dealing with device problems. It means that a high level of team situation awareness (TSA) is essential in the accurate prediction and prevention of emergency situations, and in the reduction of mistakes in team decision-making [1].

TSA is an important indicator for the collaboration performance of cabin crew team. A higher level of TSA usually means better team performance, higher efficiency in human–computer interaction, and higher accuracy of the team decision-making. This indicates the importance of research on TSA for cabin crews.

In recent years, a number of studies have been conducted on TSA. "Team" is proposed as not a simple group of individuals, but a combination of two or more members [2]. The members have a dynamic interact with each other, share interdependence, and constantly adapt themselves to the situations. They not only have their own particular role/function, but also share a common goal/mission. Wellens defined TSA as team members' common recognition of current environment [3]. Salas thought that TSA is team members' common understanding of context at a particular time [4]. Endsley argued that TSA consists of individual's SA and SA they shared. The shared SA refers to the overlapping part of each individual, which the common understanding on the environment [5]. Endsley is considered that SA has three levels [6]. The first level is perception, which means that crews detect and perceive relevant information from cabin environment, such as the position of the ship presented, course, speed, cargo state, wind strength, traffic flow, and other information from displays and controls. The second level is understanding, which means crews summarize perceived information to produce understanding of current state based on their knowledge, skills, and experience. For example, they fully understand various seaworthy conditions of turbine equipments. The third level is prediction, such as the perception and understanding of the context. In this level, crews predict future state, such as changing trends and potential mistakes. Wu believed that communication among team members is helpful for the development of shared mental model, and then lead to better team performance [7]. LV proposed two types of team mental models, i.e., task mental model and team mental model, and discussed the relationship between the models and team performance [8].

While previous studies provided preliminary reference for the research on TSA, more attention should be paid on this topic, as little studies have been conducted to analyze influencing factors of TSA, and to establish TSA model in both qualitative and quantitative way. Moreover, there is a lack of TSA research especially in engine room system. This study aimed to analyze influencing factors of cabin TSA, and develop TSA model in both qualitative and quantitative manner in order to provide theoretical framework for future ergonomics evaluation of man–machine interface as well as human error prevention.

2 Analysis of the Influencing Factors for TSA in Engine Room

The team in engine room is consisted of several crews, who have mutual cooperation, complementary capabilities, and shared responsibility so as to complete some tasks or achieve the same goal. So the performance of a team should be greater than the sum of performance from the individuals. The main elements of the team in engine room include crew, equipment, display mode, interactive mode, mutual message, and environment.

① Crew: as the core subject and entity, with the attributes of age, task role, experience, habit, education, hobby, personality, etc., crew promotes the occurrence and development of interactive behavior through its own changes in an interactive environment. ② Equipment: as the main entity having the attributes of function, capability, position, etc., equipment perceives the instructions from the crew to produce a certain way of feedback, considering the interactive environment. ③ Display mode: the equipment feedbacks the information processing results to the crew in a certain kind of display mode, with the attributes of display style, display mode presented content, location, and others. ④ Interactive mode: there is a wide variety of interactive channels and actions for the interaction, the interaction mode catches the attributes of interaction device, interactive action, interaction time, etc. ⑤ Interaction message: generates in human–computer interaction, such as between chief engineer and electrical engineer, engineer and equipment, between display interface, between devices, including the attributes of message type, message importance, frequency, presentation location, etc. ⑥ Interactive environment: aiming at the interactive tasks among the crews and equipments, with the status of the task, task type, time pressure, and other attributes, interactive environment helps the crew to produce the corresponding psychological characteristics under different types of task status, and also help the equipment to read the input accurately and make the right response [9].

The performance of cooperative work in a team is highly dependent on TSA that the crew team has. A high level of TSA can reflect and predict team performance, which means that a higher level of TSA results in better team performance.

The consistency of TSA is a widely used indicator in the evaluation of TSA [10]. Consistent TSA is an important for modern equipment, information systems and teamwork to cooperate and communicate together. Therefore, the consistency of TSA is an important prerequisite for the crew team to make effective decision and coordinated actions. A more consistent TSA could lead to more coordinated action and more consistent decision-making, thereby leading to a higher level of team performance.

3 Modeling of Crew TSA

3.1 Qualitative Description Model of Crew TSA

The distributed cognition theory shows that cognitive activity consists of representations inside and outside, not only in the crews' brains, but also in all the elements of engine room, such as crew, equipment, display mode, interactive mode, mutual message, and environment. Distributed cognition shows how the information that is received by different individuals and different objects they used is represented. Distributed cognition constructs a cognitive model in which equipments are assumed to have human cognitive processes, and human-like cognitive ability. The equipments represent on the interface display to complete its cognition. A more human-friendly designed interface is more likely to reduce cognitive load, and consequently resulting in a more natural and efficient human–computer interaction.

The theory of distributed TSA describes the dynamic process of TSA. From the perspective of distributed cognition, the units are different, but they can all independently achieve the purposes of the three levels of perception, understanding, and prediction of SA model. Each unit can be set as an Agent, and the crew team can be considered as a cooperation system of multiple Agents. TSA in engine room distributes among various Agents, with real time adjustment by the Agents based on changing tasks. The formation process of TSA can be grouped into two phases: individual cognition stage and team collaboration stage, shown in Fig. 1 [10].

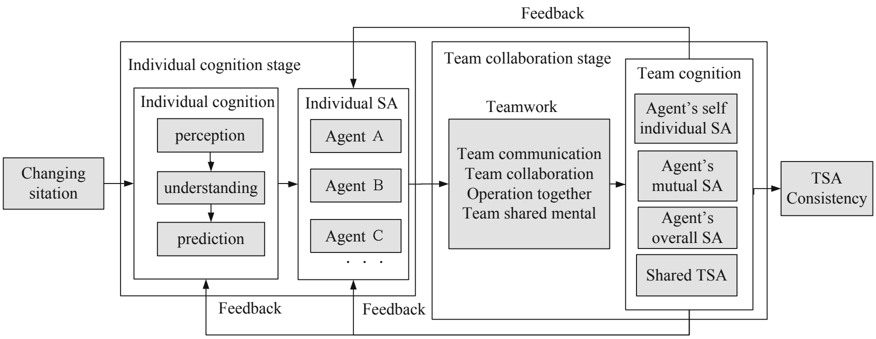

Fig. 1 The formation process of TSA

In individual cognition stage, the situational context information is received by the crew team. Each Agent handles the situation elements in real time to form their own cognition according to the division of tasks. As each Agent has different point of views, experiences, and abilities, they will have different individual SA, even encountered by the same environment.

In team collaboration stage, the Agents communicate, collaborate, and operate together to form TSA on their shared team mental model in accordance with teamwork structure. Information is communicated through audio or non-audio form, such as telephone, data transmission system, shared audio, display interface, and paper documents. There are both serial and parallel behaviors in the teamwork. For example, parallel work occurs when crew A, B, and C observe, diagnose, and repair together under an equipment fault problem. The three Agents are in serial form when crew A is in charge of observing, B of diagnosing, and C of repairing on the same problem.

When in the process of feedback, each Agent analyzes the local shared cognition and adjusts their own individual cognition according to certain consistency protocol, so as to reduce the cognitive differences with the team. Restricted by the team network structure, the consistency protocol only affects adjacent node, leading to a partial consistency. However, since the crew team is a completely linked network, the communication makes the partial consistency gradually spread into the entire network over the time, and it will be evolved as global consistency to generate consistent TSA.

For multiple human–computer interaction of team crews, relationships among the element nodes of team network are more important than their individual SA. Information transferred among the team networks is the key to ensure efficient teamwork. At a specific time point, the Agent should know which link in the network is to be used and where to be transmitted. Therefore, to obtain what should be and what need to be known at the right time plays a core role in the process of producing and maintaining high level of TSA [11].

3.2 TSA Influencing Factors of Team Crew

With the change of maritime missions, crews perform continuous information process to form their individual self-SA by obtaining task-related information and improving mental model of perception and understanding. The sources for individual SA and TSA are the same, and TSA is formulated through the crew's co-work based on the self-SA.

Therefore, the crews' individual SA and their influencing factors are main factors that influence TSA. In addition, attributes belonging to the crew teamwork can also influence TSA, such as team mission planning, roles and job configuration, crew resource management, and team decision-making, and so on, shown in Fig. 2 [12].

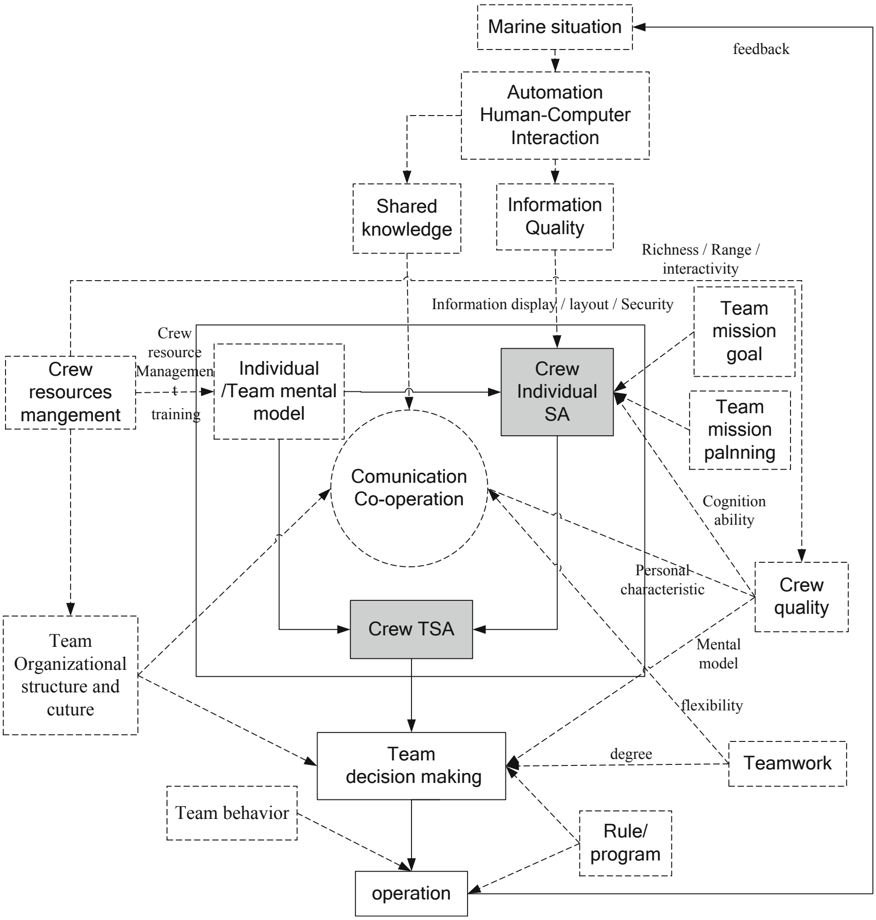

Fig. 2 TSA influencing factors of crew team

3.3 The Consistency of TSA

For the crew team, the input information is the changing situation of maritime task over time. TSA is formulated with the emergence of consistency and reflect the team performance, by the information processing of crew team perception, understanding, judgment, decision-making and communication. Figure 3 shows the emerging process of consistency [10, 12].

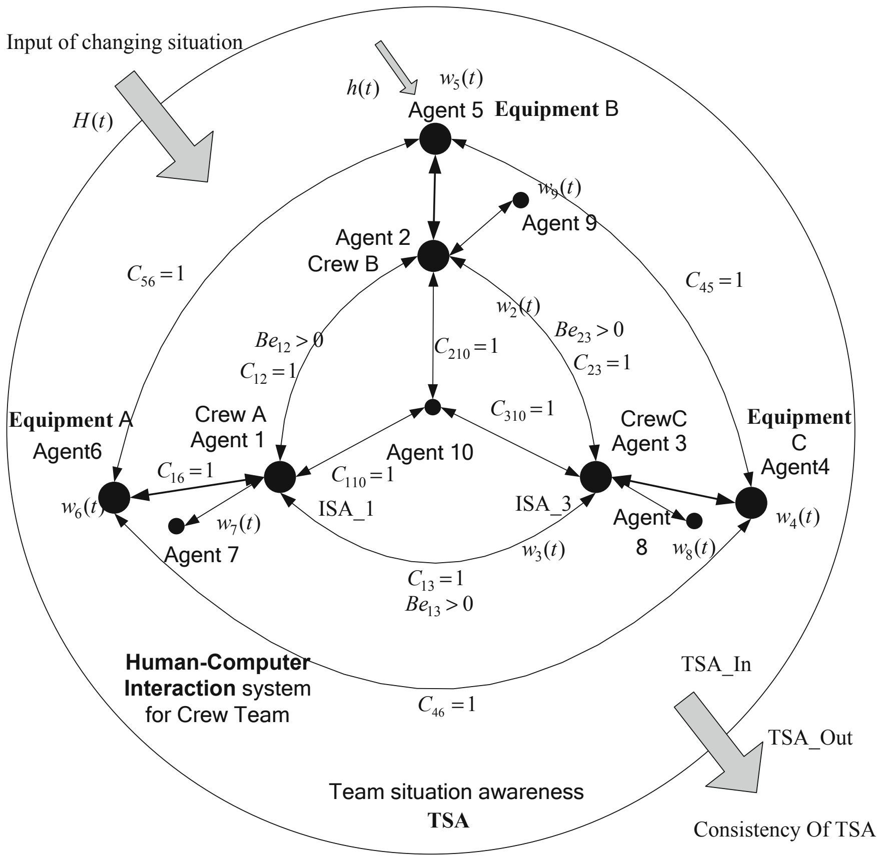

Fig. 3 Emergence of TSA consistency

3.3.1 Input of Changing Situation

For the crew team, the obtained input of situation information is set as $H(t)$, and the updated information input for the Agent i in a unit time is $h_i(t)$. In a distributed crew team network, dispersed arrangement and different roles of the Agents may result in a delay of information distribution, with different situational contexts obtained for each Agent. However, the differences caused by the distribution of information can often be ignored in the study of TSA, but the capability of situation processing for each Agent is considered as main cause. It is the influencing factors for the input of situation, such as team mission planning ($a1$) role and configuration ($a2$), and organizational structure ($a3$).

The updated information input for the Agent i can be represented as follows:

$$h_i(t) = f\_h_i(a1, a2, a3) \quad (1.1)$$

Factors, such as mission planning, job role, and organizational structure, could lead to the differences of updated information input during the Agents.

3.3.2 Capability of Situation Processing

The capability of situation processing means the updated information fully understood by the Agent i in a unit time can be set as $w_i(t)$, demonstrating the Agent's inherent ability of perceiving, understanding, and predicting, which is individually different. Several factors cause the capability differences of situation processing during the Agents, such as crew resource management ($b1$), cooperation ($b2$), and team behavior ($b3$). So:

$$w_i(t) = f\_w_i(b1, b2, b3) \quad (1.2)$$

For certain Agent, when the capability of situation processing is less than the input of changing situation, $w_i(t) < h_i(t)$, namely the Agent can only recognize on the part of the current situation, so that level of SA is less than 1; when $w_i(t) > h_i(t)$, the Agent can fully perceive, understand and predict all the current situation, so that the level of SA is equal to 1, which is an ideal state.

3.3.3 Individual SA

At certain time point, the recognition result of the Agent i is on the maritime task situation, which means the individual SA can be denoted by ISA i (t). In the absence of communication and feedback, the individual SA is cumulative result of incremental self-cognition, completely dependent on the individual's own capability of situation processing. Due to the dynamic characteristics of the individual cognition accumulation, the different individual SA will be formed among the Agents and the difference will vary and increase with the time. Consistency of TSA depends on the team collaboration stage and feedback processes.

There are some significant factors influencing the formation of crew individual SA, such as the design of human–computer interface (HCI), information quality, degree of automation, workload and so on, such as HCI design ($c1$), information quality ($c2$), degree of automation ($c3$) and workload ($c4$). The HCI design is a central issue at present, because enhancing SA by the optimization and improvement of HCI is more intuitive and easier. Therefore, research on the enhancement of HCI for the purpose of increasing SA is very important. So:

$$ISA_i(t) = f\_sa_i(c1, c2, c3, c4) \tag{1.3}$$

Moreover, the individual SA is correlated with the input of changing situation and the capability of situation processing. Better capability of situation processing is more helpful for achieving and maintaining high levels of individual SA.

3.3.4 Crew Teamwork Network

The relations among the crew Agents teamwork network is expressed as $\left[C_{ij}\right]$. When there is a link between the Agent i and Agent j, then the relation can be noted as $C_{ij} = 1$. While conversely, when no relationship between the two, it can be set as $C_{ij} = 0$. Different degrees of communication trust on each Agent results in different degree of communication effect, therefore, the different weights should be assigned according to the relationships among Agents. There are some factors influencing the crew teamwork network, such as cooperation ($d1$), group communication ($d2$), organizational structure ($d3$), role and configuration ($d4$), and team mission planning ($d5$). So

$$[C_{ij}] = f\_C_{ij}(d1, d2, d3, d4, d5) \tag{1.4}$$

In the Fig. 3, there is a direct relationship between the Agent 2 (Crew B) and Agent 3 (Crew C), so $C_{23} = 1$, and no direct relationship between Agent 5 (Equipment B) and Agent 3 (Crew C), so $C_{53} = 0$.

3.3.5 Degree of Communication Trust

The set of degree of communication trust is demonstrated as $[Be_{ij}]$, where Agent i trusts to Agent j a level of Be_{ij}. If a two-way communication exists between Agent i and j, then $Be_{ij} > 0, Be_{ji} > 0$. For the same communication behavior, Agent i and j may have different degrees of trust, $Be_{ij} \neq Be_{ji}$. While no communication exists between i and j, $Be_{ij} = Be_{ji} = 0$. Network of communication has the same topology with the teamwork, with a trust value assignment in the network, and specific assignment value can be set in accordance with the actual marine task. Usually, the Agent should receive more trust, so it has stronger capability of situation processing. Through communication Agent obtains the partial shared cognition according to the consistency protocol to feedback and update its individual SA. There are several factors effecting communication trust, such as team decision ($e1$), group communication ($e2$), organizational structure ($e3$), role and configuration ($e4$), and team mission planning ($e5$). So

$$[Be_i(t)] = f\_be_{ij}(e1, e2, e3, e4, e5) \tag{1.5}$$

In Fig. 3, if Agent 2 (Crew B) is the chief engineer, with better capability of the information processing than Agent 1 (Crew A); then Agent 3 (Crew C) may have more trust to Agent 2 than Agent 1, and $Be_{32} > Be_{31} > 0$.

3.3.6 Consistency Protocol

Consistency protocol is a rule acting among the Agents. During the process of TSA, Agent continuously handles with the task situation. On the other hand, it adjusts its own individual SA according to the cognition of neighbors and shared knowledge based on the consistency protocol, with the goal of the same cognitive evolution. Both will jointly promote individual SA, therefore, complete incremental of individual SA consists of two parts, one is due to the capability of situation processing, and the other is increased by the consistency protocol. There are some factors have the influence on the consistency protocol, such as team decision (*f*1), team behavior (*f*2), organizational structure (*f*3), role and configuration (*f*4), crew resource management (*f*5). So

$$[Rule_{ij}] = f\_rule_{ij}(f1, f2, f3, f4, f5) \tag{1.6}$$

In Fig. 3, Agent 2 (Crew B) compares its individual SA with Agent 3 (Crew C) and adjusts corresponding awareness in a consistency protocol with some addition or subtraction, according to the difference with Agent 3.

3.3.7 Expression of Consistency

As for the crew team, due to personal differences existed among the individuals, and a variety of differences induced during the adjustment with the consistency protocol; therefore, it is unable to reach an absolute consistency that the each Agent is of different level of SA. When the difference among the Agents has litter affect on the team judgment, team decision-making, and team execution, it is considered to reach at a relatively consistency of TSA. Generally, two indicators typically can be used to evaluate team relatively consistency of TSA.

(1) Internal consistency (*TSA_in*): It reflects the degree of cognition difference when the TSA reaches on a relatively consistent state, which indicates the ability of communication and coordination among the Agents.
(2) External consistency (*TSA_out*): It reflects the level of average cognition of outside task situation when the TSA reaches on a relatively consistent state, which indicates the cognition ability of the whole team.

Both the internal and external consistency can be expressed as below [10].

$$TSA_i\_in = f(h_i(t), w_i(t), ISA_i(t), C_i, Be, Rule\ldots) \quad (1.7)$$

$$TSA_i\_out = f(h_i(t), w_i(t), ISA_i(t), C_i, Be, Rule\ldots) \quad (1.8)$$

The two indicators can be used for evaluating on different aspects of crew TSA, to demonstrate the ability of forming the consistent TSA for the crew team.

4 Conclusion

In this current paper, we proposed an innovative qualitative description model and a new framework of quantitative modeling of TSA. We also specified the TSA formation process, identified influencing factors of TSA, and described the emerging of TSA consistency. It is believed that the TSA model should bring benefit for security assessment and optimization design, and provide a theoretical basis for future research on TSA among ship crews.

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Status and Effect Factors of Job Self-regulation of 253 Airline Pilots

Yuchuan Luo and Xuemei Deng

Abstract *Objective* To study the status of job self-regulation of airline pilot and analyze its associated factors. *Method* 253 airline pilots of CAAC were investigated and the influence of different variables on job self-regulation was explored. *Result* Interest on job of married pilots is significantly higher than unmarried pilots; environment control of captain and copilot is significantly higher than first officer; interest on job of pilots who worked 1–10 years is significantly lower than other pilots; the score of rule of pilots who worked 11–20 years is significantly higher than other pilots; the score of total questionnaire of pilots who worked above 21 years is significantly lower than other pilots. *Conclusion* Marital status, position, and working years have significant effects on job self-regulation of pilots and we should manage them.

Keywords Airline pilot · Job self-regulation · Effect factors

Job self-regulation of airline pilots refers to: Under the intrinsic motivation, the airline pilots can accomplish the tendency and performance of the flight work independently and consciously. The pilots with higher job self-regulation can determine the job objectives and develop work plans before the work, conduct self-monitoring, self-feedback, self-regulation, and self-plan to the work process and strategy at work and take the initiative to create the physical and social environment beneficial to the work as well as conduct self-examination, self-summary,

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self-evaluation, and self-remedy to the work results after the completion of work activities. Therefore, understanding the status of job self-regulation of airline pilots will help to improve the current selection and cultivation methods for Chinese pilots and improve the management efficiency of airline to pilots so as to reduce the flight accident rate and ensure the flight safety and efficiency, which have realistic significance.

1 Method

1.1 Testing Tools

Use self-compiled "Questionnaire on Job Self-Regulation of Airline Pilots" [1]. The questionnaire contains 8 dimensions and 25 items and 3 polygraph questions. These dimensions are environment control, rule, self-efficacy, behavior control, emotion strategies, working method, job interest, and target location. The questionnaire uses Five-level Likert Scale with options in sequence of "completely non-conformity, basically non-conformity, unconfirmed, basically conformity and completely conformity." 1–5 points are given, respectively. After testing 208 airline pilots, 8 factors were obtained through exploratory factor analysis, explaining 62.934 % of the total variance. The load of corresponding factor of each item was between 0.532 and 0.852 and the confirmatory factor analysis conducted with AMOS7.0 also proved the results of exploratory factor analysis. Cronbachα coefficient of total scale was 0.743 and Cronbachα coefficient of all dimensions reached over 0.516 as well as the correlation coefficient of retest was over 0.606 ($P < 0.01$); the correlation between scores of 31 subjects attending the retest and evaluation of leaders of 31 subjects was investigated. The results are $r = 0.738$ and $P < 0.01$, proving that the questionnaire has good reliability and validity and can be used as a tool for testing the job self-regulation of airline pilots.

1.2 Subjects

Considering the authenticity of answers of subjects, randomly select 307 airline pilots from 4 airline companies of the CACC. 307 questionnaires were given out and 307 questionnaires were collected. Excluding the questionnaires with incomplete information, answers with significant tendentiousness and untruthful answers, 253 valid questionnaires were collected (Table 1).

Table 1 Sample distribution (n = 253)

Variable	Marital status		Position			Serving years (year)			Working years (year)		
Type	Married	Unmarried	Copilot	First officer	Captain	1–5	6–10	Above 11	1–10	11–20	Above 21
n	193	60	108	18	127	184	41	28	119	62	72
%	76.3	23.7	42.7	7.1	50.2	72.7	16.2	11.1	47.0	24.5	28.5

1.3 Statistical Method

Use SPSS17.0 to conduct *T*-test and multi-factor variance analysis.

2 Result

The study has investigated the effect of marital status on the job self-regulation of pilots (see Table 2). The results show that the score of unmarried pilots is significantly higher than that of married airline pilots in the dimension of job interest ($P < 0.05$), showing that the interest in the job of unmarried pilots is significantly lower than that of married airline pilots.

The effect of position, serving years, and working years on dimension and total has been investigated (see Table 3) and the results show that there are significant differences in the environment control of airline pilots in the different positions ($F = 4.806$, $P < 0.01$); there are significant differences in the interest, rule, and total score of airline pilots with different working years ($F = 3.613$, $P < 0.05$; $F = 7.049$, $P < 0.001$; $F = 4.277$, $P < 0.05$). The further pairwise comparison shows that the score of captain and copilot in the dimension of environment control is significantly higher than that of first officer; the interest score of airline pilots who worked 11–20 years and above 21 years is significantly higher than that of other pilots who worked 1–10 years; the score of rule of airline pilots who worked 11–20 years is significantly higher than that of other pilots who worked 1–10 years and above 21 years; the total score of job self-regulation of airline pilots who worked 1–10 years and 11–20 years is significantly higher than that of other pilots who worked above 21 years.

Table 2 Status of job self-regulation of different marital status pilots (n = 253)

	Unmarried (n = 60)	Married (n = 193)	t
Action	3.84 ± 0.75	3.85 ± 0.70	−0.034
Self-efficacy	3.81 ± 0.49	3.74 ± 0.63	0.900
Interest	3.55 ± 0.75	4.14 ± 0.62	−5.488[a]
Method	3.80 ± 0.80	3.72 ± 0.70	0.721
Emotion regulation	3.73 ± 0.61	3.76 ± 0.60	−0.390
Goal	3.71 ± 0.65	3.79 ± 0.77	−0.719
Environment control	4.35 ± 0.44	4.39 ± 0.47	−0.705
Rule	3.98 ± 0.60	4.13 ± 0.52	−1.947
Total	30.87 ± 2.35	31.56 ± 2.67	−1.780

[a] P < 0 05

Table 3 ANOVA of different variables on dimension and total (n = 253)

	Action	Emotion regulation	Goal	Self-efficacy	Interest	Method	Rule	Environment control	Total
Position	0.135	0.300	0.415	0.714	1.703	1.774	0.093	4.806[b]	0.067
Serving years	0.328	2.092	0.280	2.065	0.368	1.065	0.180	0.094	0.457
Working years	0.984	1.398	2.673	1.660	3.613[a]	1.525	7.049[c]	0.170	4.277[a]

[a] P < 0 05
[b] P < 0.01
[c] P < 0.001

3 Discussion

The results of study show that, the effect of marital status on pilots is mainly reflected on the job interest, namely, the score in the dimension of job interest of unmarried pilots is significantly higher than that of married pilots, which shows that the interest of unmarried pilots mainly focuses on the things out of work and the married pilots are more interested in the job. This result is in line with previous study results [2–4]. This is because that a desperate need of unmarried pilots in this life stage is to find a spouse. It is not only the reflection of physiological needs of biological human, but also the reflection of various social needs of social man, such as being gregarious, raising, fun, control, achievements, and so on. If the problem is solved well, it can help pilots form a positive attitude toward life and good mental health; if the problem is not solved well, the serious psychological damage to the pilots might be caused. Therefore, for this problem, we recommend that we should first face up to the need of airline pilots and allow their interest transfer in a certain extent; meanwhile, we should strengthen the guidance for the pilots and help them handle the relationship between love, marriage, and flight correctly as well as meet the needs of pilots for love and marriage under the premise of ensuring flight safety and efficiency as much as possible.

In the aspect of position, the score in the dimension of environment control of captain and copilot is significantly higher than that of first officer, showing that first officer takes less initiative to create and maintain the environment beneficial to the work in the process of flying. This may be due to the particularity of pilot stage. In the current evaluation system, promotion from first pilot to the captain is often evaluated from the technical status only instead of evaluating from nontechnical skills so as to cause the ability enhancement toward technology of first pilot in the work and ignore the training in nontechnical skills, such as creating good environment.

The score in the dimension of interest of airline pilots who worked 11–20 years and above 21 years is significantly higher than that of airline pilots who worked 1–10 years. The interaction of different dimensions has been investigated and the results show that there are no significant differences in the interest of married pilots with different working years and there are no significant differences in the interest of unmarried pilots with different working years. We think most of unmarried pilots who worked 1–10 years are still in the unmarried stage, more focus is put on the marriage and love and less interest is put on the work.

The score of rule of airline pilots who worked 11–20 years is significantly higher than that of airline pilots who worked 1–10 years and above 21 years. This shows that airline pilots who worked 11-20 years pay more attention to the role of relevant regulations, rules, and standard operating procedures in the actual work. The relevant regulations, rules, and standard operating procedures are analyzed strictly, designed carefully and have accepted practice inspection so that they give full consideration to the performance optimization, simple operation, and sufficient safety margin. Compliance with regulations, rules, and standard operating procedures in the flight can achieve a high degree of unification of efficiency, simplicity, and safety; deviation will reduce efficiency, detract safety margin, and sometimes bring potential trouble to the operators and increase the work load and possibility of additional error [5]. Based on the investigation results, we suggest strengthening the technical training for airline pilots who worked 1–10 years and above 21 years and also making the thought of abiding by the regulations, rules, and standard operating procedures run through the whole teaching and production flight.

The total score of job self-regulation of airline pilots who worked 1–10 years and 11–20 years is significantly higher than that of airline pilots who worked above 21 years. This may be because that with the growth of age, the metal, physical, and other abilities of pilots who worked above 21 years decline and the borne work responsibility and family responsibility do not reduce significantly but have the upward trend; combined with high pressure for a long time [6], high job strain [7], and shift and work by turns [8], the enthusiasm and initiative to flying will gradually reduce and mental and physical fatigue will appear, resulting in a situation similar to the job burnout and making the job self-regulation of pilots who worked above 21 years decrease. For this, we think airline companies and the society should pay attention to the reduction phenomenon of job self-regulation of pilots who worked above 21 years and improve the job self-regulation of airline pilots with long working years through good education, guiding pilots to increase the sense of recognition and achievement of flight work and establish good social support system and so on.

4 Conclusion

The study results show that the interest in the job of unmarried airline pilots is significantly lower than that of married airline pilots; the score in the dimension of environment control of captain and copilot is significantly higher than that of first officer; the score in the interest of airline pilots who worked 11–20 years and above 21 years is significantly higher than the airline pilots who worked 1–10 years; the score of rule of airline pilots who worked 11–20 years is significantly higher than that of airline pilots who worked 1–10 years and above 21 years; the total score of job self-regulation of airline pilots who worked 1–10 years and 11–20 years is significantly higher than that of airline pilots who worked above 21 years.

In the management measures, we think: for unmarried pilots, airline companies should understand the rationality of behaviors of airline pilots and help them understand and handle the relationship between marriage and love and job correctly; for first officer, airline companies should enhance the requirements in the aspect of nontechnical skills, such as environment control; for the pilots who worked less than 10 years and above 21 years, airline companies should strengthen the requirements and guidance in regulations and rules; for senior pilots who worked above 21 years, airline companies and the society should give them more spiritual and material support to improve their job self-regulation.

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The Testing Research on Basic Cognitive Ability's Influence Factors in Special Vehicle Crewman

Qun Wang, Fang Xie, Sijuan Zheng, Zhongliang Wei and Qianxiang Zhou

Abstract In order to investigate the factors that affect a certain type of special vehicle crewman's basic cognitive ability, this paper starts from the basic connotation of basic cognitive ability, to determine the test content that affects the cognitive ability including depth perception, spatial perception, sound/light simple reaction time, attention span, attention focus ability, etc. About 107 subjects participate in the static environment test, the variance analysis method is used to deal with test results. The analysis result shows that: the crewman's basic cognitive ability is greatly influenced by individual operating mode and external environmental factors, while different ages, educational background, and region have no obvious effect on the basic cognitive ability in the crewman. These conclusions have a certain reference value for the design of this special vehicle.

Keywords Special vehicle · Cognitive ability · Mental resources · Ability test

1 Introduction

At present, the technical development of special vehicle has changed from mechanization to informatization and this has made the amount of information received by the crewmen in a geometric growth, but the basic cognitive ability of human is limited. Therefore, in the ergonomic research of special vehicle, it is necessary to study the task characteristics and basic cognitive ability characteristics of crewman, analyze the influence factors, coordinate the relationship between crewman and

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vehicle, balance the division of tasks of crewman and vehicle for use and reasonably allocate man-vehicle functions to ensure the successful completion of tasks [1].

According to the Multi Resources Theory of Wickens [2, 3], the process of completing the task by people can be considered as a process of using their own abilities. People decompose useful ability resources from information input, information processing, and information output and these abilities can be divided into visual ability, hearing ability, and other basic cognitive abilities. This paper starts from mental resources of crewman to combine main operating tasks of vehicle crewman for obtaining main basic cognitive ability need. Analyze its influence factors through experimental test to provide data support for man-machine interface design of the vehicle.

2 Test Methods and Steps

2.1 Subjects

The subjects are 107 crewmen aged from 20 to 25 with 5 driving years. They respectively come from Hebei, Shanghai, Anhui, Fujian, Jiangsu, Shandong, Zhejiang, Guangxi, Guangdong, Henan, Hubei, Gansu, Shanxi, Shanxi, Sichuan, and such 19 provinces and cities. Visual acuity or corrected visual acuity is above 1.0. There is no color blindness and color amblyopia. They are right-handed people and all know and agree on the test content before the test.

2.2 Test Content Design

(1) Because this measurement content is basic cognitive ability of crewman, the test on crewman is only conducted in the static environment and there is no test on vehicle in the driving state;
(2) All basic cognitive ability tests are conducted in the daytime and there is no ability test at night;
(3) All subjects have accepted physical examination and their physical conditions and intelligence are normal. Routine examination is not required, including color vision, height, and weight and so on.

In conclusion, the test content is related to the basic abilities of vision, perception, memory, attention thinking, and imagination of crewman. Test items are ultimately identified as: depth perception, spatial perception, sound/light simple reaction time, attention span, attention focus ability.

Table 1 Test equipment and function

No.	Equipment's name	Equipment's function
1	Depth perception tester	Test the visual perception ability and judgment ability of the distant objects
2	Space perception tester	Test the crewman reaction ability When face the complex information task load
3	Sound/light simple reaction time tester	Test the ability to respond to sound and light stimulation
4	Attention span tester	Test focus breadth on the target and work efficiency
5	Attention focus ability tester	Test the ability of continuous attention to the target object

2.3 Test Equipment and Methods

(1) Preparation of test equipment

Test equipment is expressed in the following Table 1.

(2) Test methods

In order to reduce the contingency of test results, every subject is tested for three times and the mean value of measurement results are used as the final result of the measurement. Combined with data processing, analyze various factors that affect the crewman's basic cognitive ability.

3 Test Results and Analysis

3.1 Normal Distribution Test

Through the verification, the kurtosis coefficient and asymmetry coefficient of five parameters are less than 1, so the sampled data of five cognitive parameters conform to the normal distribution [4], and the statistical results are expressed in the following Table 2.

Table 2 The normal distribution test consequence of cognitive parameters

Statistics	Depth perception	Spatial perception	Acousto-optic response		Attention span	Attention focusing
			Optic-response	Acousto-response		
Asymmetry coefficient	0.726	0.961	0.514	0.870	−0.265	−0.658
Kurtosis coefficient	−0.186	0.945	0.054	0.236	−0.622	0.054

3.2 Statistical Analysis of Test Data

The specific analysis of the data of each test project is conducted below:

3.2.1 Depth Perception

Depth perception is the perception of people for object distance. This test mainly uses Three Needle Test of Haime Hertz and data analysis by SPSS and judges the threshold of depth perception of subjects under different conditions to get the differences of depth perception. The accuracy of binocular depth perception is better than that of monocular depth perception in general [5]. Experimenter records error value of subject moving from variation stimulus to the standard stimulus from different positions (nearest, near 5, far 5, farthest).

As shown in Figs. 1 and 2, number nearest, near 5, far 5, and farthest in the measurement of binocular depth perception as 1, 2, 3, and 4, respectively. Then conduct one-way analysis of variance. Through four ways of multiple comparisons, there are not significant differences ($P > 0.05$). So in the experiment, the starting position of variation to stimulate has no obvious effect on the depth perception of people.

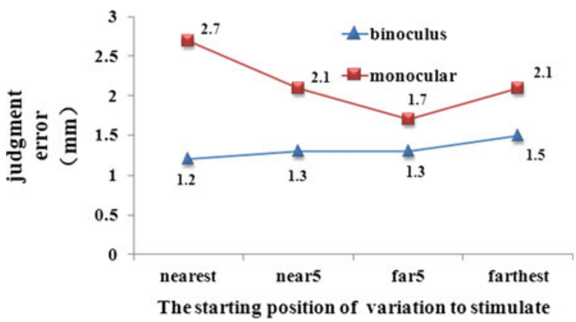


Fig. 1 The comparison of eyes judgment error at different starting position

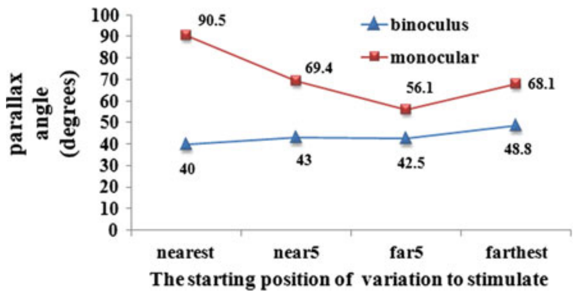


Fig. 2 The comparison of single—eyes angle difference at different starting position

3.2.2 Spatial Perception

The test is mainly used for studying the spatial structure features of stimulus and determining and distinguishing the reaction time of complex graphics. This test designed three different graphics in total, respectively block, bar, and irregular shape. Each graphic appears in two different spatial positions 1 and 2. Spatial perception can be used to evaluate the crewman's reaction ability when facing complex information task load.

The spatial perception parameters calculated with recorded values in the experiment are expressed in the following Table 3.

From the calculation results in Table 4, we can see that compared with block, bar and irregular graphics, the spatial perception ability to block is the highest, followed by bar, and the lowest is irregular shape. When the same graphic appears in the different spatial positions 1 and 2, we can find that the spatial perception ability to the same graphic in the feature 2 is better than that in the feature 1, which is related to the complexity of spatial positions.

3.2.3 Sound/Light Simple Reaction Time

Figure 3 shows the statistical results of different factors. Comparing the data and from the acousto-optic tasks at the same time, we can see that people's response to light is faster than that to sound. Moreover, in three voices, people's recognition capability to high pitch is the fastest, followed by bass and then alto voice. This may be because that alto voice is between high pitch and bass and is easily confused, so it is difficult to distinguish alto voice. Due to the distribution of attention,

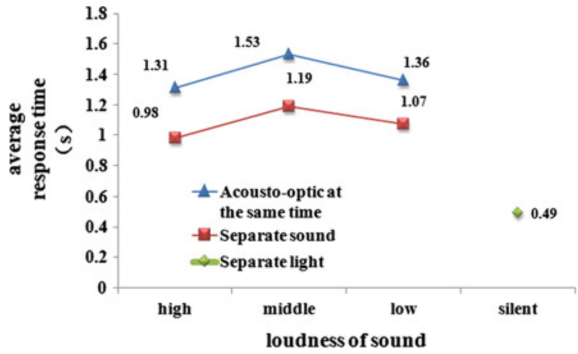
Table 3 The calculation results of spatial perception parameter

Pattern type	Mean value	Standard deviation	Maximum	Minimum
Block 1	1.4	0.6	3.0	0.6
Bar 1	1.5	0.5	3.1	0.7
Irregular 1	2.2	0.6	3.6	1.2
Block 2	1.4	0.4	2.6	0.7
Bar 2	1.3	0.3	2.1	0.8
Irregular 2	2.1	0.7	3.6	0.8

Table 4 The calculation consequence of attention span parameters

State	Mean value	Standard deviation	Maximum	Minimum
Non-interfering	8.3	1.8	12.0	4.5
Noise	8.6	1.6	12.0	4.5
Audio	8.5	1.7	12.0	4.5

Fig. 3 The data comparison



people's reaction ability to voice or light in the dual task is significantly lower than that in the single task ($P < 0.05$).

3.2.4 Attention Span

Attention span is also called attention range. It refers to the number of objects that people can notice clearly at the same time. The statistical results of attention span data of subjects in the conditions of noninterfering, noise, and audio are expressed in the following Table 4.

Analyze the attention span values in the different working conditions (noninterfering, noise and audio) through one-way variance and then obtain that $P > 0.05$, namely, three conditions have no significant effect on the attention span.

3.2.5 Attention Focus

Attention focus ability can be used to evaluate crewman's ability to pay continuous attention to the target object. In the test, the subjects are divided into three groups and tested according to circle, triangle, and square. Taking environmental state (whether interference or not) and pattern turn (clockwise/anticlockwise) as independent variables, conduct two-way analysis of variance. The statistical results are suggested in the following Table 5.

Table 5 The calculation consequence of Attention parameters (non-interfering + clockwise)

Combination of the independent variables	Mean value	Standard deviation	Maximum	Minimum
Non-interfering + clockwise	0.663	0.14	0.923	0.203
Non-interfering + anticlockwise	0.653	0.150	0.910	0.185
Interference + clockwise	0.653	0.150	0.910	0.185
Interference + anticlockwise	0.671	0.174	0.959	0.180

From the results of two-way analysis of variance, the main effect of environmental state and pattern turn on the attention focus ability is not significant ($P > 0.05$) and their interaction effect is not significant either ($P > 0.05$). In a similar way, the data of attention focus on triangle and square are processed and the same results are obtained. However, from Table 5, people's attention focus ability to the patterns turning anticlockwise is poorer than that to the patterns turning clockwise, which may be related to their daily living habits. Meanwhile, in the noninterfering situation, compared with the condition of interference, it is easier for people to focus.

3.3 Different Ages, Educational Background, and Regions' Influence on Various Cognitive Parameters

Conduct one-way analysis of variance of different ages (20–21, 21–22, 22–23, 24–25), educational background (junior high school, technical secondary school, senior high school and professional high school, junior college, and undergraduate course), and regions' (North of China, East of China, Central of China, South of China, Southwest of China, Northwest of China, Northeast of China) influence on various cognitive parameters of subjects. The significant analysis results are expressed in the following Table 6.

From the above results, we can know that besides the significant differences in light reaction ability between subjects with different educational background ($P < 0.05$), other different ages, educational background and regions have no significant effect on various cognitive parameters of subjects, so it can be considered that there is no significant difference in cognitive ability of subjects with different ages, educational background, and regions.

Table 6 The significant analysis consequence of different ages, educational background, and regional's influence on various cognitive parameters

Cognitive parameters	Depth perception ability	Spatial perception ability	Sound/light simple reaction time		Attention span ability	Attention focus ability
			Light reaction	Sound reaction		
Participants attribute						
Age	0.909	0.831	0.497	0.410	0.266	0.547
Education background	0.533	0.275	**0.004** (<**0.05**)	0.053	0.487	0.244
Region	0.098	0.830	0.141	0.647	0.7	0.498

4 Conclusions

This paper collected five cognitive parameters data of 107 people through test methods and obtained the following conclusions through the analysis and discussion of these data:

(1) The starting point of variance to stimulate has no significant effect on people's depth perception;
(2) The crewman's light reaction is faster than sound reaction. And it is found that in three voices, crewman's recognition capability to high pitch is the fastest, followed by bass and then alto voice.
(3) The crewman's spatial perception ability to block is highest, followed by bar, and then irregular shape. Due to the different positions, the complexity of the same graphic is different and the spatial perception ability will be different;
(4) The attention focus on tracking different shapes of patterns of crewmen is different and will be affected by the turning of patterns;
(5) The influence of different ages, educational background, and regions on crewman's various cognitive parameters is not obvious.

The above conclusions have a certain reference value for the design of this special vehicle.

Crewman's basic cognitive ability characteristics have important effect on observation, judgment, decision-making, coordination, and other tasks in the process of control and their influence factors shall be considered in the preliminary stage of vehicle design, so as to more fully play the role of man-vehicle operation efficiency of special vehicle.

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Evaluation of the Crew Workload to Quantify Typical Mission Profile Special Vehicles

Fang Xie, Qun Wang, Xiaoping Jin, Yuan Liao, Sijuan Zheng, Li Li, Qianxiang Zhou and Zhongqi Liu

Abstract In the special vehicle research, the crew workload quantitative assessment may be a human-vehicle system function rationally allocated, the occupants optimal design tasks provide important reference. In this paper, base on special vehicles semi-physical simulation simulator test environment, explores the impact of breakthrough deep attack workloads quantitative assessment method of two typical mission profiles. The study innovative uses of cognitive attention measuring device measured the crew workload, to decompose mission profile, cognitive channel subjective evaluation questionnaires, and task performance and subjective evaluation of the results of the analysis. The research methods and conclusions made by the crew used workloads the quantitative evaluation system provide an important reference.

Keywords Workload evaluation · Mission profile · Channel theory · Attentional

1 Introduction

In human-machine-environment system, crew workload is defined as the achievable workload within a given period and it is jointly determined by crew status, type of task, and task difficulty, thus, it has an influence on the performance of main task. According to the Yerkes–Dodson Law, task performance will increase with the

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workload/pressure to some fixed point, as the workload/pressure is too high, the task performance will decrease, so there exists an optimal workload interval with regard to the given goal [1].

Workload management is an important topic of human factor in the design of human-machine-environment system for special vehicles. According to the crew workload, feedback regulation can be realized to achieve the goal set in task requirements for reasonable control of human-machine-environment system, which has a very important significance in the work efficiency of the system, safety and crew health [2]. Quantitative evaluation of workload is the prerequisite for workload management and consequently it can guide the optimized design of system and task and make a rational allocation of human–machine operation functions to improve task performance.

Workload evaluation includes subjective scaling evaluation [3], main task performance and auxiliary task performance evaluation [4] and physiological index evaluation [5]. Physiological index evaluation is drawing more and more attention for its visibility, high efficiency and timeliness, but data gathered by the method has loud noise and is largely affected by individual difference, and the application of physiological index evaluation to task workload monitoring system with real-time feedback still needs subjective evaluation, task performance, and other methods and results as the standard. Subjective scaling evaluation lacks objectivity, but in combination with scores by expert, it can be used as the important benchmark for objective results, while the method of auxiliary task performance has always been restricted on application due to its powerful invasion, and peripheral detection task (Peripheral Detection Task, PDT) is a kind of special driving subtask that can be used to measure the crew workload and the method has been improved in ISO/DIS 17488 standard, relevant researches show that, as a kind of methods for auxiliary task performance evaluation, the method has low invasion and good ecological validity toward main task. From characteristics analysis of the several methods for quantitative evaluation of workload, we can see that subjective scaling evaluation and task performance evaluation are the foundation for quantitative evaluation of workload. As a whole, the evaluation of crew workload in human-vehicle system is an important research content, providing an important reference for reasonable allocation of human-vehicle system functions, optimal design of tasks, and so on. The paper explores the methods for quantitative evaluation of workload of two typical mission profiles based on semi-physical simulation simulator experiment. The study innovative uses of cognitive attention measuring device measured the crew workload to decompose mission profile. It also designs subjective evaluation questionnaires according to the channel and analyzes the task performance and results of subjective evaluation. Methods adopted and conclusions drawn in the research proves an importance reference for the establishment of quantitative evaluation system of crew workload of special vehicles.

2 Data Collection and Description

2.1 Data Collection

2.1.1 Combat Scenario

To research the characteristics of crew workload under different mission profiles, the research chooses two typical mission profiles of impact breakthrough and deep attack and the two task processes have strong representative because they cover each basic element of special vehicle tasks.

Impact breakthrough refers to the remote target attack in typical tasks. In the mission profile, vehicle commander discovers the remote attack target and points at the target, gunner shoots with the cannon (with marching fire) and first attacks the opposite side if case of discovering a target in motion. The drive is responsible for driving; vehicle commander is mainly responsible for target searching, target indicating, internal command and external liaison; and the gunner is mainly responsible for target searching, shooting with cannon and communication in the vehicle.

Deep attack refers to close target attack in the typical tasks. Vehicle commander discovers close target and applies overhead fire. Driver is responsible for vehicle driving and communication in the vehicle; vehicle commander is mainly responsible for target searching, shooting, internal command, and external liaison; and gunner is responsible for target searching and communication in the vehicle.

Besides the difference in distance of the attack target, the two tasks are also different in the operational staff of attack operations. In the mission profile of attack breakthrough, the gunner is responsible for receiving instructions from the commander and aiming at remote target for shooting; while in the mission profile of deep attack, the vehicle commander is responsible for attacking the close targets.

2.1.2 Apparatus and Subjective Evaluation

Experimental facilities include special vehicle human-vehicle environment lab, camera, physiological feedback instrument, and cognitive attention measuring device. Camera is mainly used to record images and sounds in the experimental process for extracting data of task performance.

Cognitive attention measuring device, as one of the quantitative means for cognitive workload in the research, is used to obtain the performance of the crew's response to simple stimulated task (response time). Cognitive attention measuring device (Detection Response Task, DRT), based on detection response task, is the portable improvement from traditional PDT and is more suitable for application scenarios in the research. User shall wear the adjustable head wearing of LED tube of DRT on the head, with the tube stretching out from the left surface of the user, button bound to finger pulp of the leading finger of the user and both are connected

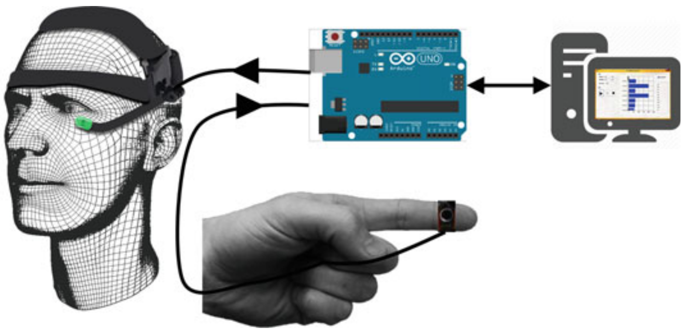

Fig. 1 Detection Response Task device

through the covered wire and the chip; the chip with built-in hardware control program communicates with computer software control program via a serial port to realize triggering of detection response task, performance data recording, and data file generation and the structure diagram is shown as Fig. 1 [6].

DRT can be used to conveniently complete quantitative measurement the tested cognitive attention workload. The excess of the cognition task execution personnel used in main task shall be used in detection response task for response, as shown in Fig. 1. If the tested personnel presses the leading finger button, it shows that he has noticed that LED light is on, and the response time of the detection response task (unit: ms) and the missing ratio (unit: %) can be used to evaluate the workload of the tested, the higher the two indexes, the greater workload of the tested crew. Provided the total cognition of the crew remains unchanged within a given period, the method quantizes the excess of the cognition the crew input in the task through the performance of detection response task to indirectly quantize the cognitive resources occupied by the task.

The part of subjective evaluation is conducted after the experiment of each mission profile, during which the crew implements the task execution process of the role in different mission profiles according to the task and scores the subtasks classified by time series from 0 to 10 points, separately according to five channel loads of vision, audition, cognition, movement and speech and the total workload, and higher score indicates heavier workload.

2.1.3 Experiment Design and Participants

With the application of full-factor experimental design, two mission profiles adopt within-subjects design and the between-subjects design has only one variable, that is, task roles. The experiment has two independent variables and roles are grouped into between-subjects variables at Level 3. With regard to the driver, vehicle commander, and gunner, because the task undertaken by the driver is in single style and has little change, so the research focuses on the quantitative evaluation of the workload of the tasks of the vehicle commander and gunner; the task profile is within-subjects variable at Level 2. All tested crew shall complete impact breakthrough and deep attack and repeat the measurement for three times for each level. Data analysis shall be carried out on samples for repeated experiment with workload measurement of DRT.

Subjects are experienced healthy crew without eye diseases and the eyesight or corrected visual acuity is above 1.2. Subjects are in great condition on the day of test. The experiment has obtained nine sets of valid data, 27 person times in total. Each mission profile has obtained 81 repeated measurement samples and each task role obtained 54 repeated measurement samples.

2.2 Data Description

Indexes shall be extracted from single mission profile experiment and the applied workload research indexes include task performance of the crew (s), workload measurement (response time: ms; missing ratio: %) and subjective five channel workload evaluation data. The driver shows consistent performance during task execution and undertakes single tasks, and workload analysis shall be conducted toward two task execution personnel, that is, the commander and gunner. Part of task performance in data set is shown in Fig. 2.

The time nodes that require data recording separately refer to the moment upon completion of the order given by the commander (here completion means all completion by the driving and gunner), successful target attack (hearing the guns shall prevail), and train order recovered by the commander (including reporting to the superior and giving orders to the driver and gunner). In case of missing values resulted due to equipment, measurement error and other factors, the principle of constant mean value shall be adopted to replace the missing value with the mean value of measurement results of the same subject in corresponding measurement group.

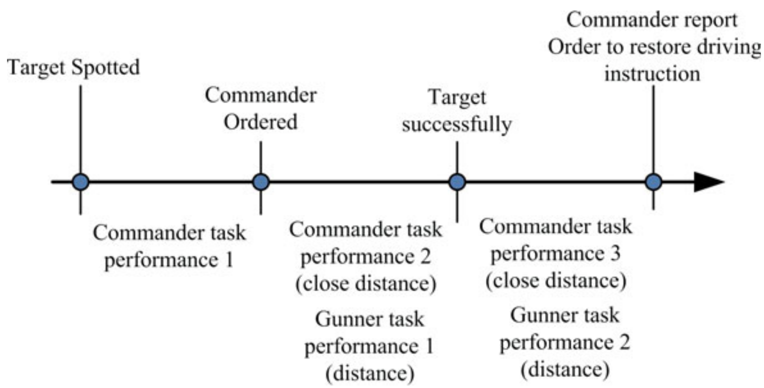

Fig. 2 Combat task flow

3 Results and Discussion

This section gives a summary of data analysis results from three aspects and Sect. 3.1 gives an analysis of task performance and quantitative results of DRT workload to mainly discuss the influence of different types of mission profile and roles of task execution personnel on workload; Sect. 3.2 takes subjective score as the object of analysis to focus on discussion on the law of different scorn changing with task process and the relationship between them and the score of total load.

3.1 Workload Quantification Analysis

Results of completion time of different mission profiles at each task execution stage are summarized in Fig. 1, from which it can be seen that different task types have a significant influence on workload, of which remote attack object is more difficulty and takes more time, not only in the completion time of attack task, but also in the time of the process when the commander gives attack order. In the mission profile of impact breakthrough, the time the commander takes to give orders is significantly more than that of deep attack ($F(1,51) = 14.16$, $p < 0.001$) (Table 1).

Quantitative results of DRT workload are shown in Fig. 3 and the different of response time is obtained by using the average response time of detection response tasks in all events except the missing ones to minus the basic response time after static measurement. When it comes to the task role of the commander, the commander is responsible for implementing attack task in the mission profile of deep attack, in which case its response time difference and missing ratio are significantly increased as compared to impact breakthrough; while for the task role of the gunner, the gunner is responsible for implementing attack task in the mission profile of impact breakthrough, in which case its response time difference and missing ratio are significantly increased as compared to deep attack.

3.2 Subjective Evaluation

As for the tasks of the commander and gunner, the total scores of each stage shall be centralized for polynomial fitting to get the subjective scores of workload changing

Table 1 Task performance (mean value, s)

Task	Commander			Gunner
	Order	Complete mission	Regain order	Complete mission
Breakthrough	9.78	–	8.41	50.44
Deep attack	6.74	13.63	8.51	–

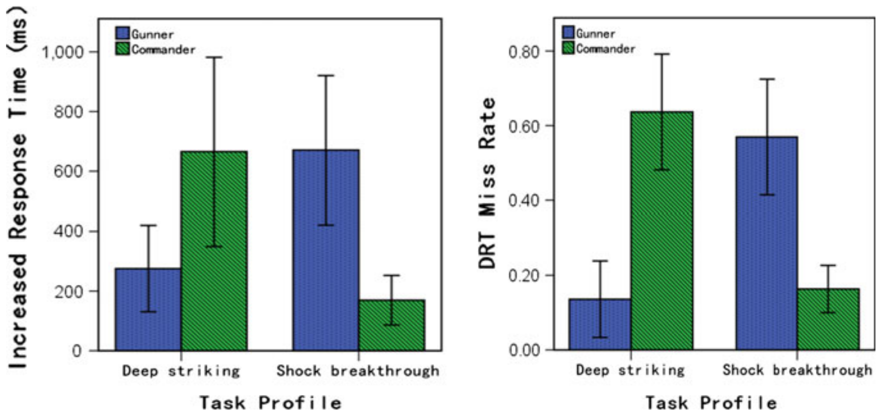

Fig. 3 Cognitive workload quantification result measured by DRT

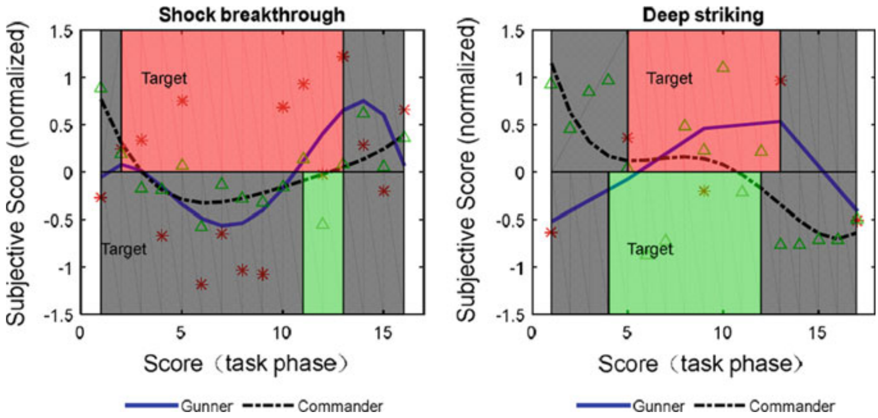

Fig. 4 Workload subjective evaluation (overall)

with task stages as shown in Fig. 4. The first colored half is the task phase divided for the gunner while the second colored half is the task phase divided for the commander, of which the part in red refers to the corresponding attack phase of mission target for the gunner's workload score while the green part refers to corresponding attack phase for mission target of the commander's workload score. It can be seen that the workload scores of the commander and the gunner have different variation tendencies.

Under two mission profiles, the commander gets higher workload scores at the stage of giving orders. In the mission profile of impact breakthrough, after the commander gives the order, the gunner shall be responsible for target searching and task attack, thus it can be seen that the subjective score has a significant decrease at the second stage, lower than the average (that is, 0 after being centralized), while at the stage of back to vehicle driving after successful target shooting, the commander plays a dominant role again and the workload score gains an increase; in the mission profile of deep attack, the commander shall be responsible for giving orders to surpass to attack, and the workload is higher at the first stage of the task, while after entering the stage of target attack, no significant decrease occurs, after successful target shooting, there is a significant down trend.

Under two mission profiles of the gunner, the gunner's workload score is low at the stage as the commander gives an order. In the mission profile of impact breakthrough, after the commander gives an order, the gunner's score severely changes at the stage of attack task and the workload score is low at the stage of initial search, while as tracks the target and maintains until the target is shot in the end after entering the later stage of attack task, the workload score is significantly increased, but after the attack target is successfully achieved, the workload score has a significant decrease; in the task profile of deep attack, the gunner's workload score is higher at the junctions between the first and second stages and the second and third stages, indicating that under the mission profile, the main workload of the gunner comes from reception and adjustment of the commander's orders at task junctions.

Subjective score not only gets the total workload of the task at each stage, but also gets the workload scores of the five channels including visual, auditory, cognitive, motor, and speech channels. Correlation between the total workload score and the score of each channel is summarized as shown in Table 2 and the correlation is tested with Pearson correlation. Thus, it can be seen that the total score of workloads of the major roles executing attack tasks is highly correlated to the score of visual, cognitive and motor channels, which is reflected in the scores of the role of gunner in mission profile of impact breakthrough and the role of commander in the mission profile of deep attack.

Table 2 Correlation between the overall evaluation score and the tunnel score

Channel	Breakthrough		Deep attack	
	Gunner	Commander	Gunner	Commander
Visual	0.928**	0.547*	−0.836[a]	0.910**
Auditory	0.293	0.047	0.189	0.188
Cognitive	0.927**	0.726**	−0.531	0.929**
Motor	0.977**	0.069	−0.346	0.664**
Speech	0.385	0.327	0.189	0.150

*At the level of $\alpha = 0.05$ (two sides), significantly correlated to the score of total workload
**At the level of $\alpha = 0.01$ (two sides), significantly correlated to the score of total workload
[a] High coefficient of correlation shows certain significance ($p = 0.078$); because less score items, but fails to pass the test

4 Conclusions

The research explores the impact of breakthrough deep attack workloads quantitative assessment method of two typical mission profile based on semi-physical simulation simulator test. It innovates the use of the evaluation method of the driver's cognitive attention workload in the technical field of active safety of the vehicle to measure the task workload of the crew of special vehicles, and remarkable achievements have been made. Except for the quantitative method of DRT workload, the research gives a reasonable decomposition of mission profile and designs the subjective evaluation questionnaires by channel to analyze task performance and results of subjective evaluation. Conclusions are reached as follows:

1. Analysis of the quantitative results of overall workload shows that remote attack target is more difficult and takes more time, which is characterized by long completion time of attack task and long process for the commander to give attack orders. In the mission profile of deep attack, the commander is responsible for attack task and its response time difference, mission ration, and impact breakthrough are significantly increased by comparison; while in the mission profile of impact breakthrough, the gunner is responsible for attack task and its response difference, missing ratio, and deep attack are significantly increased by comparison.
2. The change law of multichannel workload subjective score in the task process shows that the overall score of workloads of major roles is highly correlated to the scores of visual, cognitive and motor channels. The gunner's workload score of each channel changes severely with time while the commander's workload of each channel has no significant change with time. In impact breakthrough, the gunner's workload has two peaks in two nodes after receiving the commander's order, that is, starting target search and locking the target for attack, and in deep attack, the commander obtains higher workload scores at the stage of giving an order and the later stage of target attack.

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Influence of Semantic Task on Selective Attention

Yajuan Bai, Sai He, Renlai Zhou, Yuping Luo and Yaofeng He

Abstract To study the effect of semantic task on visual selective attention is helpful to establish a more effective visual salient area calculation model. This study selected 24 pieces of natural images from the image library, the eye movement data of subjects were recorded by eye tracker. This paper study on selective attention of natural vision while people watching photography with semantic task analyzes the features of eye gaze. The result of experiment indicates that semantic task can affect selective attention. On semantic task conditions, attention of object is likely onto the area with semantic meaning. Semantic task can also counteract the preponderance of feature salience. The type of photography can affect the first fixation velocity of AOI. The process time of semantic information change depends on the task type.

Keywords Natural scene · Semantics · Task-oriented · Selective attention

1 Introduction

How human beings know the world through obtaining external information has been always one of the problems needed to be concerned in psychology. In the process of human beings knowing and understanding the objective world, 80–90 % of the information is obtained through eyes. Visual selective attention research is the key content of the research on Basic Psychology and Experimental Psychology.

The visual attention mechanism of human beings mainly includes two processes, which are top-down process and bottom-up process respectively. Top-down process is also known as a task-driven visual attention process. Bottom-up process is also called as a data-driven visual attention process.

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In the field of computer visual simulation and psychology, there are three views for the influences of selective attention on picture interest areas, which forms their own computation models accordingly.

The first view is feature-driven capture view (stimulus-driven capture view). People's attention to the stimulus when feedforward visual processing depends mainly upon feature saliency and bottom-up feature saliency determines the sequence of selective attention. In the field of psychology, scholars headed by Theeuwes [1] put forward feature integration theory. The view held that the feature integration theory mainly included the following several assumptions: (1) When the attention was distributed in the stimulus, the analysis on local feature differences was carried out from bottom to top and has nothing to do with the top-down process. Only after the most distinctive feature singleton was selected could the top-down knowledge take effect; (2) the first feedforward saccade is based on feature-driven process; (3) the top-down controlled spatial information may affect information obtained through the first saccade. This influence was realized through changes and this window was determined by the experimental tasks. However, although the top-down process affected the attention window, the processing in the window was still carried out from bottom to top. As time passes by, it continuously changed in the direction from top to bottom.

The second view is conditional attention capture theory (contingent capture hypothesis). People headed by Folk et al. [2] held this view and believed that only when feature singleton had the features related to the tasks can attract attention and its selection for stimulus was always affected by the implicit or explicit task objectives, namely top-down influence.

The third view is feature weight theory (dimension-weighting account). Müller et al. [3] put forward this theory and believed that people's attention to feature singleton was not only under the top-down influences, but also under the bottom-up influences, which mainly showed that people would increase the weight of those features related to the tasks to make them easier to be noticed. When weighted the features, the whole feature dimension (such as color, orientation, brightness, etc.) would be taken as the object, rather than some feature value (such as red and green). In computer vision, the guided search theory put forward by Wolf [4] had gradually gotten attention. This theory was similar to the feature weight theory and Wolf believed that people would weight the features related to the tasks to make it easier to be detected. The main differences lie in that Müller considered that this weighting aimed at the whole feature dimension, but Wolf believed that a certain single feature value can also be weighted. In recent years, the researchers have found, for the attention research based on the tasks, that the existing search models based on feature saliency are not perfect, need to introduce some top-down factors, and task requirements can even change the influences caused by the feature saliency completely.

When people watch complex scenes, both feature stimulus and tasks need to have an impact on people's attention and task requirements can even change the influences caused by the feature saliency completely. Einhäuser et al. [5] used the grayscale pictures of natural scenes, designed the dynamic and static experiments, felt free to watch the two states of task search, recorded the eye movement track of the subject and analyzed the fixation point, saccade direction, search time, and fixation time of the subject.

In the static experiment of people can be allowed to watch freely, the first fixation point of the subject is obviously biased to high-contrast areas in the pictures and the first saccade direction has also appeared a high-contrast bias. This phenomenon shows that the feature stimulus plays a strong guiding role under the condition of free watching.

In the search task test without preference, the subject is required to search the targets may appear on both sides of the pictures and other positions by probability while judging the natural/non-natural scenes. In this search task without preference, the influences of gray change on the attention of the subject are disappeared completely and quickly. This shows that in the search task, the guiding role of the search task to the attention is stronger than that of the feature stimulus.

In the search task with reverse preference, when the search target appears on one side of the picture with low contrast, the first fixation point of the subject is obviously biased to low-contrast areas and the saccade direction has also appeared a low-contrast bias. This shows that the subject not only ignores the significant cues of high physics, but also actively eliminates effects of high significant features. In addition, the analysis on saccade direction shows that the influences of physical significance on the attention only exist in the initial few saccades, but the influences of task requirements on the attention need to exist in the whole process of the experiment.

In this paper, the horizontal distance of vertical center line of the fixation point is adopted to assess the bias learning and define the value of the fixation point in high-contrast area as positive and that in low-contrast area as negative.

In the experiment without bias, if the subject does not find the search targets in the initial several experiments, the observers will quickly restore "freely observed" and bottom-up dominant mode. When the subject realizes the probabilities of the targets appearing on both sides are equal, the task requirements will continue to show a leading advantage, even if the subject does not find the target in the initial experiment.

In conclusion, the top-down and bottom-up research on visual attention in psychology mostly adopts the artificial pictures and artificially controls the characteristics of the pictures. For example, Einhäuser adopted the grayscale pictures of the natural scenes in the experiment and used artificial methods to increase the physically salient areas. The search targets are also the fixed graphic objects.

In daily life, people often carry out picture observation and scene recognition with semantic tasks, such as find people and vehicle and others in the pictures. This research investigates the influences of task requirements and feature saliency on selective attention of the subjects under the semantic task and verifies the applicability of the test results obtained by Einhäuser under the natural scene semantic task.

2 Research Method

Show the subjects some natural scene pictures, establish two experimental conditions of free search and character search and record the subjects' eye movement data; natural scene pictures use visual computation model to calculate the feature salient areas; compare and analyze the data of feature salient areas of natural scene, eye movement fixation area of free search and eye movement fixation area of character search to obtain the influences of feature salience and semantic task on the attention under the condition of semantic task.

2.1 Experimental Design

The experiment is a mixed design based on two factors: 2 (task modes: free search and character search) × 3 (picture contents: have character obviously, do not have character obviously, and do not have character).

Task I free search: Let the subjects search all the details of the pictures and report all contents they saw after presenting all the pictures.

2.2 Experimental Stimulus Materials

There are 24 real pictures with different contents from the actual photo gallery and the resolution is 1024 × 768. Among 24 pictures, 8 pictures have character obviously, 8 pictures do not have character obviously, and 8 pictures do not have character.

2.3 Subjects

There are 18 undergraduates of Beijing Normal University, including 12 male students and 6 female students. These students' age is within the range of 19–23 and they have normal vision and corrected vision. The subjects are randomly divided into two groups, of which 9 students are carried out free search and the remaining 9 students are carried out character search.

2.4 Experimental Instruments

Tobii T120 eye tracker with 17 inch plan, the highest resolution of 1280 × 1024 and vertical refresh rate of 120 Hz. Within the error range (0.5°), if the fixation time of the eyes on one point reaches 100 ms, it shall be recorded as one-time fixation; one set of computer whose CPU is core2; one set of CRT display with 17 inch plan, resolution of 1024 × 768, and vertical refresh rate of 85 Hz. Tobii T120 with build-in Tobii Studio is used for program composition, presentation and data export, TET Server is used for data acquisition.

2.5 Experimental Procedure

Help the subjects sit in the experimental chair and ask them to relax; before the calibration, the subject will be informed of the following contents, “Next, the screen will appear red circle and your job is to keep an eye on the red dot until it disappears. In this process, the body and the head should keep still as far as possible”; present the instructions; present pictures and record the subjects’ eye movement; the subjects will report in accordance with different tasks and after the completion of report, the experimenter will press the button to continue the experiment. The experimental procedure is as shown in Fig. 1.

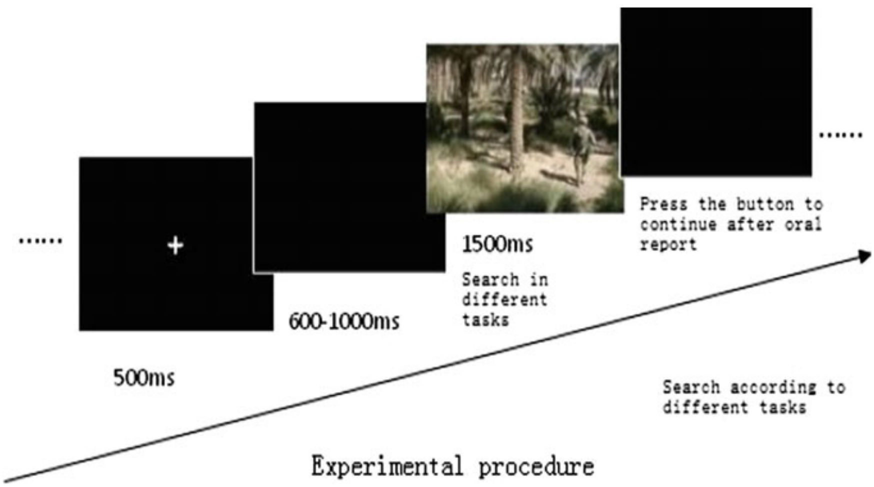

Fig. 1 Flowchart of experiment

3 Analysis of Experimental Results

3.1 Analysis on Differences Between Feature Salience and the Subjects' Eye Movement Data

Figure 2a identifies 4 salient areas for the computer, as shown in Figure. Figure 2b is the human eye heat map when free looking and Fig. 2c is the human eye heat map when searching people. The methods for analysis on differences between human eye movement and computer recognition results:

Fixation point whose fixation area and significance are consistent with the computer recognition can score 1; fixation point whose fixation area is consistent with the computer recognition but the significance is different can score 5; and fixation point whose fixation area and significance are not consistent with the computer recognition can score 0 and the accumulated scores of each fixation points are the consistency scores of the pictures.

According to the above calculation rules, calculate the consistency scores between human eye movement data of 24 pictures and computer recognition results and the consistency scores between human eye data and computer recognition in the free search are shown in Table 1. The consistency scores between human eye data and computer recognition in the character search are shown in Table 2.

In 24 pictures, there are significant differences between the computer recognition and the subjects' eye movement data. Figure 3 is sketch map of consistency score of the computer recognition and the human eye data.

Carry out independent sample T inspection for consistency score of free search and character search and the difference of $p = 0.135742 > 0.05$ is not significant.

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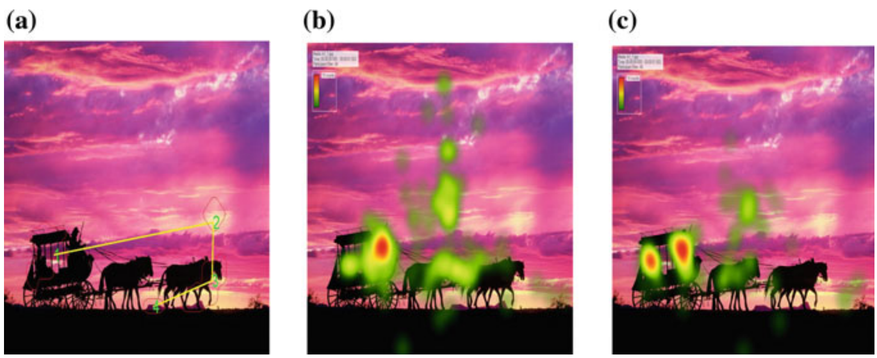

Fig. 2 Sketch map of salience

Table 1 Coincidence score of free looking

Number	Type	Consistency score	Number	Type	Consistency score
1	With characters	0.5	13	Not obvious	0
2	With characters	0.5	14	Not obvious	1
3	With characters	1	15	Not obvious	0.5
4	With characters	0	16	Not obvious	0.5
5	With characters	1.5	17	No characters	0.5
6	With characters	1	18	No characters	0
7	With characters	1	19	No characters	0.5
8	With characters	2	20	No characters	1
9	Not obvious	2	21	No characters	0
10	Not obvious	1	22	No characters	0
11	Not obvious	0	23	No characters	0
12	Not obvious	0.5	24	No characters	0.5

Table 2 Coincidence score of searching person

Number	Type	Consistency score	Number	Type	Consistency score
1	With characters	0.5	13	Not obvious	0
2	With characters	0.5	14	Not obvious	1
3	With characters	0.5	15	Not obvious	0
4	With characters	0	16	Not obvious	0
5	With characters	1.5	17	No characters	0.5
6	With characters	0	18	No characters	1
7	With characters	0.5	19	No characters	0.5
8	With characters	1	20	No characters	1
9	Not obvious	0.5	21	No characters	0
10	Not obvious	0.5	22	No characters	0
11	Not obvious	0	23	No characters	0
12	Not obvious	0	24	No characters	0.5

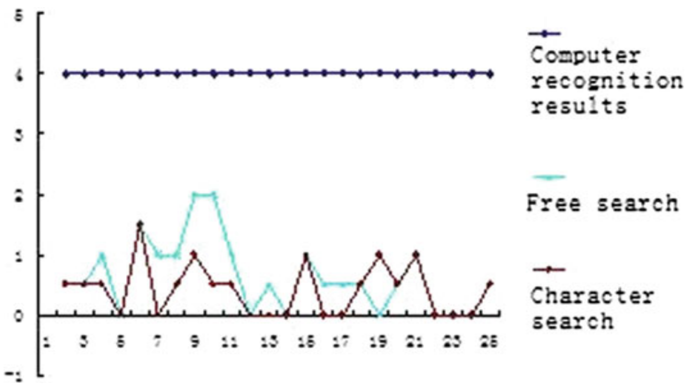

Fig. 3 Chart of contrast

3.2 First Fixation Velocity of Main AOI

Through the analysis of variance, it can be found that there are significant differences in the free search group: $F = 3.519$, $p = 0.048 < 0.05$, and the ex post test shows there are significant differences between the level with people and the level without people ($p = 0.015$).

Through paired samples T inspection, the first fixation velocities of main AOI of two search tasks have no significant differences in the overall level and the local level. However, the two groups have high correlation between the overall level and the level which have character obviously: Overall level $r = 0.625$, $p = 0.01$; level which have character obviously $r = 0.924$, $p = 0.01$.

3.3 Fixation Time of AOI Area

Select the representative pictures to carry out an independent analysis. Hot air balloon is a typical map with no obvious characters and here AOI area is divided into physical stimulus area, hot air balloon area and balloon frame area (Tables 3 and 4).

Table 3 First fixation velocity of AOI

Number	Type	Average	*N*	Standard deviation	Mean standard deviation
1	Character search	0.5301	24	0.23909	0.04880
	Free search	0.5665	24	0.23652	0.04280
2	Character search—with characters	0.3800	8	0.18544	0.06556
	Free search—with characters	0.4186	8	0.27833	0.09840
3	Character search—not obvious	0.5994	8	0.23853	0.08433
	Free search—not obvious	0.5790	8	0.16478	0.05826
4	Character search—no characters	0.6110	8	0.24048	0.08502
	Free search—no characters	0.7019	8	0.18182	0.06428

Table 4 Fixation time of AOI

Features	Type	Average	N	Standard deviation	Mean standard deviation
Physics	Character search	14	0.3793	0.21477	0.05740
	Free search	6	0.2823	0.12036	0.04914
Balloon	Character search—with characters	17	0.7715	0.23750	0.05760
	Free search—with characters	17	1.0481	0.30202	0.07325
Frame	Character search—Not obvious	12	0.4219	0.14475	0.04178
	Free search—not obvious	15	0.8465	0.19340	0.04993

We can intuitively find through this table that the number of attention capture under the physical stimulus has significant differences in different tasks. In the free search group, the attention of 14 persons (17 in total) is captured by the physical stimulus while the attention of 6 persons (17 in total) is captured by the physical stimulus in the character search.

In the fixation time, through the independent sample test, it can be found that the fixation time duration of the balloon and frame has significant differences between groups: Balloon level: $t = 2.968$, sig. = 0.006; frame level: $t = 6.312$, sig. = 0.000.

4 Conclusion and Discussion

(1) Semantic tasks have significant influences on selective attention

In the natural scene picture observation, there are significant differences between free search and character search and computer recognition results. Even in free observation condition, the subject's selective attention is mostly focused on semantic-related areas, which indicates that clear or unclear semantic tasks have significant influences on selective attention and can reduce the advantage role of feature salience in visual search.

(2) Clear semantic tasks have more obvious bucking effect on feature salience

Comparing with free search, it is more difficult for the character search tasks to be attracted by the non-semantic and easier to be attracted by the areas similar to character features.

(3) The interest intervals of different types of pictures have different first fixation velocities

The first fixation velocities in interest intervals change with different picture types and the first fixation velocity of the scene pictures with characters is quicker than the scene pictures without characters. For the pictures lacking the subjects, the velocity of the subject's fixation point moving from the center of screen to other positions is slower.

(4) The processing time for different semantic information changes with the different tasks

The processing time for semantic-related information is longer than that for non-semantic-related information.

5 Compliance with Ethical Standards

The study was approved by the Logistics Department for Civilian Ethics Committee of Beijing Special Vehicle Institute.

All subjects who participated in the experiment were provided with and signed an informed consent form.

All relevant ethical safeguards have been met with regard to subject protection.

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Development of Computerized Tests for the Evaluation of Human Three-Dimensional Spatial Ability

Xianliang Mu, Yu Tian, Chunhui Wang, Junpeng Guo and Shoupeng Huang

Abstract Three-dimensional (3D) spatial ability is a critical cognitive ability of humans. The existing tests for 3D spatial ability are mainly paper-and-pencil tests. In the present paper, we developed computerized tests to evaluate human spatial ability. We chose 3D mental rotation test and 3D perspective taking test as the typical types of 3D spatial ability. And the computerized tests for the spatial abilities were developed in two versions, the desktop-based spatial tests and the web-based spatial tests. 30 subjects took the desktop-based spatial tests (the 3D mental rotation test and 3D perspective taking test) twice, another subjects took the web-based spatial tests (the 3D mental rotation test and 3D perspective taking test) twice. Their spatial abilities were evaluated through the index of "mean reaction time/accuracy." Correlation analysis shows that the test–retest reliability of the computerized tests are all quite high, while the web-based spatial tests demonstrated higher reliability than the desktop-based spatial tests. Those data indicate that the computerized 3D mental rotation test and 3D perspective taking test can be well applied to the evaluation of Human's 3D spatial ability.

Keywords 3D spatial ability · Mental rotation · Perspective taking · Computerized cognitive test

1 Introduction

Three-dimensional spatial cognitive ability is one of the important cognitive abilities of humans. This cognitive ability is crucial for humans to accomplish space navigation, architectural design, spacecraft and aircraft control, and other tasks. Therefore, how to accurately test and evaluate the three-dimensional spatial cognitive ability of humans is a key problem. More and more domestic and foreign

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researchers are devoted to the research work in this field. However, the researchers have not reached a consensus on the classification and definition of the subcomponents of spatial cognitive ability. The paper applies the classification of three-dimensional spatial cognitive ability of Hegarty et al. [1, 2] There are at least two types of three-dimensional spatial cognitive abilities. One is the ability related to Spatial Manipulation of 3D Objects, which requires humans to carry out Spatial Transformations and Manipulation of a Perceived Object; the other is the ability related to Spatial Orientation, which requires humans to imagine how a scene looks like from different viewpoints. Based on the research of Oman, Wang et al. [3–7], the ability of Spatial Manipulation of 3D Objects and the ability of Spatial Orientation are also closely related to the performance of astronauts when they are executing the space tasks in space flight. Based on the above background, the present study selects three-dimensional mental rotation test astronauts to evaluate the ability of Spatial Manipulation of 3D Objects of humans; selects three-dimensional perspective taking test to evaluate the ability of Spatial Orientation of humans.

At present, "Three-dimensional mental rotation," "Three-dimensional perspective taking," and other three-dimensional information processing ability tests all have various mature test paradigms and test materials, such as Vandenberg and Kuse [8] Mental Rotation Test (3D mental rotation), Guay's [9] visualization of viewpoint (3D perspective taking), etc. The present study has designed a test platform that meets the requirements of three-dimensional spatial cognitive tests based on the existing mature test paradigms. At present, the method of "Paper-and-pencil test" is mostly used. The method has the advantages of low cost, simple. and practicable operation, however, there are also many disadvantages. First, there is relatively less data information recorded in paper-and-pencil test. Only accuracy of answers within limited time can be obtained. The data information during the test process cannot be obtained. Moreover, manual scoring is inefficient and there may be mistakes in manual scoring. Second, the material library of paper-and-pencil test is small so that there is no randomness existed in the order of the problems. The problems often cannot be used for repetitive tests, which leads to the fact that the method does not apply to cognitive ability monitoring within a certain time range. Third, paper-and-pencil test does not apply to the tests under special environments. For example, during manned space flight, paper-and-pen cognitive test are so inconvenient in test material preparation, test operation, data storage, and other aspects. Computerized cognitive test platform can overcome the above disadvantages and can record abundant data, such as being able to record the subjects' answering time of each question and other information; the data recorded by the computerized cognitive test platform is accurate and reliable, and applies to the tests carried out in spaceflight and other special environment. Therefore, the present study has specifically designed and developed computerized "Three-dimensional mental rotation test" and "Three-dimensional perspective taking test," and tested their reliability.

2 Test Method

2.1 Test of Mental Rotation Ability

Mental rotation refers to the process of rotating two-dimensional or three-dimensional objects by mental imagery. Shepard et al. [7] first put forward the concept and the experimental paradigm of mental rotation ability. Its sample pattern for test is as shown in Fig. 1A.

At present, the common measuring paradigms of mental rotation include: “Vandenberg Mental Rotation Test,” “Card Rotation Test,” and “Cube Comparison Test.” These tests are paper-and-pencil tests which are difficult to be applied to multiple repeated tests. To facilitate the repeated tests, Michael Peters, and other researchers drew a material library of four-part three-dimensional mental rotation graphs of large sample. The material library contains 6912 pieces of three-dimensional graphics: Among them, there are 16 kinds of different three-dimensional configurations (among which, typical configuration is as shown in Fig. 2). The same configuration has erect image and mirror image states, 72 rotation angles (rotates every 5° from 0° to 355°) and can rotate around the x-axis, y-axis, and z-axis. The material library of three-dimensional mental rotation test in

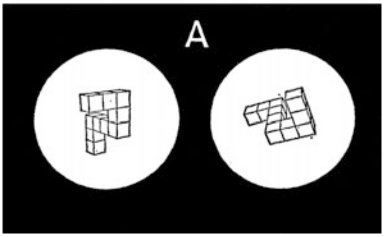


Fig. 1 Examples of 3D mental rotation test

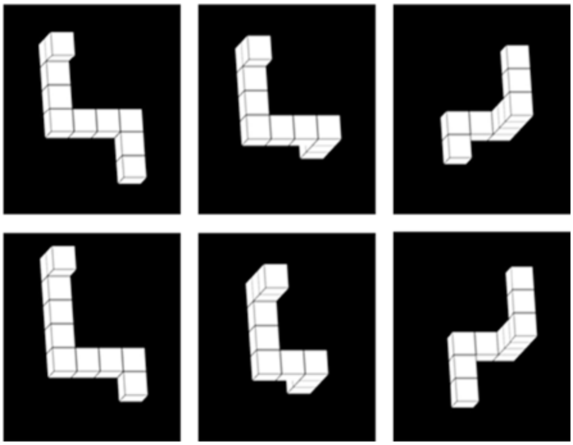


Fig. 2 Typical structures in the materials library of 3D mental rotation test [10]

the present study is from Peters Michael [10], who draw the drawing of the graphics library.

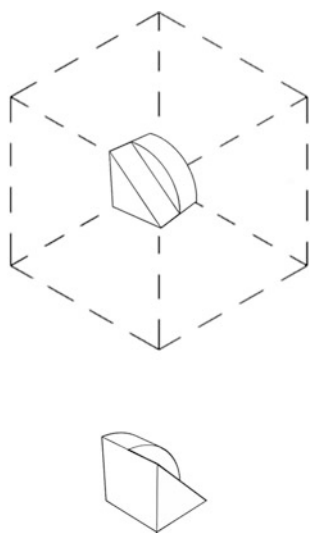
2.2 Test of Perspective Taking Ability

Spatial Perspective Taking refers to the mental process of humans to imagine how a scene looks like from different viewpoints. It can be divided into two-dimensional Spatial Perspective Taking and three-dimensional Spatial Perspective Taking [11–13]. Some researches have pointed out that the ability of Spatial Perspective Taking is a kind of ability related to but different from mental rotation ability. Mental rotation usually requires the subjects to complete the operation on the observed objects through imagination, however, Spatial Perspective Taking requires the subjects to imagine their own movement to a new angle of view. Therefore, the former requires to process mental imagery in the world coordinate system, while the latter requires to imagine the movement of their own coordinate system.

The test case of three-dimensional Spatial Perspective Taking is as shown in Fig. 3. The left figure presents an irregular object located in the center of a transparent cube to the subjects. The subjects need to judge which vertex is the perspective of the observed object obtained from.

Similar to the three-dimensional mental rotation tests, the existing three-dimensional perspective taking tests are paper-and-pencil tests. For example, the commonly used test of The Visualization of Viewpoints (improved by Lippa, Hegarty et al. [11] based on the test proposed by Guay et al. [13]) contains only 24 questions so that it is difficult to be applied to multiple repeated tests. Moreover, literature, there are no researchers who have put forward larger material library of three-dimensional perspective taking samples. Therefore, the present study carries

Fig. 3 Example of 3D perspective taking test [13]



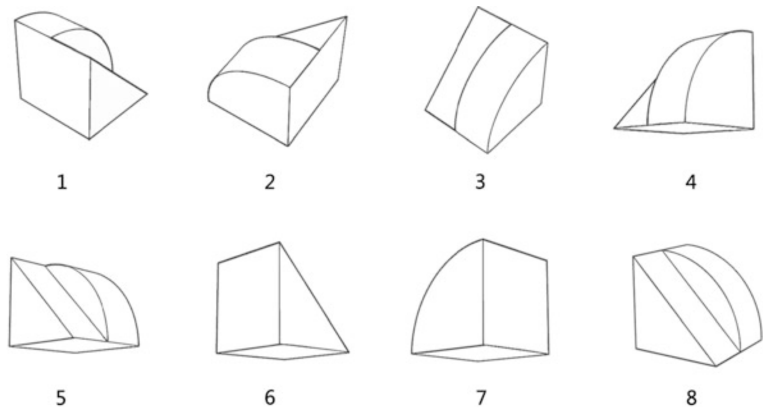


Fig. 4 The extension of 3-D perspective taking test materials library: from one alternative viewpoint to 7 alternative viewpoints *Note* Viewpoint 8 is the fixed viewpoint in the 3D cubic

out the following extension for the 24-question sample library of the three-dimensional perspective taking test proposed by Lippa, Hegarty et al.: Among the seven optional perspectives, one perspective of the original test material library is adopted for each shape. The present study redraws the 24 three-dimensional shapes through the three-dimensional drawing software and extends the observing perspective into seven perspectives (as shown in Fig. 4). As a result, the material library is extended to 168 and can better meet the requirements of repeated tests.

3 Computerized Cognitive Test Platform

Based on the above-mentioned mental rotation and perspective taking test methods, the present study has developed two cognitive test platforms, including the "desktop-based" test software and the "web-based" test system. The two platforms use the same test paradigm and material library. The reliability of the computerized spatial ability test of the two platforms has been analyzed through experiments.

3.1 "Desktop-Based" Cognitive Test Software

The "desktop-based" three-dimensional mental rotation test software and three-dimensional perspective taking test interfaces are as shown in Figs. 5 and 6. Their test interfaces are relatively simple. The software provides the feedback information of average reaction time and accuracy after the test ends instead of providing the subjects with the feedback of whether the answer is correct and reaction time after each key-press reaction.

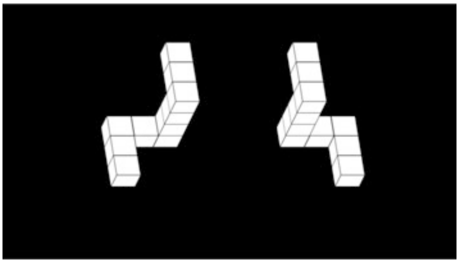


Fig. 5 The test interface of 3D mental rotation test in the desktop-based software

Fig. 6 The test interface of 3D perspective taking test in the desktop-based software

During the process of carrying out tests with "desktop-based" spatial cognitive ability test software, the following three problems have been found: The first one is that it takes time to collect data with a desktop-based test software; the second one is that the display and feedback content of the desktop-based test software is often simple so that the subjects are not very dedicated in the test; the third one is that the test data of the desktop-based test software is generally stored in local files. If different test computers are used, the data will be distributed in different computers, which may inconvenience the unified data management. To solve these problems, we have also developed a "web-based" test platform of spatial cognitive ability.

3.2 "Web-Based" Cognitive Test Platform

The "web-based" cognitive test platform contains a lot of cognitive tests, including three-dimensional mental rotation test and three-dimensional perspective taking test. In the "web-based" cognitive test system, in addition to the traditional stimulus presentation method, the test interface also provides real-time test feedback of "whether the reaction is correct" and reaction time on the right side and provides reminder of remaining time of the test on the top. Figure 7 is the test interface of the "web-based" three-dimensional mental rotation software. Figure 8 is the test interface of the "web-based" three-dimensional perspective taking test software.

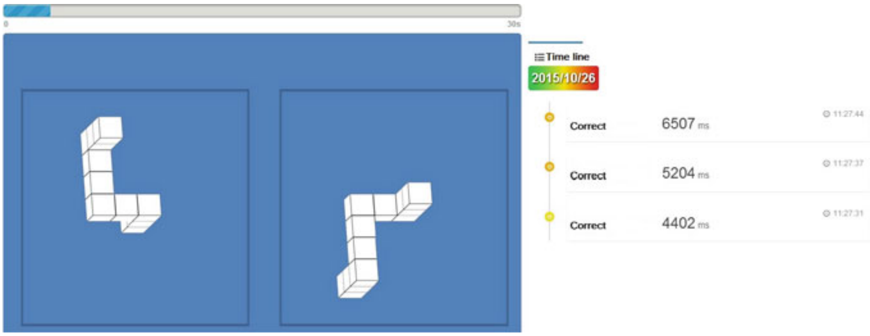


Fig. 7 The test interface of 3D mental rotation test in the web-based software

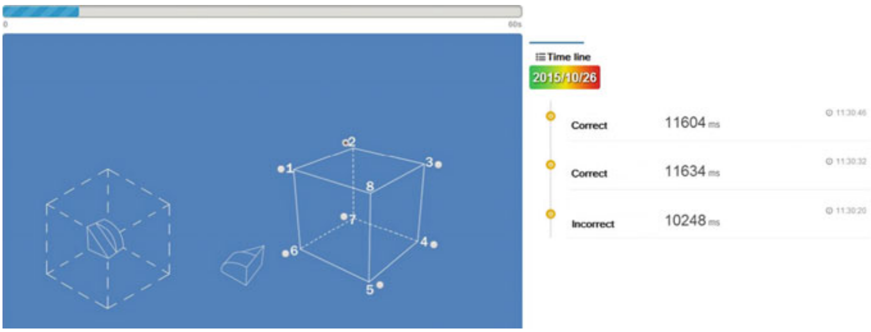


Fig. 8 The test interface of 3D perspective taking test in the web-based software

Each test of the "web-based" test platform provides real-time feedback for the subjects. Moreover, the platform will provide comprehensive achievement feedback upon completion of a test, such as the subjects' average reaction time, accuracy, rating among all the subjects. In the "Historical data" clause of the test system, the subjects can check the results of the tests they have completed. The administrators can check the results of all the tests of all the subjects in the database.

4 Reliability Analysis of Computerized Cognitive Test

To obtain the test–retest reliability of the "desktop-based" and "web-based" cognitive ability test platforms, 30 subjects were recruited to take the three-dimensional mental rotation tests twice utilizing the "desktop-based" softwares and another 30 subjects were recruited to take the three-dimensional perspective taking tests twice utilizing the "web-based" tests. In data analysis, the parameter, "Reaction

Table 1 The correlation analysis for test–retest reliability of the computerized spatial tests

	Desktop-based software		Web-based software	
	3D mental rotation test	3D perspective taking test	3D mental rotation test	3D perspective taking test
Correlation coefficients of test–retest performance	0.790**	0.582**	0.850**	0.821**

$^{**}p < 0.01$

Time/Accuracy" (RT/ACC), is selected as the evaluation index of the cognitive ability.

The test–retest reliability of software-based test has been analyzed through calculating the correlation coefficient of the performance evaluation indices of the two tests of 30 subjects in the same software. The result shows that the three-dimensional mental rotation and three-dimensional perspective taking tests of the two platforms all have good test–retest reliability. The correlation coefficient is between 0.582 and 0.850. The p values of the tests are significant at the 0.01 level (Table 1).

Through the comparison, it can be found that the "web-based" cognitive test platform has a higher test–retest reliability. This may be attributed to the richer feedback provided by the "web-based" test platform makes the subjects be able to keep a good level of devotion in multiple tests, so as to bring higher test–retest reliability.

In addition to higher test–retest reliability, compared with the "desktop-based" cognitive test software, the "web-based" cognitive test system also has the following advantages: Firstly, the "web-based" test system can more conveniently collect the performance data of larger samples through the method of remote login and test, so as to save the time of data collection; secondly, the performance data of the "web-based" cognitive test system is stored in the unified server and database so that data management is more focused and convenient.

5 Conclusion

The present study introduces the designing and developing process of computerized spatial cognitive ability. The experimental data shows that the development of the computerized three-dimensional mental rotation test and three-dimensional perspective taking test platforms have high test–retest reliability and can be used for the test and evaluation of three-dimensional spatial cognitive ability of humans. Among them, the test–retest reliability of the "web-based" cognitive test system is higher than that of the "desktop-based" cognitive test system and has certain advantages in the aspect of data collection and management. It is the direction of future development of cognitive evaluation and test.

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Part II
Research on the Machine Character

Fuzzy Time Series Based on K-means and Particle Swarm Optimization Algorithm

Zonghao Tian, Peng Wang and Tianyu He

Abstract The unequal-sized intervals have important influence on the prediction of the fuzzy time series. With the development of intelligent optimization algorithm increasingly, the theory of K-means based on particle swarm algorithm is put forward to determine the length of interval, making full use the strong local searching ability of K-means and the good global searching ability of particle swarm optimization, overcoming the disadvantage that the result relies on the initial value of K-means too much, and getting the optimal length of interval. Finally, the 22 years of enrollment of Alabama is used to verify the feasibility of the model by comparing and analyzing the mean square error of K-means model and the KPSO method.

keywords K-means · Particle swarm optimization · Fuzzy time series · Mean squared error

1 Introduction

In 1993, Song and Chissom [1–3] put forward the fuzzy time series (FTS) forecasting model based on fuzzy set theory for the first time. Because of the complexity of the structure of time series data, which leads to the length of interval becomes the key factor influencing the model's prediction accuracy. In 2001, Huarng [4] proved the length of interval affects the model's prediction accuracy, and pointed out that the theory of different length of interval can better depict the distribution of the relationship between data, and fully tap the link between the data information. Therefore, many scholars devoted to the division of the length of intervals. For example, in 2002, Chen [5], etc., divided intervals on the basis of the distribution of sample density; and Cheng, in 2006 [6], put forward the dividing

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method based on information entropy and trapezoidal fuzzy; In 2006, Huarng [7] proposed a new method based on the ratio of the data, etc.

In recent years, with the development of intelligent optimization algorithm, it is gradually applied to the fields of dividing intervals, which obtains ideal forecast result. Such as, in 2009, kuo [8] used particle swarm optimization algorithm to divide the interval, etc. But a single optimization algorithm is often due to their own weaknesses, so sometimes it cannot achieve good prediction results. In this paper it proposes a new method which combines the classic K-means algorithm with Particle Swarm Optimization (PSO) to divide intervals. The new approach overcomes the shortcoming that the K-means algorithm relies on the initial value strongly and the PSO is easy to fall into local optimum. So we establish the fuzzy time series model based on KPSO, and use the 22 years of enrollment at the university of Alabama to verify the feasibility of the model.

2 Fuzzy Time Series

Definition 1 Let U be the universe of discourse, where $U = \{u_1, u_2, \ldots, u_n\}$. The fuzzy set A of U is defined as

$$A = \frac{f_A(u_1)}{u_1} + \frac{f_A(u_2)}{u_2} + \ldots + \frac{f_A(u_n)}{u_n} \tag{2.1}$$

where f_A is the membership function of the fuzzy set A, $f_A : U \to [0, 1]$, u_i is a generic element of fuzzy set A, $f_A(u_i)$ is the degree of belongingness of u_i to A, $f_A(u_i) \in [0, 1], 1 \le i \le n$.

Definition 2 Fuzzy time series let $Y(t), (t = 0, 1, 2, \ldots)$ a subset of real numbers R, be the universe of discourse by which fuzzy set $f_i(t)$ are defined. If $F(t)$ is a collection of $f_i(t)$, then $F(t)$ is called a fuzzy time series defined on $Y(t)$.

Definition 3 Fuzzy time series relationships assume that $F(t)$ is caused only by $F(t-1)$, then the relationship can be expressed as: $F(t) = F(t-1) \circ R(t, t-1)$, $R(t, t-1)$ is the fuzzy relationship between $F(t)$ and $F(t-1)$, where "$\circ$" represents as an operator. To sum up, let $F(t-1) = A_i$ and $F(t) = A_j$, the fuzzy logical relationship between $F(t)$ and $F(t-1)$ can be denoted as $A_i \to A_j$.

3 The Clustering Algorithm Based on KPSO

The classic K-means algorithm [9] is usually used in clustering due to its simplicity and rapidity. The result of clustering can response the data structure features well. It can be expressed the distance is minimization within class and the distance maximization between the classes using distance measure. However, K-means is heavily dependent on the initial number of clusters and easily falls into local optimum. As a result, it is often difficult to obtain satisfactory clustering results of K-means.

Particle swarm optimization algorithm [10] (PSO) was found by Kennedy and Eberhart in 1995. In order to achieve the global optimal position, the particles combine their own experience and social experience, then updated their position and speed by continuous iteration. But the PSO algorithm is prone to premature convergence, which leads to the result fall in the local optimum. So the K-means algorithm and PSO algorithm are combined together, and it improves the local search ability of PSO algorithm, solves the problem of the K-means algorithm relying too much on the initial value, and obtains better clustering results.

3.1 K-means Clustering

There are n samples $X = \{x_1, x_2, \ldots, x_n\}$ in the FTS, and divided them into K sets $u_1, u_2, \ldots, u_k$ based on the similarity between the sample data. At first, select K datas from the sample randomly as the initial clustering centers $c_1, c_2, \ldots, c_K$; and then use Euclidean distance $d(x_i, c_k)$ to depict the similarity of the sample data. At last, assign every sample data to different sets with the formula (3.2):

$$d(x_i, c_k) = \|x_i - c_k\| \quad i = 1, 2, \ldots, n; \quad k = 1, 2, \ldots, K \tag{3.1}$$

$$u_k = \left\{ x_j \mid d(x_j, c_k) \le d(x_j - c_p),\ x_j \in X \text{且} p \ne k, p = 1, 2, \cdots, c \right\} \tag{3.2}$$

Thus the distance of each sets u_k is $J(u_k, c_k)$:

$$J(u_k, c_k) = \sum_{j=1}^{m_k} d(x_j, c_k) \tag{3.3}$$

The total distance between classes is $J(u, c)$:

$$J(u, c) = \sum_{k=1}^{K} J(u_k, c_k) \tag{3.4}$$

To readjust the clustering center $\widetilde{c_k}$:

$$\widetilde{c_k} = \frac{1}{m_k}\sum_{j=1}^{m_k} x_j \tag{3.5}$$

where m_k is the sample numbers of the set u_k, x_j is the data of the set u_k.

If the clustering center is the same ($\widetilde{c_k} = c_k$), and the total distance between classes $J(u, c)$ is the smallest, we obtained the optimal clustering results; otherwise, readjust the clustering center.

Make the intermediate values of the adjacent clustering centers as the boundary d_k of the interval, according to the optimal clustering center $c_1, c_2, \ldots, c_K$.

$$d_k = \frac{c_k + c_{k+1}}{2} \quad k = 1, 2, K - 1 \tag{3.6}$$

According to the formula (3.6), the domain U is divided into K subset.

$$u_k = \begin{cases} [x_{\min} - \delta,\ d_1] & k = 1 \\ [d_{k-1},\ d_k] & k = 2, \ldots, K - 1 \\ [d_{K-1},\ x_{\max} + \delta] & k = K \end{cases} \tag{3.7}$$

where $\delta = \min(c_{k+1} - c_k)\ \ k = 1, 2, \ldots, K - 1$.

3.2 Particle Swarm Optimization Algorithm

PSO is used to simulate the birds foraging process, and every bird, according to its current position, the optimal location where they went, and the optimal position of the birds, updates their speed and position, and finally search the global optimal solution, and the standard PSO is commonly used now [10].

$$V_{i+1} = w \times v_i + C_1 \times rand_1 \times (Pbest - x_i) + C_2 \times rand_2 \times (Gbest - x_i) \tag{3.8}$$

$$w = w_{\max} - iter \times \frac{w_{\max} - w_{\min}}{iter\max} \tag{3.9}$$

$$X_{i+1} = x_i + v_{i+1} \tag{3.10}$$

where w is the inertia weight, $iter$ is the current number of iterations, $itermax$ is the largest number of iterations, $Pbest$ is the optimum extremum of a particle, $Gbest$ is the optimal extremum of the populations, x_i is the current position of the particle itself, C_1 and C_2 are the learning factors of individual experience and social experience, $rand_1$ and $rand_2$ are the random number in [0,1]. The meaning of the parameters and the set range are given in the literature [10].

3.3 KPSO

K-means algorithm has stronger local search ability, but the global searching ability is weak. The PSO algorithm's global searching is well, but the convergence speed is slow when the result is close to the optimal solution. So we combine K-means algorithm with PSO algorithm in the paper, playing their respective advantages. The main idea is: when each particle updates itself speed and position, it conducts clustering using K-means algorithm, and obtains a new clustering center, repeating iteration until the optimal clustering results are obtained.

The key step of KPSO is:
Step 1: *Setting the parameters*
Determining the sample set $X = \{x_1, x_2, \ldots, x_n\}$, the largest number of iterations, the number of clustering K and particles m, and the other parameters are the same as the PSO parameters. The number of clustering K is the same as the K-means in order to comparing the result of KPSO and K-means algorithm; each particle Z has K clustering center representing a feasible solution of the particles, namely $Z_i^j = \left(c_{i,1}^j, c_{i,2}^j, \ldots, c_{i,K}^j\right) \quad i = 1, 2, \ldots, m; \quad j$ is the iteration.

Step 2: *Initializing the particle velocity and position*
first, each particle randomly selects K value as the initial clustering center in the sample data, then classify the sample data according to the formula (3.2), and used (3.5) to calculate the clustering center Z_i^1. The fitness value $J_i^1(u, c)$ which is the initial optimal fitness value of each particle is got by the formula (3.4) and (3.11), and the initial global optimal fitness value is found by the formula (3.12).

$$Pbest_j = \min(J_i^{j-1}(u, c), j_i^j(u, c)) \quad (3.11)$$

$$Gbest_j = \min(J_i^j(u, c)), \quad (3.12)$$

where $i = 1, 2, \ldots, m; \quad j$ is the iteration.

Step 3: *Iterative generating a new particle swarm*
The speed and position of each particle is updated by the formula (3.8), (3.9) and (3.10). The K-means method is used to categorize the sample data according to the new location of the particles. Update the clustering center and the fitness value of each particle and then get the best fitness value $Pbest_j$ of each particle and the global fitness value $Gbest_j$ of all particles after iteration.

Step 4: *getting the optimal clustering center*
The global fitness value $Gbest_j$ of the particle swarm does not change after several iterations. The corresponding particle Z_i^j is the optimal location of the particle swarm and the corresponding clustering center is the optimal clustering center.

According to the clustering center gotten based on KPSO, the domain is divided into K sets, namely $U = (u_1, u_2, \ldots, u_K)$.

4 The Fuzzy Time Series Based on KPSO

Using the clustering results based on KPSO algorithm and the theory of the FTS modeling which Song put forward, we establish the FTS model based on KPSO.

Step 1: *Define fuzzy sets and fuzzy data*
Defining fuzzy sets A_k by triangle membership function. According to the character of the triangular membership function, the degree of the either side shows a trend of decline when the degree that x_i is affiliated to u_k is 1, we fuzzy the sample data using the method [12] where the data is dividing non uniform, keeping the membership degree of u_k on both sides shows a trend of decline always.

$$u_k(x_i) = \begin{cases} 1 & D_k \le x_i \le D_{k+1} \\ \frac{D_{\min}}{|D_{k+1}-x_i| + |x_i - D_k|} & \text{else} \end{cases} \tag{4.1}$$

where D is the boundary of the domain division, $D_1 = x_{\min} - \delta, D_2 = d_1, \ldots, D_{K+1} = x_{\max} + \delta, D_{\min} = \min(D_{k+1} - D_k)$. Finding the corresponding fuzzy sets $A_i \;\; i = 1, 2, \ldots, K$ where each sample data is affiliated to by the biggest membership degree principle.

Step 2: *Fuzzy relationship*
According to each of the above sample data affiliating to the corresponding fuzzy sets which are sorted by time sequence, establish fuzzy logic relationships $R_{i,j}$ between the two adjacent data:

$$R_{i,j} = A_i^T \times A_j \tag{4.2}$$

where A_i and A_j is the left-hand side and the right-hand side of the fuzzy logical relationship. "×" represents as an operator of taking minimum.

By all the relationships of the fuzzy relation matrix R:

$$R = \cup R_{i,j} \tag{4.3}$$

where "∪" is a operator taking the maximum of the matrix $R_{i,j}$.

Step 3: *Forecast and defuzzification*
Use the prediction rules of FTS which was put forward by Song, and establish a prediction formula:

$$F(t+1) = \frac{\lceil R(c_i :,) \rceil}{n} \times (m_1, m_2, \ldots, m_K)^T, \quad (4.4)$$

where $F(t+1)$ is the predictive value, m_k is the center of the fuzzy set u_k, $R(c_i :,)$ is the matrix row vector in the fuzzy logical relationship R, where the maximum membership degree of the corresponding fuzzy sets of observations is at the t moment. "$\lceil\rceil$" represents an operator taking down the whole, n is the number of the largest value in $\lceil R(c_i :,) \rceil$.

5 The Example Analysis

In order to verify the feasibility of the model, it used the 22 years of enrollment for experimental data of Alabama, and compared the predicted result of the fuzzy time series based on K-means algorithm and the KPSO. According to the above modeling steps, it can get two kinds results of each model, and then used the mean square error (MSE) to measure the prediction accuracy of the model.

$$\text{MSE} = \frac{1}{n} \sum\nolimits_{i=1}^{n} (x(t) - f(t))^2 \quad (5.1)$$

where $x(t)$ is the sample data, $f(t)$ is the predictive value.

As can be seen from the analysis of Table 1 and Fig. 1, the predicted results of the fuzzy time series model based on KPSO are better than the K-means, and is more closed to the real value. The MSE of KPSO models is less than K-means, so the feasibility and reliability of the model is verified in this paper.

Table 1 The predictive results of the two models

Time	The real value	K-means	KPSO	Time	The real value	K-means	KPSO
1971	13,055	–	–	1982	15,861	16,313	15,606
1972	13,563	14,126	13,941	1983	15,984	16,313	16,174
1973	13,867	14,126	13,941	1984	16,388	16,313	16,174
1974	14,696	14,126	13,941	1985	16,807	17,364	17,431
1975	15,145	15,037	15,187	1986	16,859	18,056	17,431
1976	15,163	15,037	15,497	1987	16,919	18,056	17,431
1977	15,311	15,037	15,497	1988	18,150	18,056	17,431
1978	15,433	15,606	15,497	1989	18,876	18,748	19,205
1979	15,460	16,313	15,606	1990	18,970	18,748	19,205
1980	15,97	16,313	15,606	1991	19,328	18,748	19,205
1981	15,603	16,313	15,606	1992	19,337	18,748	19,205
				MSE	–	33,000	12,838

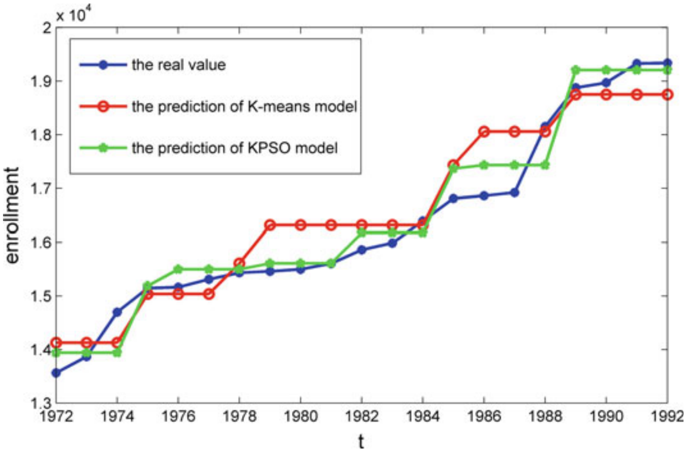

Fig. 1 The contrast figure of two model's prediction value

6 Conclusion

Sample data structure characteristic has important influence on forecasting results of FTS model. With the development of the intelligent optimization algorithms, the K-means algorithm and the particle swarm optimization algorithm are applied to divide the domain in this paper, making full use of the strong local search ability of K-means and global search capability of PSO, and overcoming the shortcomings that the K-means algorithm has strong reliance on the initial value at the same time, so we establish the fuzzy time series forecasting model based on KPSO. By comparing the MSE of the two model's predicted results of K-means and KPSO, it verifies the feasibility and effectiveness of the model in this paper.

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Investigation and Study on Habitability of a Certain Type Ship

Hanqing Cao, Chuan Wang, Jianguo Zhang, Wenhao Zhan and Fenzhou Shi

Abstract Habitability questionnaire was designed according to ship circumstance. 200 sailors who worked in two same type ships were chosen as investigation subject. The results showed that sailors subjectively regarded air quality, noise, and space as the key factors that could affect ship habitability. They thought odor, floating dust, noise, space of work area and habitation cabin odor, habitation cabin space, dishware cleanness, lavatorial odor, shower, communication of living quarters were unsatisfactory. The sailors' demand for illuminance improved markedly when they worked on sea for several years. While the demands for habitation cabin noise, personnel density and floating dust fluctuated as working time extended.

Keywords Habitability · Ship · Investigation · Subjective

The improvement of modern ship performance brought challenge to ship habitability that covered many factors [1–4]. Habitability must meet sailors' subjective feeling and will besides design parameters in national standards [5, 6]. In order to discuss the habitability of a certain type ship, we designed the questionnaire covering work area and living quarters [7]. 200 sailors who worked in two same type ships were chosen as investigation subject.

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1 Design of Investigation Questionnaire

The investigation questionnaire was designed mainly according to the potential ship habitability factors, covered subjective environmental conditions such as temperature, humidity, illuminance, ventilation, odor, electromagnetic radiation, noise, libration, floating dust, and other factors such as facility, amusement, medical care. Such factors could reflect the real situation of habitability of this type ship roundly. The sailors chose mark from 1 to 10 to every factor according to their subjective reflection from good to bad. 0–2 mark is very bad, 2–4 mark is bad, 4–6 mark is common, 6–8 mark is good, 8–10 mark is very good. The questionnaire also covered one other part in which the sailors listed six habitability factors that they thought most important and they ordered the factors based on essentiality (Fig. 1).

2 Results and Analysis

2.1 Overall Results Analysis

2.1.1 Work Area

The work area of ship covers cab, engine room and so on, the habitability of such areas mainly relates to subjective environmental conditions such as temperature, humidity, noise, and so on. The statistical result is showed in the graph below.

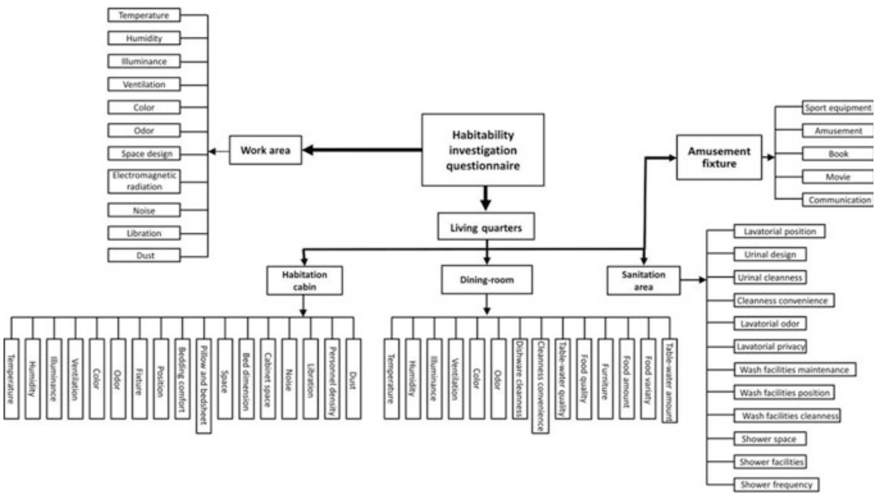

Fig. 1 Design of habitability investigation questionnaire

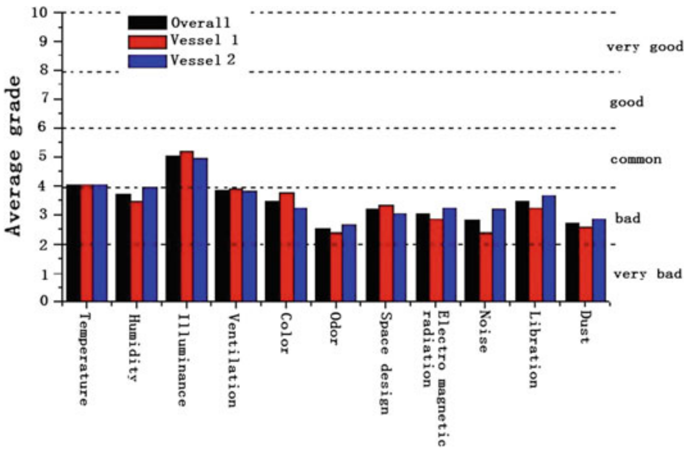

Fig. 2 Average marks of work area

In Fig. 2, we could see that the marks of all habitability factors are not so high on the whole due to the hard ship environment. The average marks of every factors in work area are calculated, the average marks of the same factors coming from sailors in different ships are different, but the overall trend is coincident. According to marks from high to low, the habitability factors could be ordered as illuminance, temperature, ventilation, humidity, color, libration, space design, electromagnetic radiation, noise, floating dust, odor.

The marks of odor, floating dust, noise are 2.505, 2.697, 2.768, respectively, all are lower than 3 points and their ranks are bad. The three factors get the lowest marks in all work area factors. And the marks of temperature and illuminance are 4.030, 5.056, respectively, their ranks are common. 41.7 and 51.8 % sailors identify with the choice, respectively. In addition, the marks of humidity, ventilation, color, space design, electromagnetic radiation, libration are between 3 and 4 points, their ranks are also bad. It means that such factors have limited effect on sailors subjectively, but the actuality could not meet the sailors' demand totally.

2.1.2 Living Quarters

Except working time, sailors spend most of their time in living quarters. The activities include sleep, dinner, amusement, cleanness, and so on. Each activity focuses on different factors, in order to distinguish characters of each activity, the part is divided into four segments, they are habitation cabin, dining room, sanitation area, and amusement fixture (Fig. 3).

According to the marks of living quarters, it could see that sailors give relatively high marks to temperature, humidity, illuminance, libration, all their marks are over 4 points and their ranks are common. While the marks of odor, habitation cabin

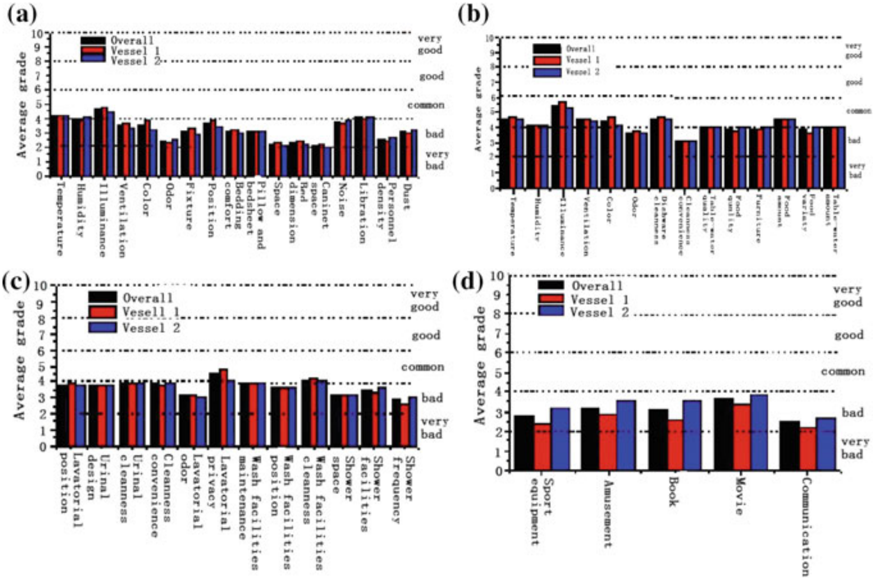

Fig. 3 Average marks of living quarters. **a** Habitation cabin, **b** dining room, **c** satination area, **d** amusement fixture

space, bed dimension, cabinet space, personnel density are 2.424, 2.197, 2.293, 2.126, 2.525, respectively, not more than 3 points and their marks are the lowest in all living quarters factors. The five factors above could be divided into two groups. The first one is odor, just as work area, sailors think the odor of habitation cabin is intolerance. The investigation shows that the odor mainly comes from body. The other four factors could be classified as the second group, which all have something to do with habitation cabin space. Bed dimension is small, cabinet space is little, personnel density is big due to the small habitation cabin space in ship. The lower marks reflect the sailors' dissatisfaction to the four factors markedly.

Among factors of dining room, sailors give lower marks to quality of food and table water, food variety. The percentages of bad rank are 27.692, 38.974, and 35.897 %. The results could attribute to the lack of fresh vegetable when they work on sea for a long period. The mark of dining room odor is higher than work area and habitation cabin, but the percentage of bad rank still accounts for 37.436 %, it is a little higher than common rank which accounts for 33.333 %. The most dissatisfactory factors in dining room are dishware cleanness and the percentages of bad and very bad rank account for 38.462 and 37.436 %, respectively. The result could attribute to the two reasons below, one is the lack of water in ship, the dishware could not be cleaned using a large amount of water. The other reason is that the space in ship is relatively small and there is no independent dishware cleanness area. The cleanness is carried out on the dining table or on the floor and the treatment of sewage is difficult.

In sanitation area, the habitability factors mainly focus on lavatory, washroom, or bathroom. Lavatorial odor got the lowest mark in all lavatorial habitability factors and the percentages of bad and very bad rank account for 31.633 and 40.816 %. During investigation on the spot, we found that there are special purifiers in lavatory, but the lavatorial airtightness is not good enough to avoid the lavatorial odor to diffuse, so the air quality of lavatorial ambient environment is not so good. The evaluation to wash facilities is not so good, especially to its position design, the percentages of very bad, bad, and common rank account for 29.082, 33.673, 33.673 %, respectively. We found that too little amount of wash facilities and unreasonable position design made sailors' personal cleanness difficult, they are the main reason that sailors are dissatisfied to washroom. Factors about shower are the most serious problem in the sanitation area. The space, facilities, frequency of shower are all dissatisfied, the percentage of very bad rank are 36.224, 31.122, 48.469 % and that of bad are 39.800, 35.204, 32.653 %, all of them are above 30 %. The lack of freshwater and the faultiness of shower facilities design lead to the result.

Among amusement fixture factors, the communication is the most dissatisfied one. During a long period sea life, some proper amusement facilities and communication with outside could prevent sailors from mental disease and extreme character.

2.2 Subjective Sort of Habitability Factors

In subjective sort, sailors list 19 factors that they think affect ship habitability most, they are air quality, noise, space, electromagnetic radiation, temperature, humidity, floating dust, personnel density, and so on. In order to make the data direct viewing, we give different factors different points based on sort. For example, when sort is 1 its point is 6, when sort is 2 its point is 5 and the like. According to this rule, we can get the graph below.

In Fig. 4, the factors could be divided into three groups clearly. The first group is air quality, noise and space, their points are 661, 537, 706, all are above 500. In Sect. 2.1, sailors give lower marks to air quality of work area and living quarters, noise of work area and space of habitation cabin. The result of subjective sort agrees with that of subjective mark. The second group are temperature, humidity, personnel density, food, whose points are 221, 179, 143, 101, respectively. Sailors are dissatisfied with temperature and humidity because the difference between different cabin is too big. When sailors enter into a new area, they could feel obvious temperature change, and they need some time to adapt to the change. When sailors enter into different cabins continually, they have no time to adapt their bodies to the change so they feel uncomfortable. The third group

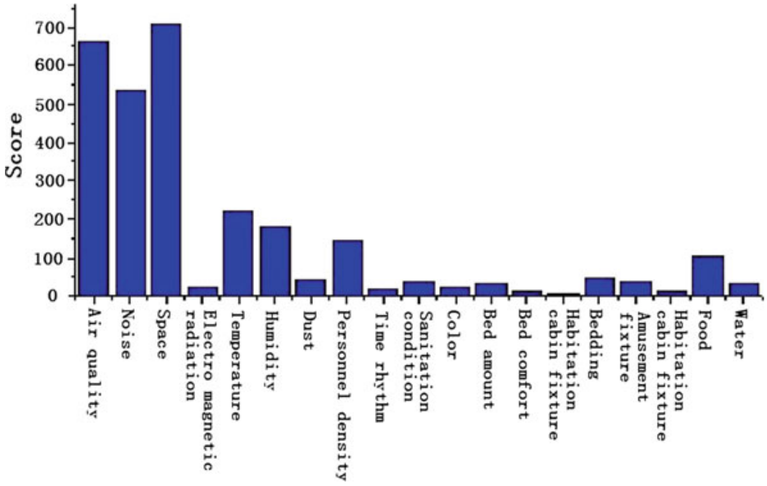

Fig. 4 Scores of subjective sort

covers the factors whose points are below 100, such as electromagnetic radiation, timetable, sanitation condition, and so on. They have some effect on habitability, but are not decisive.

2.3 *Effect of Sea Working Years on Marks*

As the sea working years extends, changes of both sailors' physiology and psychology will appear so their demand for habitability will change. All the sailors are divided into four groups based on their sea working years, 1–5 years is group 1, 6–10 years is group 2, 11–15 years is group 3, more than 16 is group 4. The differences intragroup and intergroup are compared through analysis of variance.

2.3.1 Work Area

In Fig. 5, it shows that sailors of different sea working years have similar opinions to most of habitability factors and their grade to same factors is close except group 4. All marks of group 4 are lower than that of other three groups, especially illuminance, color, and floating dust. In order to ascertain the difference, we carry out intragroup analysis of variance. The result shows that difference *P* of illuminance is $0.046 < 0.05$, it means there is obvious difference. Further, intergroup analysis of variance is carried out. The result shows that the difference exists between group 2 and group 3, group 4, their average marks are 5.490, 4.375 and 4.111, respectively. The result implies that sailors need better illuminance condition when they work on sea for a longer time (Tables 1 and 2).

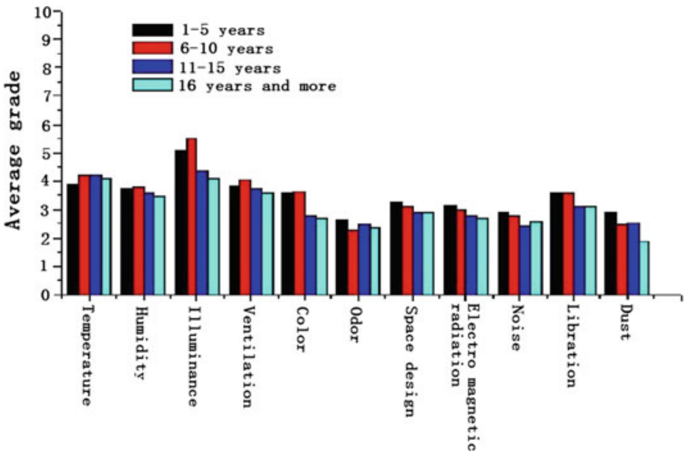

Fig. 5 Work area average marks from sailors working on sea in different years

Table 1 *P*-values of intragroup analysis of variance of work area habitability factors

	Temperature	Humidity	Illuminance	Ventilation	Color	Odor
P	0.791	0.956	**0.046**	0.861	0.098	0.569
	Space design	Electromagnetic radiation	Noise	Libration	Dust	
P	0.730	0.673	0.648	0.628	0.162	

Table 2 *P* values of intergroup analysis of variance of work area illuminance

	Group 1	Group 1	Group 1	Group 2	Group 2	Group 3
	Group 2	Group 3	Group 4	Group 3	Group 4	Group 4
P	0.090	0.182	0.204	**0.018**	**0.044**	0.720

2.3.2 Living Quarters

Based on the average marks and intragroup analysis of variance data, it could see that sailors in different groups have close opinion to most of living quarters habitability factors. But there are obvious differences in habitation cabin illuminance, odor, fixture, noise, floating dust, and personnel density. Intragroup significance values P of the six factors are 0.008, 0.025, 0.039, 0.001, 0.017, 0.013. Further, intergroup analysis of variance is carried out. Just like work area, the average mark of group 4 is lower than other three groups obviously, that means sailors working on sea for a longer time need better illuminance condition. And the same situation happens to fixture. In addition, the marks of noise, personnel density and floating dust fluctuate as sea working years extend. The trend is high-low-high-low. The interesting result implies that sailors' feeling and psychology would change in different working periods. And the specific reason needs to be verified further (Tables 3 and 4; Fig. 6).

Table 3 *P* values of intragroup analysis of variance of living quarters habitability factors

	Habitation cabin temperature	Habitation cabin humidity	Habitation cabin illuminance	Habitation cabin ventilation	Habitation cabin color	Habitation cabin odor
P	0.547	0.760	**0.008**	0.602	0.112	**0.025**
	Habitation cabin fixture	Habitation cabin position	Bedding comfort	Pillow and bedsheet	Space	Bed dimension
P	**0.039**	0.484	0.802	0.895	0.255	0.508
	Cabinet space	Habitation cabin noise	Habitation cabin libration	Personnel density	Habitation cabin dust	Dining room temperature
P	0.277	**0.001**	0.178	**0.017**	**0.013**	0.442
	Dining room humidity	Dining room illuminance	Dining room ventilation	Dining room color	Dining room odor	Dishware cleanness
P	0.217	0.970	0.389	0.542	0.236	0.746
	Cleanness convenience	Table water quality	Food quality	Furniture	Food amount	Food variety
P	0.299	0.389	0.290	0.679	0.759	0.420
	Table water amount	Lavatorial position	Urinal design	Urinal cleanness	Cleanness convenience	Lavatorial odor
P	0.866	0.270	0.427	0.543	0.428	0.215
	Lavatorial privacy	Wash facilities maintenance	Wash facilities position	Wash facilities cleanness	Shower space	Shower facilities
P	0.472	0.762	0.130	0.283	0.866	0.488
	Shower frequency	Sport equipment	Amusement	Book	Movie	Communication
P	0.262	0.465	0.809	0.422	0.901	0.659

Table 4 *P*-values of intergroup analysis of variance of living quarters six factors

Group comparison		*P*					
		Habitation cabin illuminance	Habitation cabin odor	Habitation cabin fixture	Habitation cabin noise	Personnel density	Habitation cabin dust
Group1	Group2	0.860	**0.008**	0.127	**0.010**	**0.023**	**0.010**
Group1	Group3	0.938	0.506	0.763	0.317	0.675	0.722
Group1	Group4	**0.001**	0.059	**0.008**	**0.006**	**0.023**	**0.037**
Group2	Group3	0.960	0.214	0.438	**0.008**	0.052	**0.036**
Group2	Group4	**0.001**	0.583	0.066	0.148	0.263	0.430
Group3	Group4	**0.003**	0.196	**0.029**	**0.003**	**0.024**	**0.040**

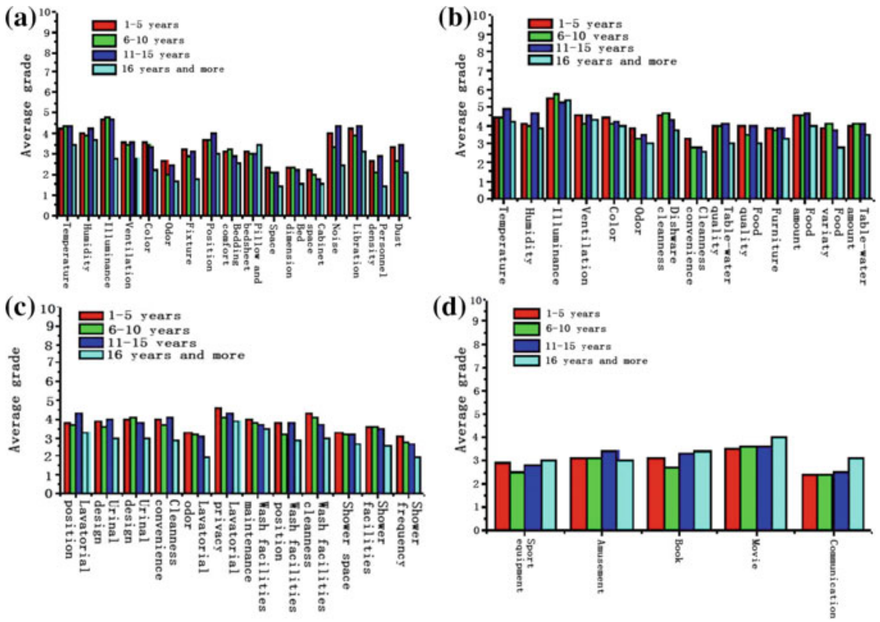

Fig. 6 Living quarters average marks from sailors working on sea in different years. **a** Habitation area, **b** dining-room, **c** satination area, **d** amusement fixture

3 Conclusion

Through the analysis of investigation questionnaire, it could be summarized as follows:

1. All marks of sailors to habitability factors are not high due to hard environment condition, especially they are not satisfied with odor, floating dust, noise of work area and habitation cabin odor, habitation cabin space, dishware cleanness, lavatorial odor, shower, communication of living quarters.

2. Sailors list air quality, noise, and space as the main habitability factors subjectively.
3. The demand of sailors for habitability will improve as sea working years extend, especially for illuminance. The demand for habitation cabin noise, personnel density, and floating dust would fluctuate as time changes.

4 Compliance with Ethical Standards

The study was approved by the Logistics Department for Civilian Ethics Committee of Naval Medical Research Institute.

All subjects who participated in the experiment were provided with and signed an informed consent form.

All relevant ethical safeguards have been met with regard to subject protection.

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A Method of Screening the Control Points of Road Stereo Image Based on RANSAC and Uniformity Theory

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Abstract To screen control points of stereo images is the key technology of stereo image localization and navigation. Due to the complexity of the background of road stereo images, the reliability and uniformity of feature points got by SIFT algorithm is too poor to be directly used for the next step of mobile measurement, localization, and navigation. A control points screening method based on random sample consensus (RANSAC) and uniformity theory is proposed, the uniformity is introduced into the evaluation criterion of RANSAC algorithm, which makes the distribution of the control points more uniform. Experimental results show that stable, accurate, and uniformly distributed control points of the road stereo image can be obtained by the method.

Keywords Stereo image · SIFT · RANSAC · Uniformity theory · Control points

1 Introduction

Mobile digital close range photogrammetry, a rapid measurement of new technology based on multi-sensor fusion, is developed rapidly with the computer processing power upgrade in nearly 30 years [1–4]. The autonomous localization technology is a fundamental problem in mobile measurement [5, 6]. In recent years, scholars have applied the digital measurable image (DMI) to the autonomous localization, by using the abundant information in DMI, the position coordinates of the moving carrier is calculated based on the Space Resection. SIFT algorithm is used for feature extraction of the DMI, but there is no effective analysis and screening method to get control points.

Control points are feature points which are not affected by light, deformation, angle, and other impacts and are stable, accurate, and uniform distribution. Screening of control points is the premise of image mosaic, vehicle localization,

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which has been widely studied in the field of automatic registration and remote sensing image [7, 8].

Compare with remote sensing images, the background of the road stereo images are much more complex, so the control points are harder to determine. In this paper, based on the SIFT feature points of road stereo images, a control points screening method based on RANSAC and uniformity theory is proposed, which ensures the uniformity and accuracy of the selected feature points. Experimental results show that the method can extract stable, accurate, and distributed control points from road stereo images.

2 Related Theories

2.1 SIFT Algorithm

SIFT algorithm is a feature detection method based on invariant technique proposed by Lowe David in 1999. After further research and improvement, in 2004, a method is proposed based on the scale space, which is invariant to image translation, rotation, zoom, and affine transformation. The feature extraction algorithm is divided into four steps

(1) Detection of scale-space extreme value. Image sequences obtained at multiple scales, which are the Gauss Pyramid, as shown in the formula (2.1).

$$L(x, y, \sigma) = G(x, y, \sigma) * I(x, y) \tag{2.1}$$

G is the scale factor for the Gauss kernel, I is the original image, L is the scale-space representation of I.

The DOG Pyramid is constructed by subtraction of the adjacent scale-space function in Gauss Pyramid, as shown in (2.2)

$$D(x, y, \sigma) = L(x, y, k\sigma) - L(x, y, \sigma) \tag{2.2}$$

Each pixel in DOG Pyramid is compared with 26 neighboring pixels.

(2) Precise determination of key points. The location and scale of the key points is accurately determined through Tri Quadric Spline Function fitting.
(3) Determination of main direction of the feature points. The gradient value $M(x, y)$ and direction $\theta(x, y)$ rat the feature points (x, y) are as follows:

$$m(x, y) = \sqrt{(L(x+1, y) - L(x-1, y))^2 + (L(x, y+1) - L(x, y-1))^2} \tag{2.3}$$

$$\theta(x,y) = \text{atan}\left(\frac{L(x,y+1) - L(x,y-1)}{L(x+1,y) - L(x-1,y)}\right) \tag{2.4}$$

So, a feature point has three attributes: location, location, and direction.

(4) Generation the SIFT feature descriptor. In order to enhance the robustness of feature points, each key point is described by 4×4 seed points, and each seed point contains eight directions. So, each feature point is described by a vector of $4 \times 4 \times 8 = 128$.

2.2 RANSAC Algorithm

There is a certain number of false matching pairs in the results of SIFT feature points matching between two images, even after the anti-noise, anti-curvature changes in the layers of screening. At present, the widely used method is to use RANSAC, which is proposed by Fishchler in 1981. The main idea is: In the matched point set S, s points are randomly selected as the sample points, and then the model is constructed. A set of S_i metric is composed based on an interior point in a certain distance threshold T. When the number of points within the set S_i is less than the threshold value T, there are more out points (outliers). A new set of sample points were selected after several repeatedly. After N experiments the largest set of S_i is selected, which composed the consistent set, and then re-estimate the model with all the internal points of S_i.

The characteristic of RANSAC is that the parameters of the model will be improved gradually with the increase in the number of iterations.

2.3 Uniformity Theory

Definition 1 Monopolized ball: Suppose s is the largest countable set of n-dimensional Euclidean space, for any $x \in s$, $M(x) = \min(d(x,y))$, $y \in s$, then exist $x_1 \in s$, which make $M(x) = d(x,x_1)$, $MP(x) = x_1$, which calls adjoining neighbor, $M(x)$ is the distance of the adjoining neighbor. The closed ball $B(x)$, which has the center of x and the radius of $M(x)/2$; is called the monopolized ball of x, in which volume is denoted as $v(x)$. There are an unlimited number of externally tangent closed tubes of $B(x)$, and each has the same volume, one of them is marked as $CU(x)$, which calls monopolized ball, the volume of which is $vc(x)$.

Lemma 1 *Each monopolized ball is non-overlapping in certain boundary point set and their recent spatial relations are tangent.*

Definition 2 Uniformity Suppose pt: $S \subset A \subset R^n$ is a pattern, there are k points in s. $a = \sum_{i=1}^{k} v_i(x)$ is marked as the total volume of the monopolized ball, and $A_v = V^*(A)$ is marked as the volume of the polyhedron, then $L(k) = \sum_{i=1}^{k} vc(x_i)/A_v$ is called the Uniformity of the pattern S.

The uniformity of the two dimensions can be defined as

In the rectangular, the uniformity of a pattern is the ratio of the total area of monopolized circle to the area of rectangular of $\pi/4$ times.

Let a be the total area of monopolized circle, A is a rectangular area, and then $L = \frac{4\mathrm{a}}{\pi\mathrm{A}}$ is the pattern uniformity.

Uniformity of L has the ability to describe the uniformity, which is consistent with human intuition. Uniformity is the degree of separation, which is a general description of the interior point of a finite set. It is more uniform as the value of uniformity more big and vice versa.

3 Method of Screening the Control Point of Road Stereo Image Based on the RANSAC and Uniformity Theory

This method consists of four steps: (1) SIFT algorithm is used to extract the feature points of road stereo image. (2) The preliminary selection of the feature points based on the regional homogeneity. (3) Feature points matching for stereo image pair. (4) Screening of the matching points with RANSAC and uniformity theory.

3.1 SIFT Feature Point Extraction

The background of the road in stereo image is complex, so the control points are always faded into the background noise. So, it is necessary to filter out the stability, accuracy and uniform distribution feature points, which is the premise and difficulty of further research and application of road stereo image. SIFT algorithm is a feature detection method based on the scale space, which is invariant to image translation, rotation, zoom, and affine transformation, and is more suitable for road stereo image compared with the edge, corner, shape, and other features.

3.2 The Initial Screening of the Feature Points Based on Regional Uniformity

Regional uniformity is the uniformity of a particular area in the image. Let $a(x, y)$ be the coordinates of a certain SIFT feature point of the image and t is a threshold of uniformity. Then, the initial screening of the feature points based on regional uniformity consists of four steps

(1) A square is formed with $a(x, y)$ as the center, which width is 41 pixels.
(2) The uniformity of the SIFT feature points in the square is calculated.
(3) When the uniformity is less than t, the least gradient peak in the square are removed.
(4) Repeat (2) and (3) until the uniformity of the square is greater than or equal to t, t is set to 0.28.

Through the above steps, a large number of SIFT feature points, which meet the set of uniform degree, and have a large gradient peak is screened out.

3.3 Feature Point Matching of Stereo Image Pair

After extracting and screening SIFT feature points of the stereo image, it is needed to match feature points between the left image and right image, so that the points of the same name is found.

Given the SIFT feature points in the left, nearest neighbor (NN) and the second nearest neighbor (SCN) feature points in the right are found using the *k*-d tree search strategy. If NN distance/SCN distance is less than a threshold then accept this pair of matching points; the lower the threshold, the less SIFT matching points, the more stable the matching. But the stability of the price is the loss of a large number of effective feature points, so the threshold value is much critical. According to the literature and a large number of experiments, the threshold of the [0.6, 0.7] range is the most suitable.

3.4 Feature Point Screening Based on RANSAC and Uniformity

SIFT feature point screening method based on RANSAC algorithm is widely used in image mosaic, image registration and other aspects. Judgment condition of RANSAC mainly depends on the size of the matching points of the model, and the distribution of these matching points is ignored, so it is only suitable for the image of more uniform distribution, but is invalid to the image with uneven distribution of feature points. The background of the road in stereo image is complex, so the control points are always faded into the background noise. The reliability and uniformity of the feature points obtained by the SIFT algorithm are poor. So, it is less effective to use the RANSAC algorithm directly.

In this paper, the uniformity theory is introduced into RANSAC, the product of the number of matching points and the uniformity of the point set are used as evaluation criteria, so that the screening results is not only satisfy the geometric consistency, but also meet the uniformity of the feature points, the basic steps are as follows:

(1) To obtain the total number of M of matching point pairs in 3.3. According to $N = \log(1 - p_n)/\log[1 - (1 - a)^m$, the random sampling times N is confirmed, in which, p_n = 0.95, m = 4, a is the error rate.
(2) Using random selection of four pairs of matching points to calculate the initial homography matrix.
(3) Set constraint conditions: the satisfactions are interior points, others are outlier points. Constraint condition setting method is as follows: (a) The matching points in the left image are transformed by homography matrix; (b) The Euclidean distances are calculated, which are between the transformed matching points and the matching points in the right image; (c) the distance d is the constraint conditions, d > 4 for the outer points, d ≤4 for the inner points.
(4) Calculating the uniformity of the interior point set L, mark the product between number c and uniformity as $R = cL$. When R is greater than or equal to the set threshold value, re-estimate the homography matrix using the interior point number, and end the current round of operation. If R of the interior point set is less than the threshold value, re-select data samples in the data set, and repeat steps (2), (3), and (4).
(5) After N times of iteration, N interior points sets are obtained. Select the inner point set with the maximum R value. End of algorithm.

4 Experiments and Analysis

Experiments are carried out on the SIFT feature extraction at first, then results of the proposed method and the traditional RANSAC algorithm are compared.

Figure 1 shows four results of stereo image matching points in Field Road. (a) shows a direct matching of SIFT feature points, which number is 79. (b) is the matching results of SIFT feature points after regional uniformity, which number is 48. (c) is the screening results of (a) using the RANSAC algorithm, the number of the matching points is 17. (d) is the screening results of (b) using the method proposed by this paper, the number of the matching points is 15. Generally speaking, matching points in (c) are grouped in two pieces of regions, and the uniformity degree is poor. While in (d), there is a significant improvement in the distribution of the matching points.

Figure 2 shows four results of stereo image matching points in Country Road. (a) shows a direct matching of SIFT feature points, which number is 204. (b) is the

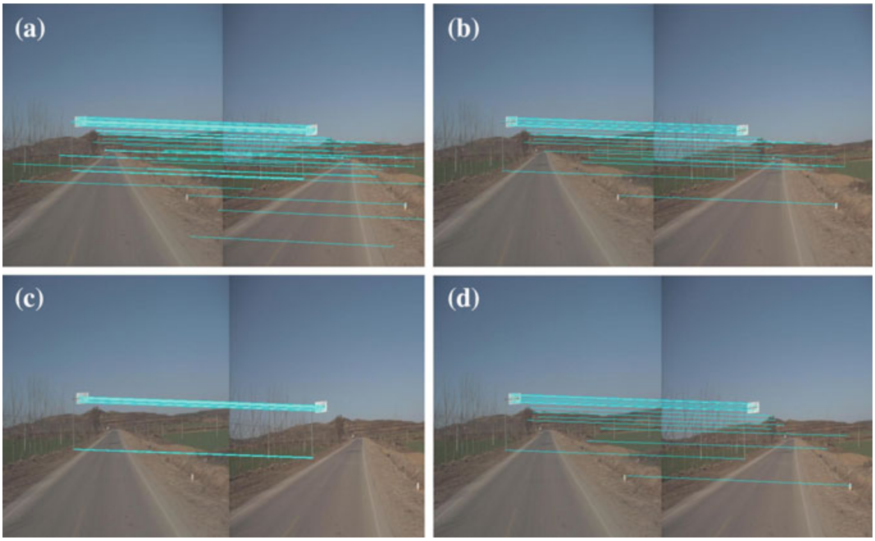

Fig. 1 Comparison of stereo image matching points in field road. **a** SIFT feature point matching **b** SIFT feature point matching after regional **c** RANSAC screening for matching point **d** method proposed in this paper

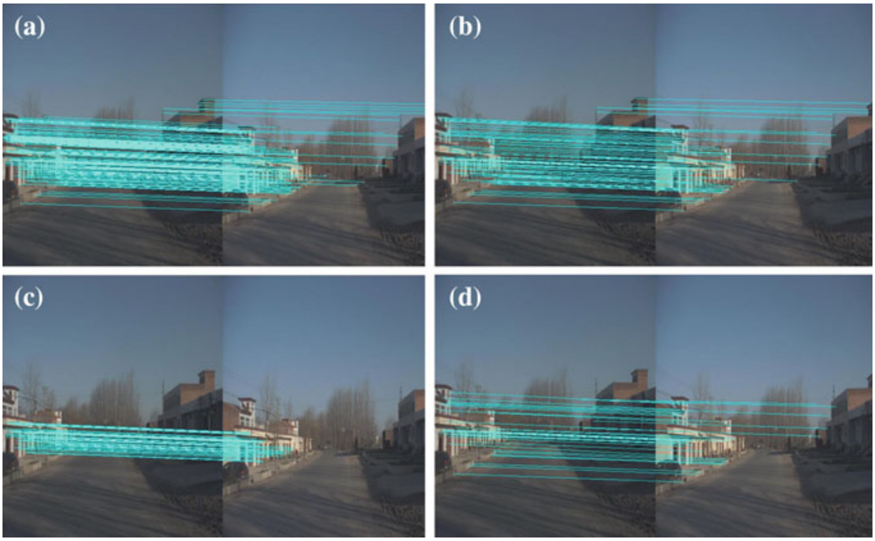

Fig. 2 Comparison of stereo image matching points in country road **a** SIFT feature point matching **b** SIFT feature point matching after regional **c** RANSAC screening for matching point **d** method proposed in this paper

Table 1 Comparison of control point screening result

Stereo image	Method	Number of the matching points	Correct rate of matching	Control points screened	Correct rate of matching	Distribution uniformity of control points
Field road	RANSAC-SIFT	79	0.87	17	1	0.01
	Method proposed	48	0.92	15	1	0.35
Country road	RANSAC-SIFT	204	0.86	64	1	0.02
	Method proposed	82	0.90	85	1	0.28

matching results of SIFT feature points after regional uniformity, which number is 82. (c) is the screening results of (a) using the RANSAC algorithm, the number of the matching points is 64. (d) is the screening results of (b) using the method proposed by this paper, the number of the matching points is 35. Generally speaking, matching points in (c) are so grouped that the uniformity degree is poor. While in (d), there is a significant improvement in the distribution of the matching points.

Table 1 compares the results of traditional RANSAC-SIFT method with the results of method in this paper, it can be seen that, for the two types of images, matching points are significantly reduced, and the matching accuracy is significantly improved after regional uniformity. The matching correct rate is up to 1, and the uniformity of the matching point distribution is greatly improved when the method proposed is used. In conclusion, this method, comparing with RANSAC-SIFT, is a more effective way of stereo image feature extraction and selection.

5 Conclusions

Road stereo image is a kind of digital measurable image (DMI); Vehicle location and navigation technology based on DMI is the frontier and trend in the field of mobile measurement. In which, screening of stereo image control points is difficult and critical. Control points are feature points with accurate and stable capability and are uniformly distributed; there is no report on the screening technology of stereo image control point at present.

In this paper, the SIFT algorithm, RANSAC algorithm, and the theory of uniformity are combined with, the uniformity theory is introduced into the RANSAC-SIFT process, and a whole set of method for the selection of the control points of road stereo image is proposed. The experiment results show that this method can obtain accurate, stable, and distributed control points which lays foundation of researches of stereo image matching, Kalman estimation of motion locus of control point, vehicle autonomous positioning, and navigation.

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The Research of Application of Noncontact ECG Detection System in Manned Spaceflight

Lin Zhang, Guangjie Zhai, Hong Yan, Zhi Xu, Zhonggang Liang and Jinzhong Song

Abstract To solve the defects of ECG detecting with wet electrode in manned spaceflight, including skin allergy, complex operation, and conductive gel drying up, uncomfortableness and other issues, a noncontact ECG detection system with the capacitively coupled electrode was proposed in this paper. With this detection system, the ECG acquisition experiments in spaceflight medical monitoring state were carried out. And the comparison experiments of the waveform morphology similarity between this detection system and wet electrode detection system were carried out. The results show that this system can realize the clear detection of the P wave, QRS wave, and T wave of the space lead, compared with the ECG signal from wet electrode, the waveform morphology similarity is >95 %, which meet the quality requirements of ECG waveform of the space doctors.

Keywords Capacitively coupled electrode · Noncontact ECG detection system · Manned space flight

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1 Preface

When astronauts perform manned space flight mission, the cardiovascular system will have a series of adaptive changes and spacemotion sickness may be caused. These adaptive changes of cardiovascular system mostly can be reflected in the ECG signal of astronauts. Therefore, the monitoring of ECG signal will run through the whole process of manned spaceflight.

At present, in the field of manned spaceflight in China, the acquisition of ECG signal is conducted by bonded wet electrode. This electrode needs to use conductive paste to ensure the good resistance contact between skin and electrode. In the special environment of manned spaceflight, its application has some defects [1].

First, the conductive paste applied between electrode and skin can only maintain about 24-h good contact. When needing longer time to detect ECG signal, the conductive paste will dry so as to lead to the changes of contact resistance between electrode and skin, so the sensitivity and signal to noise ratio of ECG signal will reduce.

Second, when conductive paste transmits signals, due to the contact with skin for a long time, the chemical compound in it will penetrate to the skin and then cause some allergic reactions, such as pruritus, blister and other sickness.

Third, from the perspective of user–human, astronauts are not pleased with this electrode experience. First, using wet electrode needs to expose skin and then wear it after wiping the skin. Make preparations in the limited space of the aircraft. Astronauts are not the same sex, so it will bring inconvenience to the operation. The cold and slimy conductive paste will contact with the body directly and the cold metal contact surface will cover it. The complex operation and sticky conductive paste bring uncomfortableness for people, which make astronauts have potential inimical emotion to wearing electrode easily.

Fourth, in some special conditions, the changes of pressure environment of astronauts may lead to the disconnection of ECG electrode and skin, so the ECG data of astronauts cannot be obtained.

With the start of the construction of space station project and the development of deep space exploration, the monitoring time of ECG signal of astronauts in the medium and long-time manned flight will become longer and longer. Complex operation of bonded wet electrode and allergy and other problems will be more obvious. So it is urgent to find a more convenient and reliable ECG detection method.

As a new-type ECG sensor, capacitively coupled electrode can realize the noncontact detection of ECG signal. The noncontact ECG detection system established according to this can detect the ECG signals through clothes without contacting with skin directly. If this noncontact ECG detection method is applied to the manned spaceflight, on the one hand, astronauts do not need to take off their clothes, clean the skin and make other series of preparations, which is very convenient; on the other hand, noncontact with skin can reduce the uncomfortableness, completely eradicate skin allergy, reduce the inimical emotion and agitated emotions and improve the job morale and quality of astronauts.

At present, many researchers have established the ECG detection system using capacitively coupled electrode. This system can detect QRS wave stably to meet the needs of daily health care monitoring of heart rate and other ECG information extraction. The detection of P wave, T wave and some waveform details shall be improved [2]. In the initial experiment of capacitively coupled electrode by WRAIR, the best placement for electrode was mentioned, which was about 4 inches below the left and right nipples [3]. Some researchers proposed to put the electrode in the chest so that the detected signal quality can be comparable to the traditional wet electrode [4]. In the manned space flight in China, the acquisition of ECG signal with space lead is the basic constraint for ECG detection and analysis.

In this paper, with capacitively coupled noncontact ECG detection system, ECG signal acquisition experiments in the spaceflight medical monitoring state were carried out and clear detection of P wave, QRS wave and T wave was realized. And the comparison experiments of the waveform morphology similarity between this detection system and traditional bonded wet electrode detection system were carried out.

2 Construction of System

2.1 Capacitively Coupled Noncontact ECG Detection System

The difficulties in capacitively coupled noncontact ECG detection are: The signal is weaker and source impedance is high; It is interfered with electromagnetic field caused by AC conductors in the spacecraft easily; The influence of intrinsic noise of circuits [4]; It is easily affected by the artifacts caused by human body activities. The above factors affecting signals determine the technical requirements of system design: Input mode of signal amplifier shall be the differential method with enough high gain and quite low noise level; High input impedance and common mode rejection ratio; Electrode shall have a certain shielding and anti jamming abilities; Select components with low noise and low drift and conduct reasonable grounding as well as add decoupling capacitor at the power output end and so on. According to the above requirements, the composition diagram of capacitively coupled noncontact ECG detection system constructed in the experiments is shown in Fig. 1.

Capacitively coupled electrode uses active shield active electrode, as shown in Fig. 2. The bottom surface of electrode is inductive surface and the top layer is the impedance conversion and filter circuit. The electrical signals detected by the inductive surface of electrode shall first pass through the T-level pre-amplifier for impedance conversion and then for high-pass filtering. Then, signals from two approaches enter into the instrumentation amplifier for differential amplification and

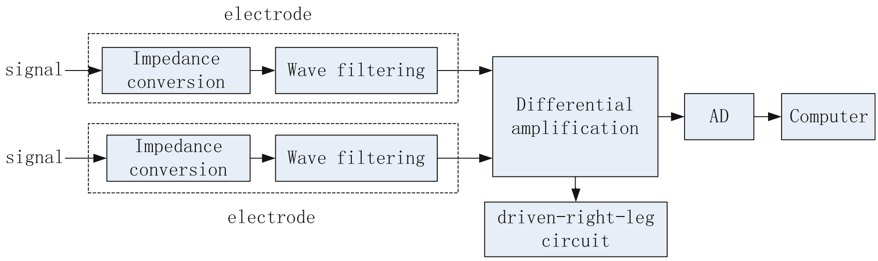

Fig. 1 System design

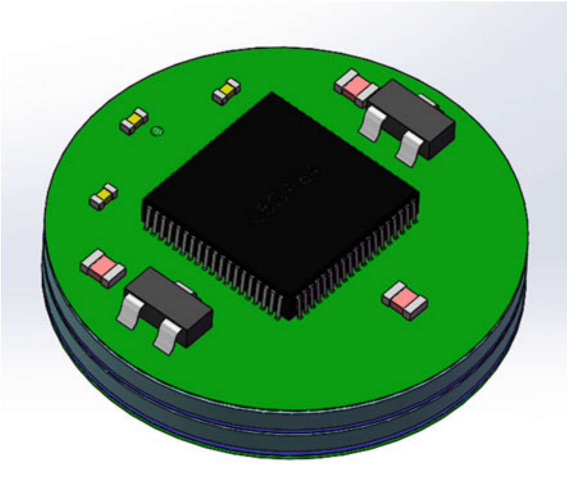

Fig. 2 Capacitively coupled electrode

the analog ECG signals obtained are sent to the AD conversion system for AD conversion. Then the signals are transmitted to the computer. The common mode signals are led out and then fed back to the body through drive electrode.

2.2 ECG Acquisition Experiment

2.2.1 Wearable Mode of Electrode

The underclothes of astronauts are cotton vests. Therefore, the electrode is placed in the human body through the cotton vest in the experiment. Chest axillary lead is one of the space leads. Positive pole of electrode is located on V5 of precordial lead and negative pole is located on the manubrium. In the experiment, the induction electrode is placed in the position of chest axillary lead. The elastic bandage is used for the wearing and fixing of ECG induction electrode. The elastic wrist strap is used to fix the drive electrode on the wrist directly.

2.2.2 ECG Acquisition Experiment

The subjects are in the normal laboratory without shield and sit quietly. The induction electrode is fixed on the chest axillary lead position through the cotton vest with elastic band. The drive electrode directly contacts with skin and is fixed on the left wrist with wrist strap. The ECG signals are collected by hardware system and then directly input into the computer for display.

2.2.3 ECG Comparison Experiment

In order to further verify the ECG signals collected by the capacitively coupled ECG detection method, the paper uses ECG detection system with traditional bonded wet electrode and capacitively coupled noncontact ECG detection system to collect ECG signals from subjects at the same time. The ECG signal detected by traditional wet electrode is referred to as RE-ECG (resistance ecg) and the signal detected by capacitively coupled electrode is referred to as CA-ECG (capacitance ecg). 10 control groups of ECG data are selected, respectively, from CA-ECG and RE-ECG and the duration of ECG data selected for comparison is 1 min.

In order to conduct quantitative analysis of waveform morphology similarity between RE-ECG and CA-ECG, this paper constructs electrocardio-correlation sequence for two sections of control ECG signals so that every element in the sequence is the description of waveform morphology similarity of cardiac beat corresponding to two sections of signals at the same time [5]. Two sections of RE-ECG and CA-ECG for comparison can construct the corresponding electrocardio-correlation sequence according to the following steps:

(1) As shown in Fig. 3, in RE-ECG, taking the peak point of R wave of the ith cardiac beat detected as the datum point, the distance from the datum point of the *i*th cardiac beat to the starting point of P wave is denoted as $C_{PR}(i)$ and the distance from the datum point to the ending point of T wave is denoted as $C_{RT}(i)$. (2) Taking the peak point of R wave of the ith cardiac beat in RE-ECG as the datum point, windowing to left and right. The left and right width is, respectively, $C_{PR}(i)$ and $C_{RT}(i)$. Extract the ith cardiac beat. Use the same method to extract all cardiac beats in RE-ECG. (3) In the corresponding CA-ECG, taking the peak point of R wave of the ith cardiac beat as the datum point, windowing to left and right. The left and right width is, respectively, $C_{PR}(i)$ and $C_{RT}(i)$. Extract the ith cardiac beat. Use the same method to extract all cardiac beats in CA-ECG. Calculate two cardiac beat sequences X and Y according to the standard calculation formula of correlation coefficient to obtain the correlation coefficient.

(4) Determine the correlation coefficient between the first cardia beat of RE-ECG and first cardiac beat of CA-ECG according to the above steps, denoted as $\rho(1)$; by

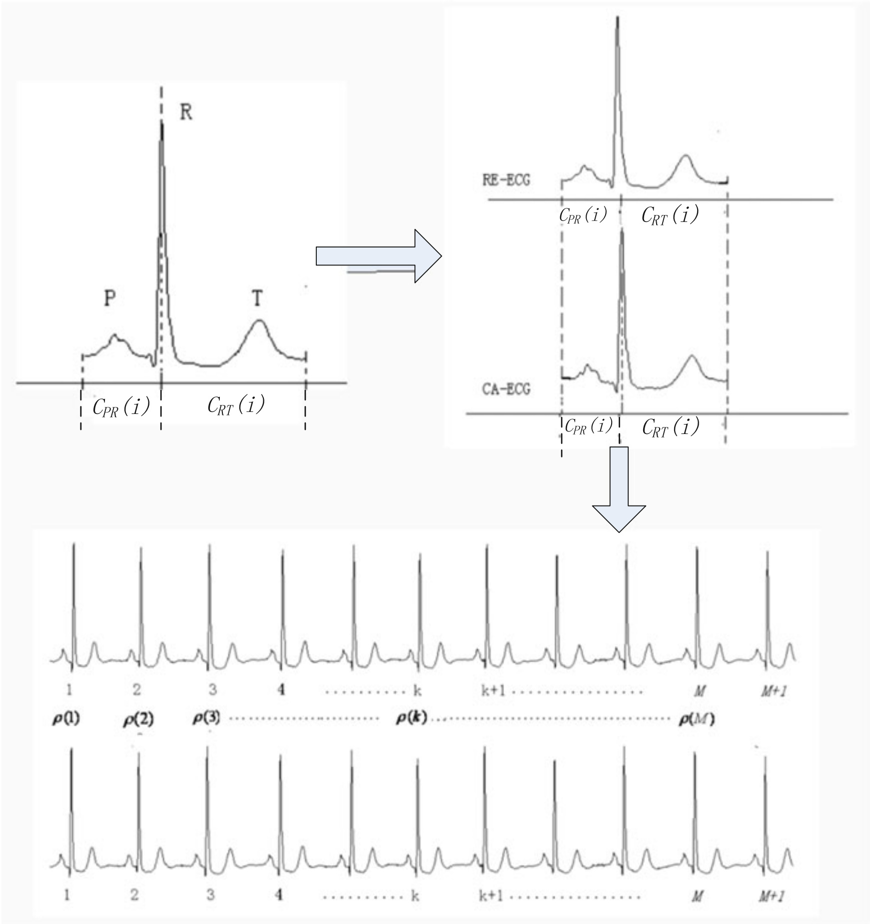

Fig. 3 Construciton of electrocardio-correlation sequence

such analogy, the correlation coefficient of the kth cardiac beat can be calculated, denoted as $\rho(k)$. If the number of complete cardiac cycles included in the ECG signals in this period is $M + 1$, the electrocardio-correlation sequence of this ECG signals is denoted as $\rho(k), (k = 1, 2, 3.\ldots.M)$.

When some point $\rho(k)$ in the electrocardio-correlation sequence is closer to 1, it shows that morphology similarity of the kth cardiac beat is higher; when $\rho(k)$ is smaller, it shows that morphology similarity of the kth cardiac beat is lower.

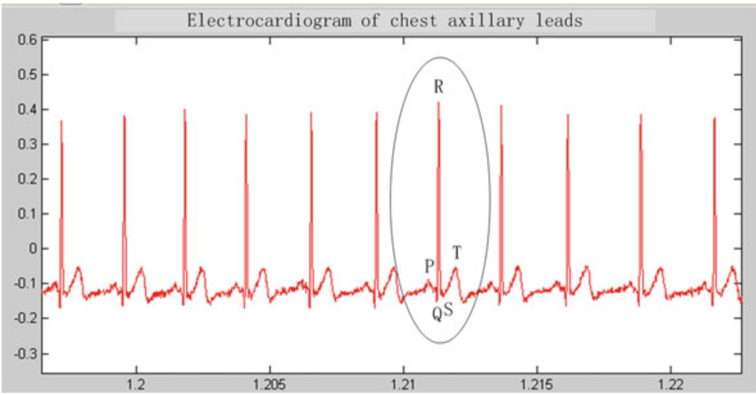

Fig. 4 Electrocardiogram signal

3 Experimental Results

3.1 ECG Acquisition Experimental Results

ECG signal collected with capacitively coupled noncontact ECG detection system is shown in Fig. 4. ECG waveform conforms to the ECG waveform characteristics of spaceflight chest axillary lead. P wave, QRS wave and T wave of ECG signal can be identified clearly.

3.2 Comparison Experimental Results of ECG Signal

Figure 5 shows a set of the control chart of CA-ECG and RE-ECG after filtering. We can see visually that the waveform details of ECG signal collected from CA-ECG and RE-ECG at the same time are very similar and P, QRS and T waves of ECG signal are collected completely. Calculate electrocardio-correlation sequence of two sections of signals and then we can see that the correlation coefficient of two-two corresponding cardiac beat is above 0.95. After calculation, the mean value of electrocardio-correlation sequence of these two sections of signals is 0.98. So the morphology of CA-ECG and RE-ECG is very similar.

Calculate the correlation coefficient of corresponding cardiac beat of CA-ECG and RE-ECG in 10 control groups to form 10 electrocardio-correlation sequences. Calculate the mean value of electrocardio-correlation sequence array and the results are shown in Table 1.

The mean value of electrocardio-correlation sequence of ten control groups is more than 0.95. Obviously, CA-ECG and RE-ECG have higher morphology similarity.

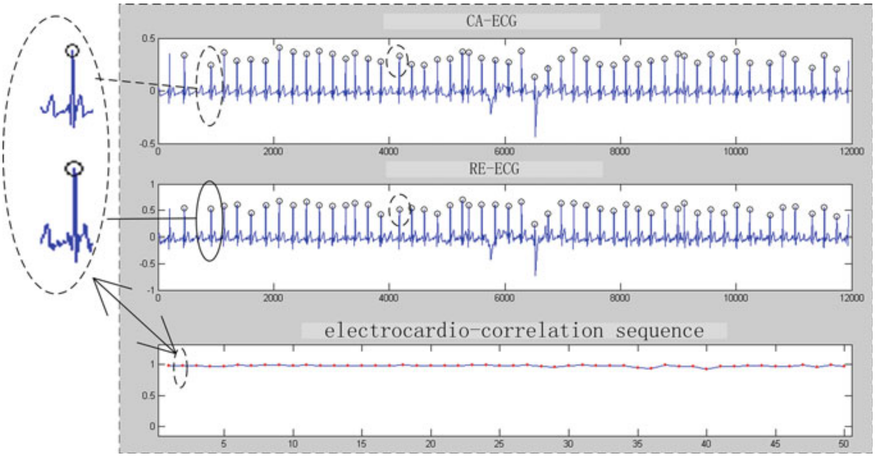

Fig. 5 Electrocardio-correlation sequence of RE-ECG and CA-ECG

Table 1 Mean value of electrocardio-correlation sequence

NO.	1	2	3	4	5
Mean	0.95077	0.95312	0.95714	0.95939	0.95931
NO.	6	7	8	9	10
Mean	0.96953	0.9724	0.9723	0.95616	0.9727

4 Conclusion

ECG acquisition experiment was carried out through the established capacitively coupled noncontact ECG detection system in this paper to prove that this system can realize clear detection of P wave, QRS wave and T wave of ECG signal of spaceflight chest axillary lead. Compared with ECG signal collected by detection system with bonded wet electrode, the waveform morphology similarity of ECG signal collected by two methods is up to over 95 %, which have high morphology similarity.

Space doctors have two methods to monitor ECG information. One is to directly observe ECG waveform and observe, interpret and judge the ECG waveform morphology depending on the professional medical knowledge. The other is to view the automatic processing results of ECG signal from ECG analysis software. According to the experimental results of this paper, the ECG signal collected by capacitively coupled noncontact ECG detection system can meet the demand for direct observation of ECG waveform of space doctor. Whether the automatic processing results of ECG signal from ECG analysis software is in line with the processing results of ECG signal collected by bonded wet electrode shall be tested and verified further.

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Research on Mouse Design Based on Ergonomics

Haijiao Sun

Abstract The rapid development of science and technology makes the mouse become the most commonly used product life and work, but also the most frequent computer equipment, so users gradually the use of mouse proposed more requirements, including comfortable operation, flexible moving and accurate positioning, operation comfort discomfort the most attention. The fatigue caused by long time and high frequency use of mouse is known as the mouse hand. The disease has exerted adverse effect on people's life and work. In the paper, based on the experimental data of fatigue of using mouse, in-depth analysis was conducted on the bone and meridian of the arm using traditional mouse as well as the wrist force. On the basis of the man–machine factors, the traditional mouse was improved in the design. Besides, the optimization scheme that could reflect mouse comfort and effectively avoid mouse hand was put forward.

Keywords Mouse hand · Bones and meridian · Force situation · Man–machine factor · Comfort · Mouse design

1 Research Objective

With the continuous development of the information era, people's life and work rely more on computer, especially the life, consumption, and entertainment habits of the generation after 1980s, 1990s, and 2000s make computer play an important and indispensable role in this group. As an important interactive tool between people and computer—the mouse is the most popular and the most commonly used product in life. When people frequently click the mouse for a long time due to learning, office, game, online shopping, and other activities, it will produce different degrees of fatigue phenomena, such as fingers, palms, wrists, and even arms, neck and shoulders and other parts will feel weakness, numbness, aching pain, and other symptoms, and this is

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what we often call “mouse hand.” Although there is no final conclusion whether this disease is carpal tunnel syndrome, it is undeniable that it has become a common occupational disease and will have a certain impact on people’s life and work.

Although prevention has a certain effect on this disease, as the most commonly used product by people, the mouse should be maximally suitable for people to use, and therefore it is necessary for us to study the man–machine factor of the mouse so as to use the mouse more comfortably.

This paper first states the symptoms and adverse effects of mouse hand to illustrate the significance of comfort of the mouse; then it points out the problems about commonly used mouse existing in its design at present through bone and meridian analysis, and gravity analysis of operation mouse, carries out an in-depth study on the man–machine factors of the mouse, puts forward the optimization scheme to embody the comfort of the mouse and effectively avoid mouse hand.

2 Research Methods

2.1 Mouse Hand and Negative Effects

“Mouse hand” [1], generally speaking, is “carpal tunnel syndrome” in narrow sense, refers to the symptom that the human body’s median nerve and blood vessel entering the hands produced when they are compressed in the carpal canal and it mainly leads to the stiffness and pain and numbness of the index finger and middle finger and weakness of the thumb muscles. For people who use the mouse frequently, it will be found that the two wrists are obviously different when the two hands are put together; the skin of the right wrist using the mouse has turned yellow and even black and already produced a thick stratum corneum. There are a growing number of people to contact and use the computer for a long time every day, especially the Web users. They repeat typing on the keyboard and moving the mouse every day and the wrist joint has the symptoms of the wrist muscle or joint numbness, swelling, pain, and spasm due to the long-term intensive, repeated, and excessive activities, which make it become an increasingly common modern civilization disease quickly.

2.2 Experiment on Fatigue Caused by Using the Mouse

As the best partner of the computer, the mouse has become an indispensable auxiliary tool in people’s life and work. People are paying more and more attention on health problems, but many people still ignore the harm caused by this partner. We all know that sitting for a long time is easy to get cervical spondylosis, but do not know long-term use of the mouse will make it easy to get mouse hand. Below we will give an experiment to prove that the use of the mouse will lead to a certain level of fatigue and we hope it can attract more attention from more users.

2.2.1 Experiment Object

S20 ordinary healthy college students are selected as the object of experimental study, ten male and female students each. They shall not have intense physical activity 24 h before experimental test. After explanation and demonstration, the experimental subjects understand the experimental objective and essential points of operation and complete all the tests. The basic information of the experimental subjects is as follows: Age (20.1 ± 2.11) years old, height (170.0 ± 4.44) cm and weight (58.4 ± 6.50) kg.

2.2.2 Testing Process

The experimental subjects use the same type of common mouse and mouse pad for 180 min continuous mouse click game *Mine Clearance*. Use the office desks and chairs conforming to the national regulations and the desks and chairs height difference range is 280–320 mm, which can maximize the relaxation of shoulder and neck muscles when writing and during computer operation and help to delay fatigue to improve work efficiency. In the experiment, it requires the experimental subjects to keep the correct sitting posture to reduce the error of the test results. The experimental subjects are asked to use the mouse with right hands.

2.2.3 Grip Strength Test

After the experiment, immediately use the same electronic grip dynamometer to measure the maximum grip strength of the experimental subjects' left and right hands, respectively, each person has been measured three times and the maximum value was taken. Figure 1 shows that there has been a decline in left and right hand griping strength before and after the experiment and the descending range of right hand (8.63 %) is more than that of left hand (2.56 %). The statistical *t* test shows that there has been no significant difference ($P > 0.05$) in change of left hand

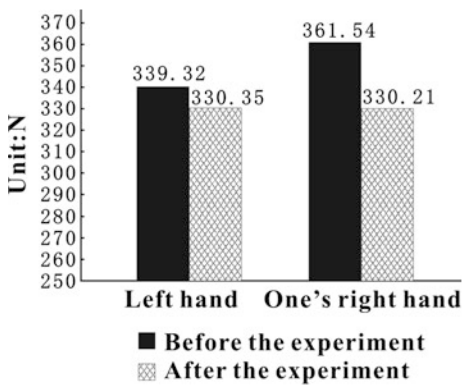

Fig. 1 Comparison of left and right hand griping strength before and after the experiment Unit: N

griping strength before and after the experiment, while there have been significant differences ($P < 0.01$) in change of right hand griping strength. In the experiment, the finger flexors and extensors of right hand holding the mouse have experienced active contraction continuously within 180 min. Although the muscle's load intensity is not large, with the passage of time, the fatigue is accumulated continuously, which makes the work capacity of muscle reduce and weaken the contractility. The grip strength shows a significant descending trend and it appears as a greater degree of fatigue.

2.2.4 Experimental Conclusion

The experiment proves that using the mouse within a short time of 180 min can produce a more obvious symptom of fatigue, so we can imagine what impact the users will cause to the health of the human body through a long-time, overloaded and high-frequency use of the mouse. As a result, it is a very important and meaningful study to improve the comfort of the mouse and treat the mouse hand by combining the man–machine engineering factors.

2.3 Analysis on Man–Machine Factors Using the Mouse

2.3.1 State of Bone and Meridian During the Use of the Mouse in Traditional Way

In the process of using the mouse, the related parts mainly include forearms, wrists, palms, and fingers. The forearm mainly includes ulna, radius, and other bones, and the wrist mainly relies on these two bones to rotate. The carpal bone is the main part in the wrist structure, its rotation makes people's wrists can back and forth freely [2]. The palm is mainly consisted of two groups of muscles, of which one is the muscle group composed of thumb flexor and abductor, the other is the muscle group composed of little finger flexor and adductor and there is a gully between two muscle groups. For different people, the depth and width of the gully are different and there are the main nerve and blood vessel of the human hand inside the gully. Moreover, it should try to avoid the above-mentioned bone and nerve compression and fatigue damage when using the mouse.

Since the popularization of the computer, the mouse has always adopted the traditional parallel design and so far it has no big change and it is still the main form for mouse design at present. But this parallel design ignores the self weight of the arm, as shown in Fig. 2, the users' forearm bone is in a crisscross and twisted state when using the mouse, which leads to the users' limbs fatigue and injury. Of course, we can see in the market that there are many mouse designs which consider and pay attention to this problem and conducts improved design on the curvature of the supporting surface of the mouse appropriately to ease the degree of twisting of

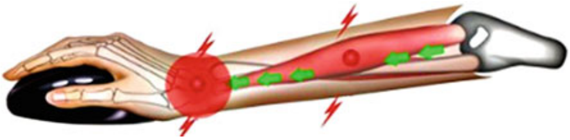

Fig. 2 Crisscross State of forearm bone during the use of traditional mouse

the forearm, but these changes are always based on parallel design, cannot solve the fundamental problem, so the effect is not ideal.

2.3.2 Force Analysis During the Process of Using the Mouse

What on earth is the force condition during the process of using the mouse? The author first paints the wrist with black color and holds the mouse on a piece of write paper just like the gesture the author holding the mouse as usual, as shown in Fig. 3 and then the imprint of the wrist when using the mouse will leave on the piece of write paper, as shown in Fig. 4. It is very simple, but it illustrates a problem through

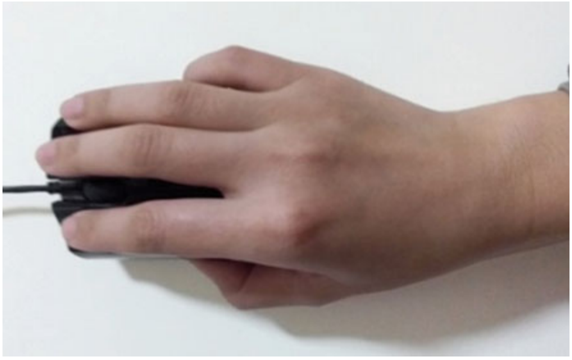

Fig. 3 State of holding mouse

Fig. 4 Analysis of wrist force

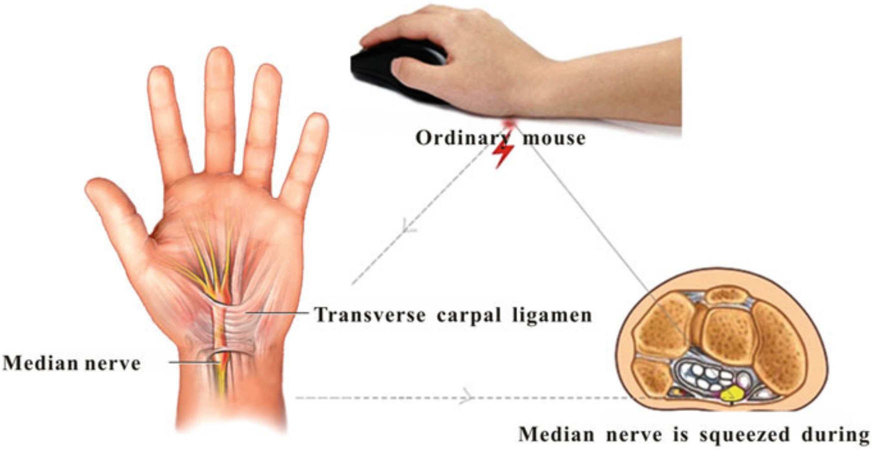

Fig. 5 Median nerve is squeezed during the use of mouse

this imprint: During the process of using the mouse, the wrist needs a supporting point, because this part is the most stressed part and also the place where the symptom of red and swollen in the wrist appears we mentioned above and even the place where a very thick stratum corneum appears.

The most stressed place of the wrist is very close to median nerve, as shown in Fig. 5 [3]. When the median nerve is squeezed, it will lead to the index finger and middle finger stiffness and pain, numbness and thumb muscle weakness, namely the symptoms of the mouse hand.

3 Research Results

Based on the analysis on bone and meridian during the operation of the mouse in traditional way, first we should focus on considering the liberation of the wrist and the median nerve in the improved design of the mouse, because this part is a very important supporting point during the use of the mouse. This problem is related to the ability to solve the compression of the median nerve and the wear to the carpal bone. Second, it is necessary to change the crisscross state of ulna, radius and its muscle during the use of the mouse, so as to relieve fatigue of the forearm and the fatigue symptoms of the neck and shoulder caused by this.

4 Prioritization Scheme of Mouse Design

4.1 Liberation of the Wrist

When using the computer, the height of the computer is preferably less than the height of the elbow when sitting, which can be beneficial to reduce the damages done to the waist and back, neck muscles and tendon sheath of hand muscle, and other parts. If the mouse height is not less than the height of the elbow, the angle of elevation between the mouse and the desktop shall be within the range of 15–30°. If it exceeds this range, the forearm muscles will be in a state of tension, which results in poor flow of blood and even makes the triceps and the deltoid of the upper arm to produce traction effect to let the shoulder joint be in a state of rigidity and make the neural network blocked [4]. In addition, try not to hang your arms when using the mouse to reduce pressure on the wrist, and therefore a wrist rest can be set in the position where the traditional mouse is close to the wrist. The wrist rest can adopt the elastic material with the memory function and it can have a certain degree of deformation according to the users' wrist natural curve and bearing weight to achieve the comfortable experience effect.

4.2 Treatment of Crisscross State of Forearm Bone

The reason why the traditional mouse can make the forearm bone be in crisscross state is because its design adopts the parallel design mode. If the mouse can stand vertically when using, it can relieve and even solve the crisscross problem of forearm bone. As a result, the flat shape of the traditional mouse must be changed into a vertical shape. If we imagine the traditional mouse as a flat box, the vertical mouse is like put the flat box upright, that is, the thumb and index finger are naturally separated and put on both sides of the back of the box and the plane that the thumb and the index finger forms tends to be parallel to the desktop, as shown in Fig. 6 [5], and thus it can eliminate the twisted state of the forearms, reduce the wrist pressure and bring the users the most comfortable and natural feeling.

In addition, it shall use the appropriate radian design to link the back of vertical mouse to two sides naturally and combine with the palm perfectly to make the bearing surface of the mouse fit well with the users' palms to the maximum extent. The larger is the contact surface between the palm and the mouse, the more

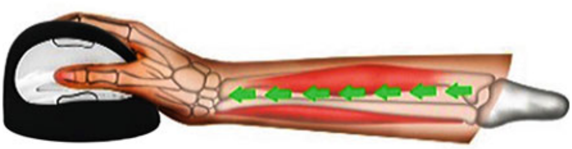

Fig. 6 Arm is relax and meridian is smooth during the use of vertical mouse

effectively it can disperse the supporting force of the mouse to the palm, and thus it can get closer to the natural gesture and ensure the maximum comfort and controllability when using the mouse.

In terms of function key, it mainly considers the thumb, index finger, and middle finger. The function key of the thumb is arranged on the left side of the back of vertical mouse, and the left button and the right button of the mouse, namely the buttons controlled by the index finger and the middle finger, are arranged on the right side of the back of vertical mouse. This is equivalent to rotating the traditional mouse upward for 75°, which certainly aims to make the three buttons more fit with the fingers. The contact surface between the buttons and the fingers can be slightly concaved inward, so that it can not only make the users feel more comfortable during the use of the mouse and hold the mouse more tightly, but also it can successfully disperse pressure and relieve fatigue of the fingers.

5 Epilogue

This paper proves the universality of using the mouse to cause fatigue through experiment, and simultaneously analyzes the bone and meridian state when appears as the symptoms of mouse hand as well as the wrist force situation when using traditional mouse and clearly points out two problems to solve the symptoms of mouse hand: One is to treat the crisscross state of the forearm bone; the other is to treat the wrist and median nerve compression. The optimization scheme has been put forward based on this to improve the comfort of the mouse and treat the mouse hand and related reference has been provided for mouse designers and manufacturers in design concept and design method and other aspects.

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Maintenance Human Factors Design and Analysis of Manned Lunar Rover

Shulin Liu, Na Jiao, Pinwang Zhao, Li Li, Wenjun Guo and Xi Lu

Abstract The manned lunar rover as an important transport and loading equipment tool, the maintainability design of it has a direct impact in the mission success and safety of the astronaut in the lunar exploration activities, and the maintenance human factors design is directly related to astronaut maintenance safety activities and important for scientific exploration mission completed. This paper from the lunar surface environment, astronaut's psychological and physiological factors, maintenance activities and resources constraints, three aspects of the maintenance human factors design elements about manned lunar rover are analyzed. In response to these factors clearly make the appropriate maintenance human factors design from the security service, modular, error protection, fault detection, and other aspects. Through the simulation results provide a strong technical support for the maintenance of manned lunar rover designed to carry out.

Keywords Manned lunar rover · Maintenance · Human factors design

1 Introduction

The maintainability is one of the basic attributes of the product, is the design characteristic closely related to the product maintenance and reflects whether the product has the ability to be maintained conveniently, fast and economically. The improper treatment of maintenance problems may not only cause economic losses, but also lead to a decline in utility of the whole product for the reason that the product cannot be maintained timely and even pay with their lives [1].

Manned lunar rover is one of the hot issues in the lunar exploration and research field in recent years [2, 3]. Whether the short-term retention or long-term residence on the lunar surface, the manned lunar rover is an indispensable important media

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and detection tool, shouldering the mission of expanding the astronauts' scope of activities, transportation science load, sampling tools and various kinds of lunar samples as well as guaranteeing the astronauts' safety and efficient completion of lunar exploration mission. As a special vehicle that is suitable for traveling on the lunar surface, its maintainability design and analysis are of great significance to the implementation of the lunar rover's maintenance and guarantee work.

The astronaut is the most important factor for the maintenance work of the manned lunar rover, so the astronaut must have a comprehensive, in-depth and accurate understanding of the specific environment and the constraint conditions for the maintenance implemented on the lunar surface before making the maintainability design for the manned lunar rover to fully consider the factors affected the maintenance humans factor design. After making the maintainability design, the existing simulation technology shall be used to conduct the maintenance human factor design to ensure the safety of the maintenance activities of the astronauts.

2 Analysis on Influence Factors of Maintenance Human Factors Design of Manned Lunar Rover

The maintenance activities of manned lunar rover on the lunar surface mainly be carried out during the process of the astronauts performing the tasks, the maintenance space is the lunar surface and the astronauts need to carry out maintenance operation dressing in space suit. Based on the characteristic of the maintenance for the lunar surface, the maintainability design of manned lunar rover should consider the factors including lunar dust environment, low gravity, lunar surface temperature, the astronauts' physiological and psychological factors and the restrictions of some maintenance activities and resources, etc.

2.1 Influences of Lunar Surface Environment on Maintenance Human Factors Design

Lunar surface environment is a severe environment that is not suitable for the human to survive. As a result, the maintainability design of manned lunar rover should meet the requirements for the safety of the astronauts' maintenance first, i.e., the safety of the astronauts in the process of maintenance activities [4]. The lunar dust is primary problem that can endanger the astronauts' health. The astronauts' lunar exploration activities will stir up a great deal of lunar dust. The lunar dust contains many kinds of high reaction active dust with very strong chemical activity, once the lunar dust is inhaled, it may cause moderate poisoning of respiratory system. The lunar dust is absorbed on the lunar rover, which may cause the instrument and meter and indicator identification to display fuzzy information, all connection parts may appear as the phenomena of clamping stagnation as well as the astronauts cannot drive the lunar rover or have difficulty in driving the lunar rover and will carry out the misoperation easily when implementing the maintenance activities. Low gravity environment is a factor that must be considered for maintenance human factor design of manned lunar rover. Manned lunar year is running in a complex, unknown and unstructured environment with 1/6 gravity [5]. In the low gravity environment, due to the relationship between acting force and reactive force and abnormal sense of direction when maintenance operation [4], the visibility on the lunar surface will change with day and night latitude and time within the range of −180″C to +150′C and this great temperature difference can lead to the fatigue failure and thermal stress of the materials [5]. The maintenance support equipment of manned lunar rover must be able to withstand extreme heat without deformation or damage [6].

2.2 Influences of the Astronauts' Physiological and Psychological Factors on Maintenance Human Factors Design

The astronauts' strength and sense of direction is reduced due to the low gravity environment on the lunar surface. The astronauts can receive the external information and energy through eye, ear and skin and other sense organs in the maintenance activities and the central nervous system will make a judgment and response to the received information and command hands and feet and other executive organs to carry out maintenance tools for maintenance. In the maintenance activities, the astronauts feel fatigued for the reason that they highly concentrate their energy for a long time, feel stressed mentally, their bodies keep in a relatively relaxed position and their muscles are in a state of tension. In addition, the astronauts carry out the maintenance activities dressing in space suit, which makes their actions be restricted. At the same time, taking the special environmental factors on the lunar surface into consideration, the quality of error prevention and logo design can significantly affect the astronauts' job safety, work efficiency, comfort and emotional experience as well as fatigue situation after long-term operation.

2.3 Influences of Restrictions of Maintenance Activities and Resources on Maintenance Human Factors Design

Due to the particularity of the lunar surface environment, the maintenance operation that can be carried out on the ground will be restricted on the lunar surface or cannot be implemented. Maintenance human factors design should also give full consideration to this. The similar maintenance work such as cutting and welding and others cannot be implemented. The degree of freedom of operation of the maintenance personnel is restricted by the space suit, so does their field of view. In the maintenance activities on the lunar surface, the astronauts' maintenance time is an important resource, but their maintenance skills are limited. In order to make the maintenance process simple and clear, strive to improve the built-in-test (BIT) requirements of manned lunar rover and increase self-repair function to reduce the astronauts' maintenance burden, improvement of maintenance efficiency and increasing of maintenance safety are the important problems that should be considered for maintenance human factors design. In addition, due to the weight restriction, the making materials of maintenance tools shall be light in weight, their strength needs to meet the requirements and have various kinds of functions as much as possible [6].

3 Maintenance Human Factors Design of Manned Lunar Rover

Comprehensively analyzing the influence factors of maintenance human factors design of manned lunar rover, the maintenance human factors design of manned lunar rover shall include maintenance safety, visibility and reachability, modularity, error prevention and identification and fault detection and other aspects.

3.1 Maintenance Safety Design

1. The astronauts' safeguard system has time limitation and it needs to consider the astronauts' maximum maintenance time in the maintenance activities when design.
2. In the low gravity environment, it is necessary to design the auxiliary handrail for the astronauts due to the unstable center of gravity.
3. The equipment has anti-oxidation layer and other protective devices and the direct or indirect damages to these equipment shall be considered in the maintenance activities.
4. To reduce the maintenance to a maximum extent, it is necessary to take the degradation use of equipment into consideration.
5. The channels and hand holes and others that the body must pass when use and maintenance shall not have sharp surfaces or edges. The edge of opening or protecting cover and others of workable hatch must be made into rounded corner or covered with rubber, fiber, and other protective materials.
6. When design, the proper operating space shall be provided based on the position where the personnel are located when use and maintenance, posture and condition of the used tools as well as the measurement of the human body to make the maintenance personnel have a more reasonable posture and avoid operation in kneeling, lying, squat and prone postures that are easily to cause fatigue or damage.

3.2 Maintenance Visibility and Reachability Design

1. The degree of freedom of operation of the astronauts are restricted by the space suit, so it is necessary to consider the influences of its operation range and field of view as well as it needs to provide enough operation space.
2. The products should be carried out in overall arrangement in accordance with the fault rate, the difficulty level of maintenance, size, and quality as well as installation characteristics and others. All parts and components that need to be maintained should have good reachability.
3. The inlet and outlet routes of the parts and components when removal should be preferably straight line or smooth curve.
4. The inspection point, test point and inspection window and other maintenance points of the products should be arranged in an accessible location and the astronauts' passing ability dressing in space suit should be considered as well.

3.3 Modular Design

1. Improve the interchangeability and universalization of the components and parts and the maintenance parts and maximize the use of the components and the parts that can be used universally in its similar products.
2. Make the critical and easily damaged components and parts or units with high fault rate to have a good interchangeability and universalization when design.
3. The products that can exchange the installation must exchange the functions. The products that can exchange the functions should also realize the installation exchange.
4. The symmetrically installed components and parts or the parts with the same functions should be designed to be the completely interchangeable products.
5. The parts need to be replaced should be designed to be modular products.
6. The replaced parts or equipment interfaces should be plugged and played.

3.4 Error Prevention and Logo Design

1. The operating instrument board interface should adopt the smooth and dustproof material or the material with the function of automatic dust removing.
2. The working parts of the same kind or with the similar functions should be arranged at a certain distance from each other to avoid misoperation.
3. The possibility of causing the human errors in the process of use and operation and maintenance should be avoided or eliminated when design.

4. The assemblies, components and parts and others with small gap, more surrounding products and difficult installment localization should have signs of locating pin, locating slot or installation location.
5. The maintenance signs should use the standardized texts, numbers, colors or lights, patterns, symbols and others in accordance with the characteristics of the products and the demands of using the maintenance. The size and position of the sign should be appropriate, brightly colored, eye-catching, and easy to see and identify.

3.5 Fault Detection Design

1. In case of the interface is loose or damaged, the system should be able to detect automatically, provide the response messages and remind the astronauts of it.
2. The test points should be arranged to facilitate the detection, be centralized or centralized by parts as far as possible and have good reachability. Its arrangement should be beneficial to the sequential detection and diagnosis.
3. The important parts should be adopted the performance monitoring and equipped with fault alarm device as far as possible. The dangerous signs should be displayed and alarmed automatically.
4. When each system designs its diagnosis proposal and test methods, it should be designed to be the structure that is able to isolate the faults to replaceable units and can be repaired and tested quickly as far as possible.
5. The interface connection of the external detection system should be disassembled and assembled quickly and have error prevention measures.

4 Maintenance Human Factors Analysis of Manned Lunar Rover

Due to the special working environment of manned lunar rover, it is a necessary means to make use of the virtual maintenance simulation method to analyze and verify its maintainability design. The virtual maintenance simulation carries out maintainability analysis and verification by means of virtual human and virtual maintenance, involves the maintenance reachability and personnel load and other factors, needs to conduct the complex inverse kinematics and dynamics computation and builds human body model creation and virtual maintenance driving method to realize the maintenance load evaluation based on human biomechanics [7].

Make use of virtual maintenance simulation to analyze the maintenance operation of replacement of fault parts of manned lunar rover to obtain the astronauts' visibility, reachability and stress situation and put forward improvement recommendations for the design structure in accordance with the simulation results.

The reachability of maintenance operation of the astronauts is as shown in Fig. 1. We can see from the Figure that the astronauts have good visibility when implementing the maintenance operation, which can meet the requirements of maintenance human factors design.

The reachability of maintenance operation of the astronauts is as shown in Fig. 2. We can see from the Figure that the astronauts cannot complete the maintenance tasks when implementing the maintenance operation, needs to improve the design of manned lunar rover and the maintenance reachability after improvement of the design is as shown in Fig. 3.

Maintenance force analysis is as shown in Fig. 4. When the astronaut operates in half-squat and bent posture, we can see that the pressure on his right hand, left shoulder and spine joint L4/L5 exceeds the acceptable range. At this moment, some joints of this astronaut have suffered the larger stress, so this maintenance action cannot be kept for a long time.

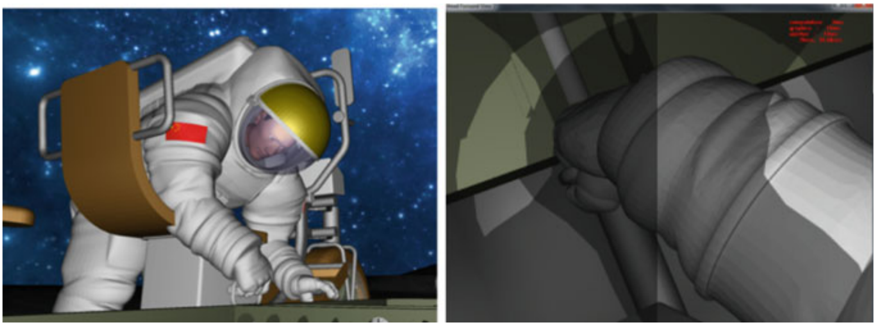

Fig. 1 Maintenance visibility analysis

Fig. 2 Maintenance reachability analysis

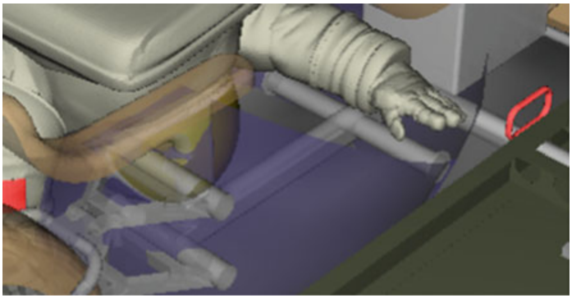

Fig. 3 The reachability analysis of improved design

Joint/Axis	% Capable	Use	Moment (Nm)	Muscle Effect	Angle (deg)	Strength Mean (Nm)	Strength Std Dev (Nm)
R Wrist Flx	99	✓	-2.4	FLXN	-7.7	10.1	3.2
L Wrist Flx	85	✓	5.0	EXTN	3.1	7.6	2.4
R Wrist Dev	63	✓	-9.4	RAD	10.8	10.5	3.3
L Wrist Dev	99	✓	-1.5	RAD	-26.5	8.1	2.6
R Wr SuPr	99	✓	3.0	SUP	26.3	13.3	4.5
L Wr SuPr	100	✓	0.3	--	-77.0	--	--
R Elbow	82	✓	-58.6	FLXN	86.1	75.8	18.6
L Elbow	95	✓	-37.4	FLXN	19.8	62.1	15.3
R Sh AbAd	99	✓	-28.3	ABD	0.0	69.2	17.0
L Sh AbAd	66	✓	-69.7	ABD	0.0	77.4	19.0
R Sh FwBk	97	✓	-48.9	FWD	0.0	103.7	28.3
L Sh FwBk	100	✓	-2.1	FWD	0.0	100.2	27.3
R Sh Hmrl	75	✓	-19.6	LAT	0.0	23.2	5.3
L Sh Hmrl	100	✓	-7.1	LAT	0.0	37.9	8.6
Trunk Flx	86	✓	-154.6	FLXN	8.0	232.7	73.3
Trunk Bend	100	✓	-15.6	RIGHT	0.3	203.0	43.9
Trunk Twst	100	✓	-3.0	CW	2.0	89.4	23.9
R Hip	98	✓	-35.9	EXTN	0.0	195.8	78.6
L Hip	98	✓	-35.3	EXTN	0.0	195.8	78.6
R Knee	99	✓	-37.8	FLXN	10.0	140.8	41.5
L Knee	99	✓	-37.3	FLXN	10.0	140.8	41.5
R Ankle	96	✓	-66.2	EXTN	8.0	150.7	49.8
L Ankle	96	✓	-63.8	EXTN	8.0	150.7	49.8
	Force (N)						
L4/L5 Comp	3515.2	✓					
L4/L5 AP	508.0	✓					
L4/L5 Lat	24.9	✓					

Fig. 4 Stress analysis

5 Conclusion

The reliable and safe operation of manned lunar rover is the basic safeguard for the astronauts to survive. As an important component part of the maintainability design, the maintenance human factors design has an important significance to safeguard the astronauts. In this paper, through analyzing influences of maintenance human factors design, we put forward related design contents and design criteria of maintenance human factors design of manned lunar rover; we make use of the virtual simulation analysis method to analyze the human factors design of manned lunar rover and propose the improvement recommendations for the design, providing the technical support and engineering implementation ways for the maintainability design of manned lunar rover.

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CFD Grid Auto-Generation Technique for Rapid Simulation of Thermal Design on Satellite Package

Shen Tian, Changyu Chen and Xiaobin Shen

Abstract In order to meet the requirements of the thermal design on the satellite package and solve the general CFD simulation problem because of the model differences, a general grid auto-generation program is developed based on ICEM in this paper. The program includes geometric model auto-drawing, auto-mixed meshing with structured grid primarily and boundary auto-definition. It greatly improve the efficiency of simulation optimization. Because it could complete grid auto-generation for any shape and size package, any shape and size satellite, any location of it, any size inlet and outlet for air conditioning, any location of it, any amount of grid and any Y Plus requirement. It completes User-defined data modification with XML text formatting and controls the scripts with C programming language. And the effectiveness of the rapid simulation method is verified by comparing with manually structure grid generation.

Keywords Thermal design on satellite package · CFD · Rapid simulation · Grid auto-generation

1 Introduction

With the rapid development of aerospace industry in our country, especially in the field of satellites, special package designs for storage and transportation determined by product properties attract more and more attentions. During the design process, the consideration of the influence of temperature is particularly important. The spacecraft will be damaged to varying degrees or even directly lose efficiency if the temperature is too high or too low [1–3]. Therefore, active control of the temperature and the

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installation of the air conditioner and other temperature adjusting devices have to be fully considered during the design and use process of the packages. For design and use of packages and a temperature controlling devices, lots of tests, and flow field analysis are needed in order to obtain better control effect.

During the process of actual design and use, since there are large differences in types and dimensions of the packages, types, dimensions, and placements of satellites, shapes, dimensions and placements of the vents of the air conditioner, power of the air conditioner, external environmental conditions and other conditions, the traditional method of guiding design and use through lots of experiments taking full advantages of the experimental data is undoubtedly a waste of time and energy and cannot optimize the preliminary designs. By taking advantage of numerical simulation technology, any experimental conditions can be quickly simulated. Both domestic and foreign CFD flow field virtual tests on satellite packages are limited to a certain model or a certain service condition. For example, Su et al. [4] used Fluent Simulation to verify the passive thermal insulation performance of a certain model of satellite package. However, for the optimization of the design and use, lots of experiments of all kinds of model conditions have to be carried out. If there is not a general high-quality grid auto-generation program, the efficiency of simulating optimization will be greatly reduced.

In this paper, a general grid auto-generation program has been developed based on ICEM platform. One-click grid auto-generation has been achieved. Taking an example of a certain working condition, compared with the calculation results of the traditional manual generation of structural grids, the effectiveness of the rapid simulation has been verified.

2 Simulated Model

The models are based on the present three kinds of satellite packages commonly used for storage and transportation (which are cuboid package, arch package, and air/marine package, respectively) of any dimensions. A satellite shall be placed at any coordinate position inside each kind of package (the satellite shall be simplified into two models of cuboid and cylinder. The satellites shall be laid down (e.g., the circular sides of the cylinder shall face to the front and the back of the page) and perpendicular to the front and the back of any dimensions). The inlet vent and the outlet vent of the air conditioner shall be placed on any side of the package (to uniformly distribute the flow field and obtain better temperature controlling effect, in actual conditions, the two vents are not distributed in the same side; both vents shall be rectangle of any dimensions in length and width; after transformation, the front and back sides of the package shall be classified as one category and denoted as FB; the right and left sides of the package shall be classified as one category and denoted as LR; according to clockwise direction, the front side shall be denoted as 1; the left side shall be denoted as 2; the back side shall be denoted as 3; the right side shall be denoted as 4); the solid grid domain of the internal satellite and the fluid-solid coupling shall be drawn up; the solid grid domain of the package walls (that is the thermal insulation layer of the package) shall not be drawn up. The wall boundary shall be prepared and the thickness of the wall shall be calculated.

The sections of the three types of packages are as shown in Fig. 1 (among which the arch package stipulates the center of the upper arc shall not be higher than the height of the lower rectangle). In direction of the length, they are considered of the same section. Taking an example of the arch package, an example including all the geometric parts has been given to illustrate the method of placing satellite and arranging two vents with the standard coordinates, as shown in Fig. 2.

3 Method of Grid Auto-Generation

The method of rapidly simulated grid auto-generation needs to solve the problems of two main parts: One is the generality of scripts recorded based on grid division software. The other is the selection and operation of the corresponding scripts meeting the user-defined requirements.

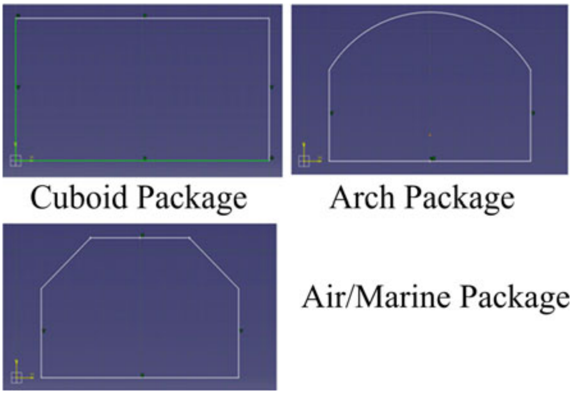

Fig. 1 Package section

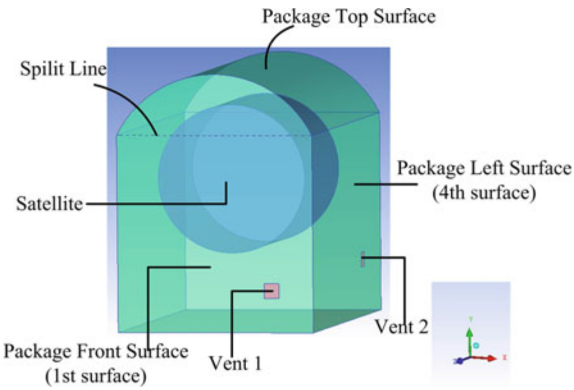

Fig. 2 An arch package example

Among the finite volume methods of computational fluid dynamics, structural grids have the advantages of orthogonality and the directivity. It can not only save the memory and capture the characteristics of the boundary layer nearby the wall, but also improve the calculation accuracy and efficiency to obtain better simulation results; however, when the model is relatively complex, especially when the parts needing grid division have various position relations and unfixed shapes, the Block division can not achieve generality. At present, the grids can only been drawn manually; nonstructural grids have the characteristic of flexibility and can deal with complex geometric shapes, fill in the grid area, combine the transition nodes, however, in the areas with rapid changes in physical quantity such as the positions nearby the wall, the simulation effect is poor and the simulation efficiency and accuracy are low. To sum up, for the high-quality grid auto-generation, the structural grids need to be based on, especially the area of rapid changes; the number of nonstructural grids shall be reduced to the greatest extent.

At present, the grid auto-generation is usually based on the script recording of the grid division software, however, for the grid division of any satellite package, a peripheral main program call is needed to automatically rewrite the script parameters and meet the requirements of various statuses.

3.1 Recording of General Scripts

(1) First, the corresponding geometric model shall be drawn according to the calculations requirements; (2) The whole package grid drawing region shall be divided into three parts: The fluid domain of the part with inlet (denoted as I), the fluid domain of the part with outlet (denoted as II), the fluid-solid coupling domain with the internal satellite (denoted as III); (3) The structural grids shall be drawn in each part. Then nonstructural node combination shall be done for each part on the interface (interior). Then smooth processing shall be done for the nonstructural grids of the interface to generate the final.msh grid file.

The scripts shall be recorded according to the three parts for three kinds of package structures.

3.1.1 Cuboid Package

(1) Record the Script 1.1: geometry-based rendering of cuboids and divide each side;
(2) Record 3 sets of scripts of 1.2.1, 1.2.2, and 1.2.3. Each script includes: the geometry-based rendering of inlet vent, outlet vent, interface interior1 and interior2; define parts; structural grid division of fluid domain I and II (The corresponding two vents of each of the sets of scripts are both on FB, both on LR or one on FB and one on LR, respectively);

(3) Record 2 sets of scripts of 1.3.1 and 1.3.2. Each script includes: the geometry-based rendering of the internal satellite; define parts; structural grid division of fluid-solid coupling domain III; combine the nodes; then smooth processing shall be done to generate the final.msh grid file (two sets of scripts shall correspond to cuboid and cylinder simulated simplified models for satellites).

3.1.2 Arch Package

The section of an arch package consists of the lower rectangle and the upper arc surface.

(1) Record the Script 2.1: geometry-based rendering of the arch (draw the split line of between the lower rectangle and the upper arc surface) and divide each side part;
(2) Record 7 sets of scripts including 2.2.1.1, 2.2.1.2, 2.2.1.3; 2.2.2; 2.2.3.1, 2.2.3.2, 2.2.3.3. Each script includes: the geometry-based rendering of inlet vent, outlet vent, interface interior1 and interior2; define parts; structural grid division of fluid domain I and II (Among them, the first three sets of scripts are on FB, however, when the grid division is different due to different position of the inlet vent (three situations including being below the split line, going through the split line, and being above the split line) and three sets of scripts need to be recorded; the actual situation of the outlet vent shall be only placed below; the vents of one of the script are on LR, one set of script is just OK. For the last three sets of scripts, one vent is on FB and the other one is on LR. Because of different position of inlet vents, three sets of scripts also need to be recorded.);
(3) Record 6 sets of scripts including 2.3.1.1, 2.3.1.2, 2.3.1.3; 2.3.2.1, 2.3.2.2, 2.3.2.3. Each script includes: the geometry-based rendering of internal satellite; define part; structural grid division of fluid-solid coupling domain III; combine the nodes; then smooth processing shall be done to generate the final.msh grid file [Among them, the first three sets of scripts correspond to cuboid model of satellites, however, the grid division is different due to different position of the satellite (three situations including being below the split line, going through the split line and being above the split line) and three sets of scripts need to be recorded; the last three sets of scripts correspond to cylinder model of satellites. Because of different positions of satellites, three sets of scripts also need to be recorded (The basis of determining relative position is a little different from that of cuboid model of satellites. It is to determine according to the position of the inscribed square of the satellite circular relative to the split line)].

3.1.3 Air/Marine Package

The section of common air/marine package consists of the lower rectangle and the upper reverse trapezium. The characteristics and basis of its script recording is almost the same as that of the arch package.

3.1.4 Examples of Script Recording

Since the script recording of the three types of packages have many common characteristics. Detail the script recording by taking the most complex arch as an example.

(1) Just one script is OK. The description is omitted.

(2) Divide the scripts into three types. Type 1: Both vents are on FB. The distance between FB side and the satellite can be calculated by the program. Then two interior interfaces shall be set at 0.3 (just <1) of the distance, as shown in Fig. 3. Type 2: Both vents are on LR, as shown in Fig. 4. Type 3: One vent is on FB and the other is on LR, as shown in Fig. 5. The following methods shall be taken for the structural grid division of fluid domain on FB: The fluid domain shall be divided into two Blocks by the split line; the upper edge shall be related to the arc line; two points shall be gotten at 0.3 and 0.7 of the arc; the upper vertex shall be related to the gotten points; designate the Face of FB and interior interface. And generate internal O-Block in the two-dimensional direction of arched section; move the vertex and make the edge corresponding to the split line overlap the split line. In this way, the problem of arched surface structuring and Y+ control of the package wall is solved.

(3) Divide the scripts into two types. Type 1: The satellite is of cuboid model. The situation of the satellite going through the split line is special. Here, it is only considered to divide the package along the lower part of the satellite. The upper part of the satellite shall not be divided. The division of the upper Block shall

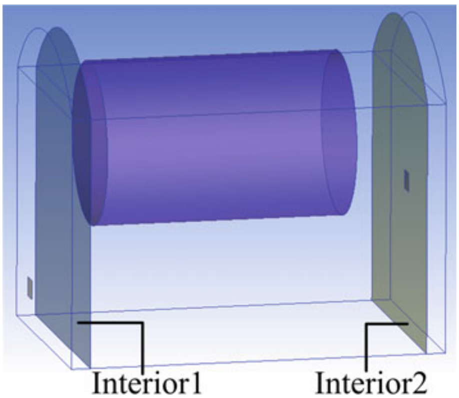

Fig. 3 Both in FB surfaces

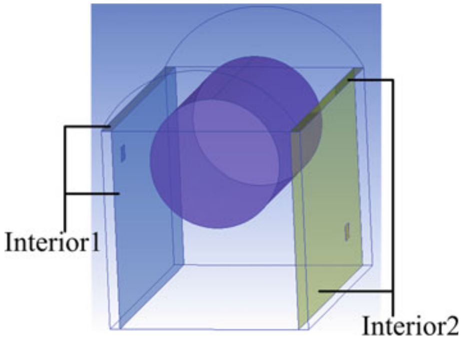

Fig. 4 Both in LR surfaces

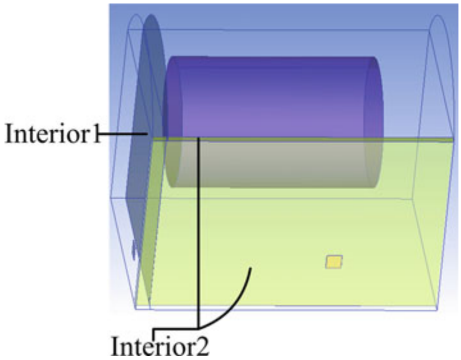

Fig. 5 One is in FB and one is in LR surfaces

be achieved by the transformation of the split line result from the correlation of vertex. To achieve the general control of grids, especially the general control of Y+ of the position where the satellite is nearby the wall, the overall Block of the satellite shall be set as Part of Solid and shall be divided into outer O-Block as a whole. Type 2: The satellite is of cylinder model. Its recording process is almost the same as that of Type 1, however, the front and back round sides of the satellite and the Faces of the corresponding front and back parts of the package shall be taken as the internal O-Block; link the edge of outer O-Block to the contour line of the round side to guarantee the grid generation quality of the position where is nearby the satellite wall.

If the package is a cuboid, it shall be just regarded as a package that only has the lower part of the arch and the script is the simplest; if the package is an air/marine package, the two end points on the top can just be regarded as the 0.3 and 0.7 points of the arc of the arch. For the rest, refer to the method of script generation of the arch package.

3.2 Main Control Program

(1) Extensible markup language (XML) can achieve data input and modification and textualize data structure.
The parent XML data frame includes: contour dimension of the package, contour dimension of the satellite, dimension of the inlet vent, dimension of the outlet vent, coordinate position of the satellite, coordinate position of the inlet vent, coordinate position of the outlet, and relevant physical parameters needed to calculate the height of the first grid layer.

(2) Programming Language C can achieve reading of the text data and specifically determine which set of scripts combination to choose.
Determination about which set of scripts combination to choose shall be made specifically according to the package type, the position and type of vents and their positions relative to the split line, the satellite type, and its position relative to the split line. That is if there are more than one set of scripts for determination, further determination shall be made according to the rules. Otherwise, the set of scripts can be directly selected. The process is as shown in Fig. 6.

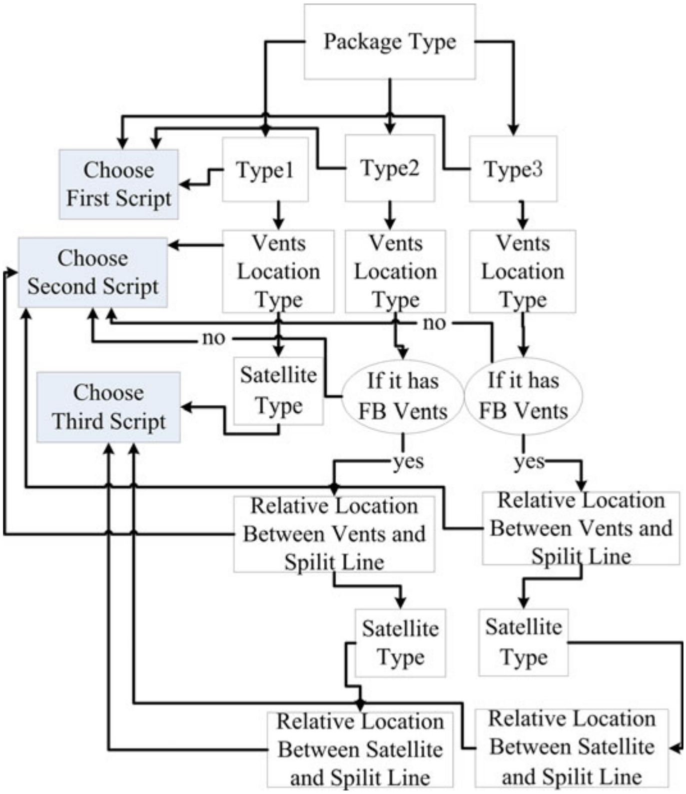

Fig. 6 Judgment steps choosing script groups

(3) Programming Language C can achieve data processing and script rewriting. The conversion needs to be done according to the input vent information to make the placing direction of the package and the placing side of the vents conform to the prerecorded scripts, so as to reasonably rewrite the script data and facilitate the loading of boundary conditions when carrying out CFD calculation; the other data shall be processed and assigned to the corresponding position of the corresponding script. The rewriting of the Part names of inlet and outlet vents through reading of vent types.
(4) Programming Language C can achieve the determination of node distribution. The maximum dimension of the overall grid shall be estimated according to the required grid scale, to write the corresponding positions; the height of the first grid layer shall be estimated according to the Y+ requirements and the physical parameters. The node distribution of the edge shall be rewritten at the corresponding positions.
(5) Programming Language C can achieve the running of the scripts combination.

4 Effectiveness Verification of Grid Auto-Generation

External environmental conditions: The ambient temperature is 35 °C (308 K). The value of solar radiation on the top is 280 W/m^2. The value of solar radiation on the side (front, back, left and right) is 140 W/m^2. The speed of the carrier is 60 km/h. The external wind speed is 10 m/s. By calculating the external convective heat transfer coefficients of the left, right, and top sides of the package according to the formula of flow along a flat plate [5]. These outer sides are regarded as surfaces with forced convection and radiation. The outside of the bottom side is regarded as a heat insulated surface. The outside of the front and back sides are regarded as radiated surfaces.

Package conditions: For arch packages, the length is 6 m, width of the arch section is 4 m and the total height is 5 m; the satellite is 1.3 m from the front side and 0.7 m from the back side. The distances between the center of the circle and the left and right sides are the same. The center of the circle is 3.2 m from the bottom and the radius is 1.3 m. For this package type, the satellite goes through the split line of the arch section. The length of each side of the vents is 0.3 m. The thickness of the insulation layer is 0.1 m. The physical properties of the material shall be set according to those of polyurethane foam board widely used in aerospace industry. The blowing-in temperature of active temperature control is 17 °C (290 K). The blowing-in speed is 2 m/s. Since there is large space in satellite packages and the blowing-in speed of temperature control cannot be too high, action of gravity, and the free convection shall not be ignored. The air fluid shall be regarded as incompressible ideal gas with gravity. The internal satellite is of cylinder model. The two vents shall be both on LR and both on FB. Steady state calculation shall be done.

4.1 The Two Vents Are Both on FB

The average temperature of the fluid region: The calculation result of the automatically generated grid is 307.13 K. The result of the manually generated structural grid is 307.38 K. The average temperature of the solid (satellite): The result of the automatically generated grid is 313.58 K. The result of the manually generated structural grid is 314.12 K. Take the section going through the vertical center line of the outlet vent. The contours of temperature are as shown in Fig. 7 (they are in the direction of FB sides and the direction of LR sides, respectively). Since most attentions are paid to the effect of temperature controlling simulation of the satellite, the line which is 0.1 m below the lower surface of the satellite is taken as the monitoring line for fluid field. The diagram of temperature distribution and comparison is as shown in Fig. 8. The line which is 0.1 m above the higher surface of the satellite is taken as the monitoring line for fluid field. The diagram of temperature distribution and comparison is as shown in Fig. 9.

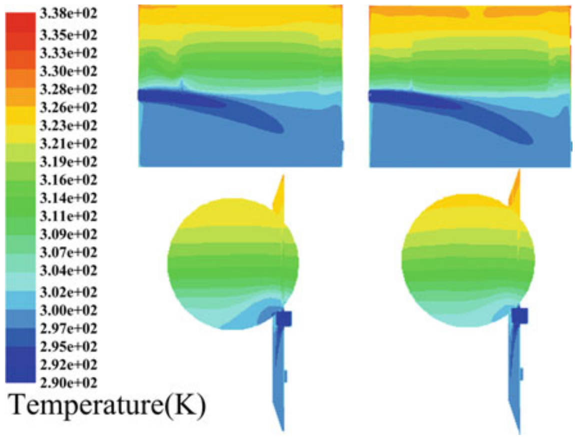

Fig. 7 Section temperature contours (auto-generation results on the *left* and manually results on the *right*)

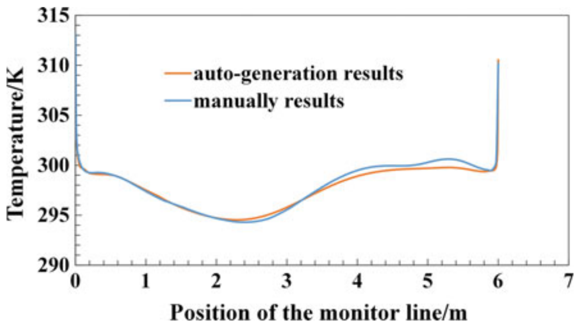

Fig. 8 Distribution of temperature on the monitor line being 0.1 m below the lower surface of the satellite

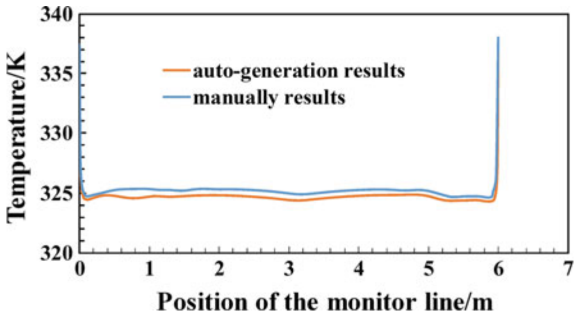

Fig. 9 0.1 m above the higher surface of the satellite

4.2 The Two Vents Are Both on LR

The average temperature of the fluid region: The calculation result of the automatically generated grid is 301.85 K. The result of the manually generated structural grid is 301.74 K. The average temperature of the solid (satellite): The result of the automatically generated grid is 300.22 K. The result of the manually generated structural grid is 300.33 K. The observation section is taken as the same as above case. The contours of temperature are as shown in Fig. 10. The monitoring lines for fluid field are taken as the same as above case. The diagrams of temperature distribution and comparison are as shown in Figs. 11 and 12.

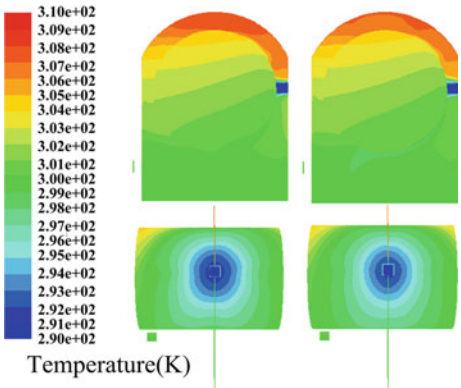

Fig. 10 Section temperature contours (auto-generation results on the *left* and manually results on the *right*)

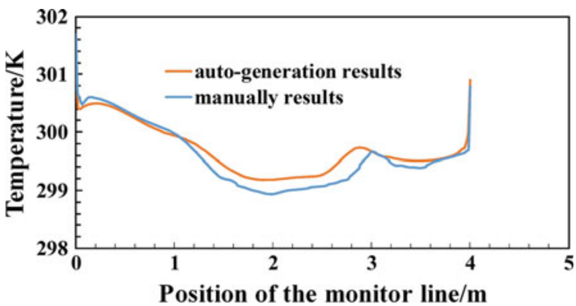

Fig. 11 Distribution of temperature on the monitor line being 0.1 m below the lower surface of the satellite

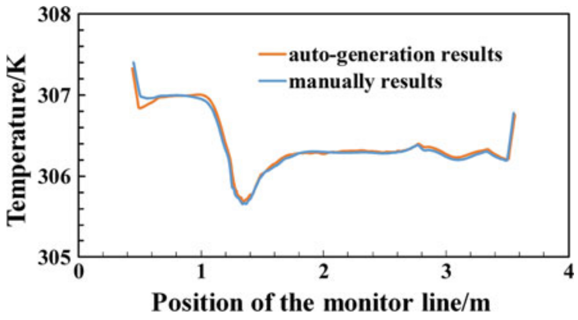

Fig. 12 0.1 m above the higher surface of the satellite

Based on assumption of operating condition including the same external environment, the same package type and dimension, the same type, dimension, and placing position of satellite and the same blowing-in temperature and flow, if the steady-state calculation is only considered, the following phenomena can be observed: Through the calculating the contours, it is known that due to the operating condition of cooling process, the air at the inlet vent is cold. Plus the influence of action of gravity, the blowing-in air settles down obviously. Therefore, is difficult to complete the temperature control for the top of the package. However, the inlet vent is placed much higher and closer to the satellite in Type II, so as to facilitate the fluid to break down and go upward. Its cooling effect on the top side is better than that of Type I. Since there is forced convection outside the left and right sides of the package during transportation and the front and back sides cannot carry out effective heat convection with the outside. When there is serious solar irradiation, cooling for the front and back sides of the package shall be given priority to. Type II, placing inlet vent on LR, is more conducive to the cooling of the front and back sides. Therefore, the layout of Type II makes the temperature controlling effect better than that of Type I.

By comprehensively comparing cloud pictures, key position data and other perimeters, it is found that the calculation result of automatically generated grid can agree well with that of manually generated structural grid. The automatically generated grid can quickly and accurately simulate the distribution of fluid field and temperature field, capture the key details, optimize the design, guide the use and conform to the theoretical analysis. The grid auto-generation method is rapid and effective.

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Suppose Future Traffic Accidents Based on Development of Self-driving Vehicles

Quan Yuan, Yan Gao and Yibing Li

Abstract With the development of self-driving vehicles, the future road traffic system will be dramatically changed, and so will be the characteristics of road traffic accidents. It is necessary to keep abreast of the dynamic development of the vehicle models to grasp the trend of the accident forms. Based on Human–Machine–Environment System Engineering theory, after study and analysis of the development trend of self-driving vehicles, considering the changes in all kinds of factors, such as human, vehicle, and road, this article supposes the new forms of road accidents that may occur in future. Due to the uneven development, there might be vehicles of different intelligence levels co-existing and influencing each other, which, together with the complexity of existing human, vehicle, and road factors, may cause even more complex traffic accident forms. New traffic phenomena in future, such as the coexistence of various self-driving vehicles and human-driving vehicles, switching between human-driving and self-driving, information security of intelligent transportation systems, and environmental interference and adverse weather factors, may cause accidents. Among them, the human factor is still important and should not be overlooked. The collision avoidance of self-driving vehicles should focus on the vulnerable road users. The study analyzes and forecasts the possible complexity of the future accidents, and suggests that in future the characteristics of accidents form change should be revealed in depth, so as to work out plans for preventing and handling the related accidents.

Keywords Intelligent transportation · Self-driving vehicle · Human–machine–environment system engineering · Road traffic accidents

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1 Introduction

According to the Internet news reports [1], Google's self-driving vehicle had its first road accident on February 14, 2016 when it collided with a bus during its lane changing. There were no casualties caused, as the driving speed was low, however, this accident has been regarded as an important event since the come out of self-driving vehicles, and indicates a new type of accidents that may occur in future.

The continuous development of vehicle intelligent securitization, while improving the road safety, is also changing the traffic system, thus the risk of accidents and the consequent characteristics are changing as well. Therefore, timely attentions must be paid to the dynamic development of vehicle models during the study of traffic safety and accident prevention, so as to grasp the development and changes of accident forms. For example, the current major car manufacturers are all actively develop intelligent vehicles represented by self-driving vehicles, among which a few prototypes have been tested in the system. It is expected that in near future these vehicles will be put to road traffic. In addition, the developing direction of future vehicles will inevitably go toward lightweight, high-speed, and environmental protection. However, due to the uneven development, there will be vehicles of different technology situation and intelligence levels co-existing, which, together with the complexity of the existing people, vehicle and road factors in China, may cause even more complex traffic accidents rather than significant reduction of accidents.

As vehicle technology develops rapidly, while the numbers of accidents declines, their forms and characteristics are changing too. Dynamic change of road accidents form requires the corresponding adjustment of traffic safety management. In order to better develop the effective vehicle safety technology, traffic safety management, accident prevention, and treatment and rescue measures for accidents, the characteristics of accident form should be studied. Through study and research of status and the trend of development of self-driving vehicles home and abroad, integrated with China's actual traffic characteristics, this article analyzed the most possible traffic accident form in future.

2 Current Situation

Intelligent vehicles have become an important direction of car development and the self-driving technology matures. The world's major car manufacturers, such as BMW, Volvo, and Mercedes-Benz have all launched the self-driving test cars. Google has carried out the long-distance actual road test of self-driving vehicles in the United States. Though the driver's current acceptance to the "self-driving" is still to improved [2], the governments of some developed countries, such as Germany, the United Kingdom, and the United States have begun to support the application of self-driving vehicles in practice. Some countries have started the research of legal responsibilities of the self-driving vehicles' accidents [3–5].

At present, under the general trend of developing intelligent vehicles such as self-driving vehicles, China's major automobile companies and Internet companies have one after another begun to develop new types of self-driving vehicles, which, coupled with the continuous development and application of intelligent transportation technologies, will lead to a revolutionary leap of road traffic. According to the Wall Street Journal website, Baidu will soon be testing self-driving vehicles in the United States [6]. Several Chinese auto companies have already promised to launch the first self-driving vehicle, the competition among the domestic independent car brands on vehicle intelligentization will be fierce. However, the relatively lagging-behind road traffic safety management should also respond to this rapid and significant change to make full preparations to meet the development trend of both vehicles and traffic technologies.

The development of self-driving vehicles grows vigorously, and tests have also been carried out on real vehicles on the road of first-tier cities, such as Beijing and Shanghai, however, currently the number of accidents caused by the normal vehicles and a variety of road users is still considerable [7]. Large population, complex geographical environment, and uneven development are the main constrain factors of road safety improvement. Facing the future advanced vehicles and traffic system, a large number of road users will have more options for transportation. The unevenness of economic development, the difference in civilization qualifications and traffic safety awareness, though gradually improving, still affects the operation of the road traffic system, and the introduction of intelligent vehicle will lead to a mix-up of vehicle types. Therefore, the future traffic safety situation of China, though gradually improving, is still not optimistic, and there is possible occurrence of various complex types of accidents, which is worth focused attentions from the researchers.

3 Future Accident Risk Analysis

Self-driving is likely to become the protagonist of the future road traffic system, however, the change from human-driving to self-driving requires a transition time, during which the road traffic system will inevitably become more complex; with the interaction among people, vehicle, road factors, complex traffic conflicts will very likely to be caused. Here, based on the human–machine–environment system engineering thoughts, examining and forecasting the risks faced by future intelligent traffic system featuring self-driving vehicles, this article discuss the factors of man, machine, and environment factors as the following.

3.1 Machine Factors

Five road vehicle automation levels published by NHTSA, from low to high are: no-automation, function-specific automation, combined function automation, limited self-driving automation, and full self-driving automation [8]. Can these vehicle of different levels of intelligence run on the road at the same time (for example the self-driving vehicles and human-driving vehicles mixing)? The risk of accidents still exists. Google's self-driving vehicles has carried out a 3.2 million kms' road test in six years and 17 minor accidents occurred [1]. Based on current technology, when the self-driving vehicle meets sudden lane-crossing of other vehicles, its collision avoidance strategy is to select a way to avoid crash as likely as possible, or a way to keep crash severity to the lowest level, which means the consequences will not be an absolute non-collision [9].

As there may be differences in judgment and decision-making between self-driving vehicles and human drivers, the accidents may occur. The future intelligent transport modes led by the inter-vehicle connection and cooperative vehicle-infrastructure system will bring lower energy consumption, higher efficiency and higher safety to the traffic system, allowing driving at higher speeds and with shorter following distances; this mode, however, has safety risks. For example, with the future queues of intelligent vehicles on the expressway driving at higher speeds and shorter vehicle distances, severe rear-end accidents involving multiple vehicles are likely to happen. With the increasing number of small-sized light vehicles in future, the collision compatibility problem among vehicles of different qualities will be involved as well [10].

The information transfer security of intelligent traffic system, as well as the reliability of the system itself, has a crucial impact on the security of the intelligent traffic system. Different levels of system disorders might be caused by the attacks to the computer information and communication systems from an external party (such as a hacker) and the small-probability calculation and identification errors, which might further errors in the interaction among human, vehicle and road.

Future intelligent vehicle technology is still based on the conventional mechanical systems, therefore the mechanical failure threats to traffic safety such as sudden performance abnormity or failures in functions including braking and steering, flat tires, component damage and sensor failures. Though the quality and performance of mechanical systems also will be improved, component failure caused by emergent factors still cannot be completely avoided.

3.2 Human Factors

During the transition period from non-self-driving to self-driving, there might be vehicle products of several different intelligence levels, including Limited Self-Driving Automation, i.e., in some occasions the drivers can completely leave the driving to the automation system. However the human–machine switch of vehicle controlling requires reasonable time. Thus, it involves switching operation between human and the humans need a certain amount of adaptation. For example, during the road test of a Nissan Leaf self-driving car by Cruise Automation, a California start-up company in San Francisco, January 2016, a collision occurred [11]. When the car was driving at about 20 miles/h speed in the right lane, it suddenly moved to the left lane, after the driver's attempt to manually adjust the direction failed, the car eventually hit a car parked aside. This incident indicated the self-driving system's error, and also exposed the problem might occur during the switching operation between human and machine.

"Self-driving" symbolizes that human driving is no longer needed for vehicle control. With the popularity of self-driving vehicles in future, the "human's driving skills" will become increasingly degraded. Therefore, a higher demand for self-driving vehicle security has been put forward: it should obtain the ability to respond to and properly handle all kinds of unexpected traffic conflicts. In future, "the human driving" skills will become very scarce, if human driving is still need in vehicle or as a reference of research and development, then the self-driving would not be able to replace the human-driving and exist independently.

In China, the death of vulnerable road users (including pedestrians, motorcycles and non-motor vehicle rider, etc.) in traffic accidents accounts for more than 60 % of the total death [7], therefore the collision avoidance of self-driving vehicles should focus on them. Currently, the electric bike riders have become the main non-motor vehicle users in traffic accidents. With the energy tension and environmental requirements, small-sized electric vehicles gradually enter the road system, and the travelers now have more choices. In future, though intelligent vehicles grow popular, due to the large population and diversity in vehicles, a large number of vulnerable road users will still be in the traffic system, who may travel by ordinary bicycles, electric bicycles, small-sized scooters, or walking. These road users will always be the self-driving vehicles' focus of collision avoidance. Whether, they can absolutely avoid any contacts, will one hand rely on the self-driving vehicle technology, and on the other hand depend on the construction and management of transport facilities, people's traffic safety awareness, and enhancement of traffic civilization qualities.

Functional characteristics to luxury vehicles might bring more diverse and flexible passengers environment in future self-driving vehicles. As human processing is no longer needed, manual performance equipment such as steering wheels and foot pedals will not be included in vehicles, so the passengers' activity space and posture will be more comfortable and flexible. For example, the passenger seats can be rotated, so that four passengers can sit opposite to each other. Each passenger can use computer or rest more comfortably, and can take recreation activities. As a result, the body postures of the passengers will be changeful and complex, bringing greater challenges to passenger protection.

3.3 Environmental Factors

Human–machine systems exist in nature and traffic environment, and the future intelligent vehicles run under certain road conditions, therefore the threats to traffic safety from the environmental condition interferences, such as the suddenly appearing road obstacles, dense city buildings, bridges, mountains, and tunnels that block signals linked to the network, as well as the sudden natural disasters, still cannot be avoided. We should not overlook the complex environmental factors in the research, development and improvement of self-driving vehicles.

Future intelligent vehicles still cannot get rid of the influence of adverse weathers, such as strong winds, heavy rain and snow and severe haze on small-sized vehicles, the road map of snow on intelligent identification and so on. According to a Bloomberg report on February 12, 2016, a Volvo self-driving car encountered strong snowstorm in its road test and the sensor could not work normally and failed to identify the road situation.

In summary, though the future intelligent traffic system can reduce the accident rate, it will not be able to eliminate various factors that could lead to accidents. We summarized the current self-driving vehicles accidents that have been reported to occur in the road tests and listed them in Table 1, we can see that the self-driving vehicles are still in the stage of technological development, the conflicts with the existing traffic conditions and road, vehicles, road factors are the inevitable. Therefore, a timely forecast of accident risk and accident form should be carried out to give the targeted consideration in the accident prevention and traffic safety research.

4 Discussion

The development of intelligent vehicles marks the progress of active safety technology, while the purpose of vehicle active safety technology research is to prevent traffic accidents, and "zero crash" is the direction to aim for. Therefore, the research

Table 1 Accidents already occurred during self-driving vehicle tests

Time	Company	Number of accidents	Accident forms	Results	Reasons
2010–2015	Google	17	Rear-end	Minor	Mainly caused by other human-driving vehicles
2016-02-14	Google	1	Side crash	Minor	Misjudgment of the self-driving car
Feb. 2016	Volvo	1	Single vehicle	Sensor failure	Influenced by the adverse weather
2016-01-08	Leaf	1	Hit a parked car	Minor	Control system failure

and development of active safety technology must establish the appropriate preventive measures against accidents of various forms. We need to gather specific characteristics from the existing traffic accident data and provide typical driving scenarios of concerns such as the typical characteristics of the accidents caused by the drivers, collision forms that are difficult to avoid in manual driving, for the research and development of active safety technology, and make them important the fact-based references.

Application network linking technology and the promotion of self-driving vehicles will bring significant influences to the road traffic. In future, most vehicles will become more intelligent, lighter in weight and of higher speed. Due to the complexity of China's road traffic system, the traffic accidents will not disappear completely; rather it will have more complex forms. The mixed traffic may include conventional human driving vehicles, modern self-driving vehicles and vehicles with different intelligence and security levels. At that time, a large number of road users will choose different traffic tools while some may still rely on bicycles and walking. Thus, the changed factors and factors remaining unchanged will mix and form a complex traffic scene in future. Based on the current accident characteristics, we consider possible changes in future vehicle models and transplant them into similar traffic scenes, to suppose and forecast the possible accident scenarios in future.

According to the aforementioned results of the discussions, though the number may be declining, the future traffic accidents will show more diverse and complex trends. Active considerations should be made in aspects of relevant laws, insurance, and issues of accident prevention, passenger protection, accident handling, on-site rescue, and so on, and early preparations should be made by the related research and development. Such preparations include, for example, the research on passengers' various sitting positions, liability identification specifications for accidents caused by self-driving vehicles, on-site rescue measurements in the complex accident scenes, etc., and more importantly, the timely feedback on the complex accident forms and scenes should be provided to the research and development process, so as to consider and avoid the risk of similar accidents, or to reduce the severity of accidents, thus make the future intelligent traffic system safer.

Developed countries in Europe and America, as well as some to the self-driving vehicles research and development departments have begun to realize these problems and actively address them. For example, according to US media Motortrend on October 8, 2015, Volvo said in public that if in future its self-driving vehicles cause any traffic accidents, Volvo would bear the all responsibilities of accidents caused under the self-driving state. Self-driving vehicles grow fastest in the developed countries in Europe and America, Britain and US have started to promote legal countermeasures, hoping to establish guiding laws and regulation for self-driving vehicles, especially in the vehicle insurance and accident-related lawsuits, compensation standards and so on.

At the same time, the diversification and complexity of traffic accident forms make a huge challenge to the reconstruction and identification work of accidents; the resulting vehicle speed analysis, responsibility identification, and ethical issues will become new research topics. For this reason, researchers should become more committed to the concerns and explorations of vehicle dynamic updates and accident form changing, so as to get better prepared for the new challenges brought by the future road traffic system.

5 Conclusion

Intelligentization and automation are the direction of advanced automotive research and development, and the development rapidly, which makes it worthy to deeply study and discuss whether the traffic accident forms will be changed accordingly, and how the change will be. At the same time, the summary of current typical accident forms can provide fact-based references to the design, research and development of the intelligent safety vehicles, and better prevent accidents in future. For advanced self-driving vehicles, human, machine and environmental factors are still affecting the risks of accidents. For example, on the general direction, there will be a transition period from human-driving to self-driving; in the respect of China's national conditions, the economic development is uneven, various types and classes of vehicles co-exist on road, including both advanced vehicles and ordinary and outdated ones; the civilization qualities and traffic safety awareness differ significantly; in some areas people and vehicles mix on the same road for a long time, which will inevitably cause accidents; with various levels of intelligent vehicles joining the traffic, the accidents might be even more complex; and vulnerable road users, as the most important collision avoidance objects, should be considered and focused in the research. Despite of the current vigorous researches and developments of self-driving vehicles, too many issues remain to be addressed and tested with time.

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Part III
Research on the Environment Character

China's Cement Industry Implicit Carbon Dioxide Emissions Research

Jinliang Zhan

Abstract Cement production is one major anthropogenic carbon dioxide (CO_2) emission source. In China, domestic demand saturated situation caused the rapid increase of the cement exports. Western developed countries, in order to prevent leakage of carbon, will apply carbon tariffs to carbon intensive imports from developing countries such as China. Under the pressure of reducing carbon emissions, it is of important significance to study CO_2 emissions in cement production process. We adopt the plant level micro data in 2500 t and 5000 t new suspension preheater dry-process (NSP) cement production line, and through data analysis, calculated CO_2 emissions in each stage of cement production process, conducted environmental appraisal, measured the amount of carbon emissions in domestic cement production and implied carbon emissions in cement for export. As a result, we found a big deviation between CO_2 emissions factors based on the direct data and in the previous literatures, and believe that the CO_2 emission factor in Chinese cement production may be overstated in previous studies.

Keywords Cement · Embodied CO_2 · Export · Carbon reduction measures

1 Introduction

According to the related research, cement production is the major one carbon dioxide ($CO_{2)}$ emission sources, and about 5 % of man-made CO_2 emissions around the world is derived from the cement production [1]. The proportion of cement carbon emissions in China's carbon emissions was less than 5 % in 1990, above 10 % in 2009, and reach 11.5 % in 2012 [2]. Chinese cement carbon emissions made up 57.7 % of the world's cement production carbon emissions in 2012, and which more than 1.22 billion t in 2013. The Chinese government announced that in 2020, CO_2

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emissions of unit gross domestic product (GDP) will be lowered by 40–45 % than they were in 2005. In 2014, the Ministry of Environmental Protection and the national 31 provinces signed the “target letters of responsibility” for prevention and control of atmospheric pollution, stating the air quality improvement targets and key tasks clearly, in order to further demonstrates the responsibility of environmental protection under the local government. Cement industry structure adjustment, the energy conservation and emission reduction are imperative, and how to measure the CO_2 emissions in different stages of cement production has become an important part of green transformation development in cement industry.

2 CO_2 Emission Calculation in the Process of Cement Production

Cement kiln is the main equipment for production, new suspension preheater dry-process (NSP) cement kiln, which has the highest energy efficiency, is used in this study.

In China, some researchers measure cement production carbon emissions mainly based on the macro data. Liu [3] using the life cycle theory, quantified the embodied CO_2 emission from energy consumption. He calculated that Portland cement, ordinary Portland cement, and slag Portland cement’s CO_2 emissions is 295.4–445.6 kg/t by using the data from the statistical year book of cement. In the production of Portland cement and ordinary Portland cement, the carbon emission quantity is higher than that of slag Portland cement 50 and 35 %, respectively [3]. Li [4] adopted the almanac data and used mathematical model to calculate carbon emission of cement industry from 2001 to 2010 in China. The study found that the emissions increased year-by-year, and the cement production and emission intensity presented linear relationship. Carbon intensity per unit product in 2006–2010 dropped from 0.69 to 0.65 t CO_2/t [4]. Jian-Bing Shi according to 2014 IPCC Guidelines for the National Greenhouse Gas Emissions Inventory and China’s cement industry air pollutants emission standards limit project, calculated that the unit product CO_2 emission intensity in 2005–2011 had dropped from 0.68 to 0.58 t/t, equivalent to a CO_2 reduction of 1.03×10^8 t [5].

On the other hand, micro-data was also used by some other researchers to study China carbon emissions in cement production. Wei [6] showed that the system’s overall framework and calculation process of CO_2 emissions calculation method are roughly the same between domestic and foreign cement production process. In the calcination of raw material and dust, the combustion emissions of fossil fuels and alternative fuel, the consumption of purchased electricity, deduction item of waste heat power generation, CO_2 calculation method, and emission coefficient are different in different links [6]. Zhao [7] investigated the specific emission in 2500 and 5000 t/d NSP production line, and expounded the relevant method of CO_2 emission quantity by using comparative analysis.

Yuan-BoGeng (2015) investigated 23 new dry process kiln and 13 shaft kiln production lines, through quantitative analysis in the cement production process, figured out that the emission factor for new dry process kilns is 787 $kgCO_2/t_{cl}$, for shaft kiln is 839 $kgCO_2/t_{cl}$ [8].

This paper mainly studies the CO_2 emission in the key stages of the cement production process, which includes carbonate decomposition in cement clinker calcination, fuel combustion, and purchased electricity consumption after the removal of waste heat power generation. The CO_2 emission in the transportation of raw material, fuel, and cement products was not considered.

2.1 Carbonate Decomposition Process

Carbonate decomposition in the cement raw meal can be calculated by the raw meal method and cement clinker method. As the data of carbonate type, contents, calcination proportion in the raw meal can be obtained directly, calculation results are fairly accurate by using cement raw meal method. The cement clinker method has some advantages, such as it is simple to operate, and has easy to access data. This article adopts the cement raw meal method to study the factory data in 2500 and 5000 t/d NSP kilns in cement production. Parameters in two production lines similar to Zhao [7]. There is a 4.5 MW waste heat power generation system in 2500 t/d production line.

Using the raw meal calculation method, according to the calculation formula proposed by Chinese Building Materials Research Institute, when using alternative raw materials, include calcium carbide slag, steel slag, magnesium slag, etc., CO_2 emissions quantity from the decomposition of carbonate minerals can be expressed by E_A, Eq. (1).

$$E_A = \frac{R_c}{(1 - L_c) \times F_c} \tag{1}$$

The denotations R_c refers to accumulation of CO_2 in the cement raw meal, L_c refers to ignition loss of the cement raw meal, and F_c refers to conversion factor of ash content infiltration quantity in cement clinker (the default value is 1.04). The calculated CO_2 emission coefficients of unit cement clinker in carbonate decomposition by using alternative material are shown in Table 1.

Table 1 CO_2 emission calculated result in carbonate decomposition process by two methods

Production line (t)	CO_2 emission coefficient ($kgCO_2/t_{cement\ clinker}$)
2500	525.86
5000	528.67

Table 2 CO_2 emission value of fuel combustion($kgCO_2/t_{cement\ clinker}$)

Production line (t/d)	Coal ($kgCO_2/t_{cement\ clinker}$)		Diesel ($kgCO_2/t_{cement\ clinker}$)	
	IPCC default	Equation (2)	IPCC default	Equation (2)
2500	449.38	315.45	2.12	2.02
5000	468.23	341.94	9.67	9.22

2.2 Fuel Combustion Process

Carbon emissions from unit coal heat consumption are 10–30 % higher than from fuel. Su-Ping Cui (2008) puts forward the CO_2 calculation formula in the fuel combustion process [9]. The formula is as follows:

$$E_B = 3.67Fqka \tag{2}$$

The denotations E_B refers to CO_2 emissions, kg. F refers to fuel consumption, kg. q refers to fuel heating power, MJ/kg. k refers to carbon emission factor of fuel, a refers to carbon oxidation rate of fuel. CO_2 emission coefficients in raw meal calcination process are shown in Table 2.

2.3 Indirect CO_2 Emissions in Consumed Electricity

The state released CO_2 emission factor is used to estimate the CO_2 emissions of coal-fired power. The formula of emissions of produced electricity is shown as Eq. (3).

$$E_D = \frac{(E_a + E_b + E_c - E_r)}{M_a} \cdot EF_{el} \times 1000 \tag{3}$$

The denotations E_D refers to the unit cement clinker electric discharge coefficient ($kgCO_2$/t cement clinker), E_a refers to power consumption for cement raw meal preparation (kWh), E_b refers to power consumption of for cement clinker calcination (kWh), E_c refers to power consumption in other process, without include the cement grinding, kWh. E_r refers to power generation by the waste heat power (kWh), EF_{el} refers to coefficient of CO_2 emissions in power ($kgCO_2$/MWh), and M_a refers to cement clinker production per year (t).

Total carbon emissions coefficient of a single production line clinker can be calculated by summing the carbon emission coefficient of each link. It also can be calculated by cement clinker and cement ratio. Cement clinker and cement ratio can be calculated by cement clinker quantity and cement quantity, the formula as shown in formula (4).

Table 3 CO_2 emission of unit cement clinker and cement

Productivity		IPCC default value ($kgCO_2/t$)	Not using alternative materials ($kgCO_2/t$)	Using alternative materials (revised $kgCO_2/t$)
2500 (t/d)	Cement clinker	1030.27	963.81	921.92
	Cement	813.78	763.09	730.44
5000 (t/d)	Cement clinker	1032	955	922.52
	Cement	827.29	769.47	743.90

Table 4 CO_2 emission coefficient in cement production by literature research

Year	In 2010	In 2011	In 2012	In 2015
CO_2 emission coefficient, $kgCO_2/t_{cement}$		445.6 [3], 650 [14]	880 [15]	830 [16]
CO_2 emission coefficient, $kgCO_2/t_{cement\ clinker}$	547 [10]			787 [8]

$$EF_{cement} = EF_{cementclinker} \cdot \frac{(M_a - M_s)}{M_c} + \frac{E_d}{M_a} \cdot EF_e \times 1000 \tag{4}$$

The denotations EF_{cement} refers to CO_2 emission factor per unit cement ($kgCO_2$/t), M_a refers to annual cement clinker output (t), M_s refers to annual sales amount of cement clinker (t), M_c refers to annual cement output (t), E_d refers to power consumption in cement grinding (kWh), EF_e refers to CO_2 emissions coefficient for the power ($kgCO_2$/MWh).

Coprocessing technology can not only solve the waste and garbage disposal problem, but also can reduce the CO_2 emission. Through calculation, cement clinker and cement ratio in the 2500 t/d clinker production line was 76.9 %, and in the 5000 t/d clinker production line was 76.2 %. The specific calculation results are shown in Table 3.

In the literatures related to the cement production, the estimated CO_2 emission factor as shown in Table 4. By comparing CO_2 emission factor of the cement production in literatures, we found that the factors are numerically volatile in each study. In some literature, the cement CO_2 emission factor was overestimated by about 4 %. In other literature, the cement clinker CO_2 emission factor was undervalued about 17.3 %. In addition, in the cement clinker production, only the carbonate decomposition process was considered in the calculation of CO_2 emissions, while the fuel emissions were not considered.

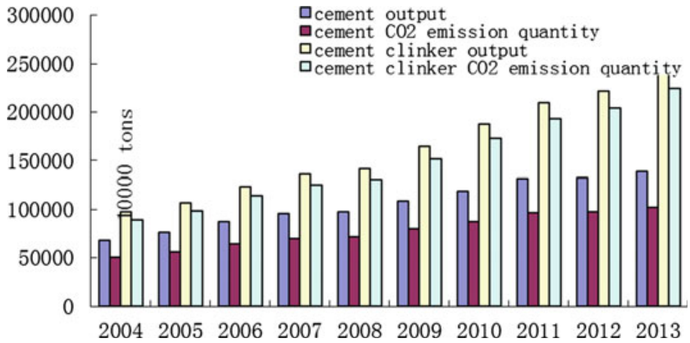

Fig. 1 The output of cement and cement clinker, CO_2 emission quantity in 2004–2013

3 The Export of Cement Implied Carbon Emissions

Since the policy of national macro adjustment to the real estate market, aggravated by the weakness of domestic demand for cement, more companies chose to reduce stocks through exports, which caused the cement exports to increase in recent years. According to the CO_2 emission factor above, the output of cement and cement clinker, CO_2 emissions quantity between 2004 and 2013, were estimated as shown in the Fig. 1.

As for the exports, according to China customs export statistics data including cement and cement clinker in 2004–2013, from China to Japan, South Korea, Britain, Germany, France, Italy, the Netherlands, the United States, we calculated the implied CO_2 emissions of the Portland cement and cement clinker, and the results are shown in Figs. 2 and 3.

Thailand, Vietnam, and other neighboring countries are stepping up efforts in cement exports in recent years. Therefore China's cement is confronted with intense competition in the global market more and more.

4 The Environmental Evaluation of Cement Production

Global warming potential (GWP) is an index, which makes all kinds of greenhouse gas corresponding to the same effect of the quality of CO_2, within 100 years. Because CO_2 plays an important role in global warming, it was used as a reference gas in study. According to the Silveira, Villela, and Coronado's research [10–13], GWP formula as follows:

$$(CO_2)_e = CO_2 + 1.9 \cdot (CO) + 25 \cdot (CH_4) + 50 \cdot (NO_x) + 80 \cdot (SO_2) + 67 \cdot (PM) \quad (5)$$

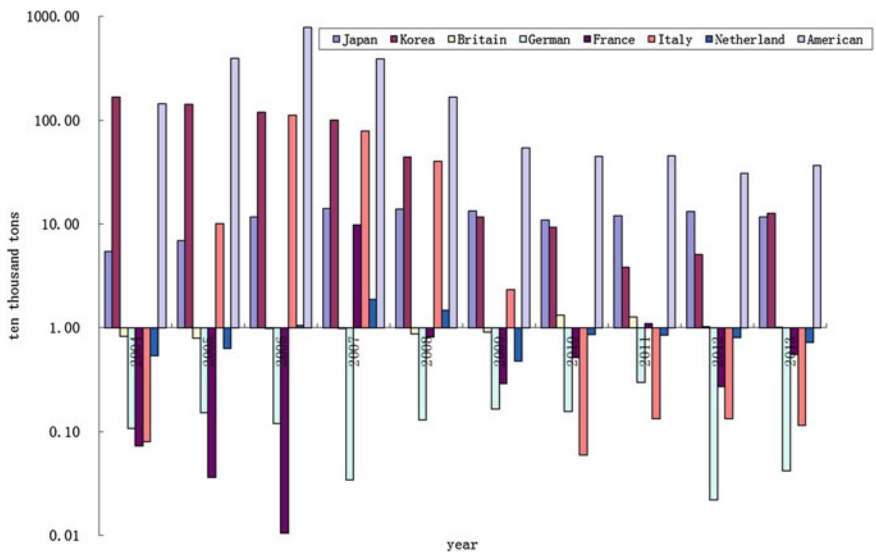

Fig. 2 Cement embodied CO_2 that China exported to developed countries in 2004–2013

The denotations CO_2 refers to carbon dioxide, CO refers to carbon monoxide, CH_4 refers to methane, NO_x refers to nitric oxide, SO_2 refers to sulfur dioxide, PM refers to particulate matter, related data as shown in Table 5.

Using discharge coefficient method to calculate SO_2, NO_x, the formula is as Eq. (6).

$$G = M \times G_{\text{coal}} \times 10^{-3} \tag{6}$$

The denotations G refers to emission quantity of SO_2, NO_x per year (t/a). M refers to SO_2 and NO_x pollution discharge coefficient (kg/t), SO_2 pollution discharge coefficient is 0.06, NO_x pollution discharge coefficient is 1.584. G_{coal} refers to the dosage of coal-fired industrial boiler system throughout the year (t).

Cardu put forward the pollution index, which through the carbon equivalent and low heating value to quantify the environmental pollution. As shown at Eq. (7).

$$\Pi_g = \frac{(CO_2)_e}{\text{LHV}} \tag{7}$$

The denotations $(CO_2)_c$ refers to GWP (kg/kg$_{\text{fuel}}$), LHV refers to the low calorific value of fuel (MJ/kg$_{\text{fuel}}$), and Π_g refers to pollution index (kg/MJ).

The ecological environment efficiency index calculation formula is shown below.

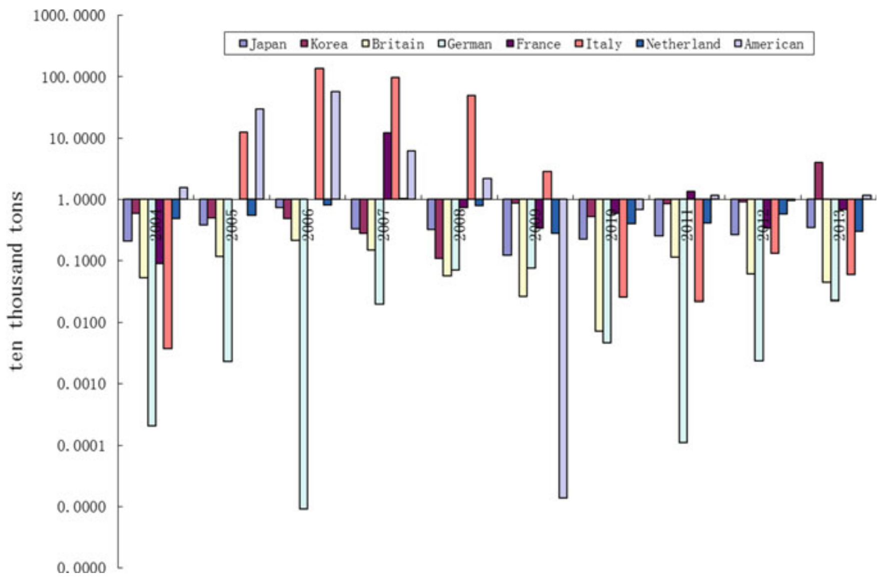

Fig. 3 Implicit CO_2 in cement clinker exported to developed countries in 2004–2013

Table 5 The estimate of PM2.5 emission quantity in China's cement industry

	$PM_{2.5}$ coefficient ($kg/t_{cement\ clinker}$)	Grinding mill $PM_{2.5}$ coefficient (kg/t_{cement})	$PM_{2.5}$ emission quantity (t)
Zhu [17]	0.005771	0.000346	8690
Tian [18]	0.01266	0.00002	17,278
Ma [19]	0.3352	0.0016	460,069

$$\varepsilon = \left[\frac{0.204 \times \eta_{\text{sysem}}}{\eta_{\text{sysem}} + \Pi_g} \times \ln\left(135 - \Pi_g\right)\right]^{0.5} \tag{8}$$

η_{sysem} refers to the proportion of cement plant annual production with fossil fuel energy consumption. Through calculating the ecological efficiency, pollution index and carbon equilibrium value, GWP value are shown in Table 6.

In the cement kiln production line of 2500 and 500 t/d, η_{system} is 18.22 and 17.79, respectively. The calculated results are shown in Table 7.

From the calculation results, the ecological efficiency coefficient of 5000 t/d production line is higher than 2500 t/d cement production line.

Table 6 GWP value of cement production line without using co-processing technology

	CO_2	CO	CH_4	NO_x	SO_2	PM
GWP 2500 t production line (kg/kg_{fuel})	5.928	0.00126	0.0000284	0.208	0.0087	0.9809
GWP 5000 t production line (kg/kg_{fuel})	5.418	0.00238	0.0000284	0.3919	0.0164	0.6922

Table 7 Related parameter calculated result

Production line	$(CO_2)_e$ (kg/kg_{fuel})	Π_g (MJ/kg)	ε
2500 t production line	82.7474	3.9577	0.9039
5000 t production line	72.70763	3.4775	0.9125

5 Conclusion

Through the environment evaluation, we found that ecological efficiency in 5000 t/d cement production line is higher than 2500 t/d production line. Therefore, the production line, which has large capacity and higher production efficiency, should be promoted in the practical application. The government should put more efforts in accelerating cement industry structure adjustment. The government should accelerate the technological innovation of the second generation of NSP cement, promote the energy conservation and emission reduction project, and enhance competitiveness of cement plants production. Chinese government should beware of the overcapacity situation caused by urbanization in the cement industry. At present, China's urbanization rate is 51.3 %, and about 35 % if excluding the 180 million migrant workers, while in developed countries, the urbanization rate is more than 70 %. The urbanization not only brings opportunity to the cement industry, but also may stimulate the cement industry at the same time. Chinese government should control the blind expansion of cement enterprises, as early as possible, so as to avoid further deterioration of the overcapacity of cement industry.

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Application of Acoustic Detection Technology in Reconnaissance Warning Equipments

Cheng Jin, Zhibing Pang, Runfeng Hou, Genhua Qi, Hongyan Ou and Changhong Yuan

Abstract *Purpose* The importance of acoustic detection technology used in reconnaissance warning equipments of future air defense operation is described through analysis. *Method* The characteristics of acoustic detection technology and acoustic detection equipments are described. The future trend of development of acoustic detection technology is also discussed. *Result* Acoustic detection technology has broad research spaces and prospects in the research and development of space weapons. It plays a very important role when used in reconnaissance warning equipments. *Conclusion* Study on acoustic detection technology and equipments is urgently needed to be strengthened. It is one of the effective ways to enhance early warning capability in future air defense operation.

Keywords Characteristics of acoustic detection technology · Reconnaissance and warning · Trend of development

1 Introduction

Acoustic detection technology is a very old discipline. Its military application originated in World War II, which played a very important role in the detection of enemy's artillery and submarines. But after World War II, due to the rapid development of light and radar technologies, it was spurned and made slow progress [1]. Modern warfare is comprehensive information warfare. Because of the application of reconnaissance and counter-reconnaissance, jamming and anti-jamming, stealth and anti-stealth, deception and counter-deception, modern warfare has become the contest of high technology among countries. Active detection

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technology and optoelectronics can not fully meet the reconnaissance demands of modern cubic war. Since 1980s, with the vigorous development of stealth aircraft, helicopters and unmanned aerial vehicles and other high-tech weapons, extensive use of anti-electromagnetic, anti-optical, anti-radiation weapons, and equipments, acoustic detection technology has shown great advantages in low-altitude, low altitude target detection. Countries race to develop acoustic detection technology. In addition, the opening up of low-altitude airspace and emergence of slow small target makes our country's demand for acoustic detection technology grow.

2 Characteristics of Acoustic Detection Technology

Acoustic detection technology mainly takes the mode of passive detection. It analyzes the acoustic characteristics of the target by using a microphone to detect acoustic signals emitted by the target. According to the delay and phase relationship generated by the target radiated noise in each microphone in the microphone array, the position feature of the target, state of motion, and attribute information are estimated [2].

Main characteristics of acoustic detection technology are as follows:

1. Acoustic detection technology applies a comprehensive, all passive detection mode. It is so good at concealment that it is not easy to be found and destroyed by enemy's electronic reconnaissance equipments, neither affected by electronic interference signals. Good concealment.
2. Acoustic detection technology is not affected by visibility conditions such as smoke, light, shelter, etc. It can bypass the mountain and spread through the jungle. So target across mountains or in jungles can be detected. It can work at night and in cloudy, foggy, and snowy days, which allows work around the clock.

With the development of modern technology, there are more and more new detection principles and detector elements. In particular, sensing, detection technology, microelectronics, signal processing, artificial intelligence, and communications technology has made rapid progress, which enables the application of acoustic detection technology in low altitude and super low altitude, battlefield reconnaissance and various military areas of home and abroad. Acoustic detection equipments also take great effect.

Main characteristics of acoustic detection equipments are as follows:

1. Acoustic detection equipments have simple structure, small size, light weight, high mobility. It can realize a large number of deployment and self-positioning by dissemination.

2. Acoustic detection equipments can form a network. By using data fusion algorithm, high reliability of passive detection, and low false alarm can be realized.
3. For some low-altitude and ground targets, which are in the fade area of electronic detection device such as radar, the application of acoustic detection equipments can cover blind area, taking unique effects.

3 Application of Acoustic Detection Technology in Reconnaissance Warning Equipment

3.1 Detection and Location

Using sound information to detect low altitude, low-altitude helicopter gunships and cruise missiles and other targets is an important application direction of Acoustic detection technology in Reconnaissance Warning Equipment. Nowadays, modern army has formed a series of products to equip our troops based on this technology, which plays an irreplaceable role in the air defense reconnaissance and early warning, especially in strong electromagnetic environments. For example, AEWS acoustic detection warning system developed by Israel can detect micro-aircraft, helicopters and fixed-wing aircraft which fly slowly. Helisearch, acoustic detection system of helicopter developed by Sweden company Swctron and Picker, helicopter alarm developed by British company Ferranti both have high detection performance. Detection range is up to 15–20 km. Azimuth accuracy is less than 1°. The ability of multi-target detection and recognition is strong [3].

3.2 Form Net to Improve Early Warning Capacity

The technology of detecting low-altitude, low altitude cruise missiles and other targets by networking acoustic detection unit has been in continuous research development, though there is no real equipment reported abroad. From the land-based network of acoustic detection unit to the buoy network, local verification tests have never stopped. Its main content is making use of information sharing and fusion technology to realize reconnaissance and early warning in a large area through the integrated use of probe information acquired by acoustic detection units routed in this area. It can improve the detection performance of the entire system at the same time. For example, in the 1990s, the United States carried out experiments of detecting cruise missiles by buoys.

3.3 Anti-stealth Targets

With the development of stealth technology, the detecting ability of reconnaissance warning equipment mainly based on radar and electro-optical is faced with severe challenges. At present, countries are seeking new means to solve the problem of detecting stealth weapons such as stealth planes and cruise missiles that can perform sudden attack invisibly. These objectives are inevitable to radiate high intensity noise and it is difficult for these air targets to remove the noise. So using acoustic detection equipments to detect stealth targets is one of the most effective ways.

3.4 Cordon Warning

Since acoustic detection equipments are simple, low cost and can be unattended after network construction, they have become a research focus of many countries. The United States once used many detector arrays consisting of five microphones to detect the sound of B-2 bomber's 8 km away. The signal's arrival direction could be roughly estimated. Signals detected by each array are transmitted to the central facility for processing. It will construct cordon to cover the path B-2 bomber may enter [4]. Such a "cordon" can flag up any aircraft flying over the coverage area. It is a simple air defense system while the effect is obvious.

4 The Development Trend of Acoustic Detection Technology

Modern war mainly depends on high-tech weapons. New weapons and equipments continue to emerge. Battle space is increasingly becoming more cubic. It is hard to distinguish the front and the back of the war. This is called Ocean, Earth, Space, Air, Electronic integrated combat. Therefore, the future development of acoustic detection equipment must be closely linked to the operational characteristics of modern warfare. From the perspective of actual combat and troop needs, performance of acoustic detection equipments should be improved and types of acoustic detection equipments should be enriched.

4.1 Increase the Application of New Microphones

While improving and upgrading the technology of current electret microphones, research on developing new microphones should be put vigorous attention, which include fiber microphone and vector microphone. Receiver sensitivity and directivity should be improved. The performance of acoustic detection equipment should also be improved from the source [5].

4.2 Layout Develops to Be Three-Dimensional

Microphone array develops from current layout of point, line, surface to grade separation layout. Besides, aperture and gain of the array should be increased with the sound source level radiated by acoustic detection target radiation continuing to decrease. Random array has greater potential in mobility and increasing array aperture than other fixed forms of array, which can constitute an array of large sound aperture. Although position of each microphone is randomly distributed, as long as the relative position between those microphones are determined somehow, and then after applying appropriate signal processing techniques, a beam of higher gain can be produced at low frequencies in order to achieve good performance of remote target detection.

4.3 Acoustic Detection Equipments Develops Towards Miniaturization

With the development of modern high technology, new acoustic detection equipments are developing rapidly towards multifunctional, multipurpose, miniaturization, and intelligent. Detection of various targets is completed by a single device. Acoustic detection equipments also develop from complex huge equipments to small and integrated equipments which are concealed, anti counterfeiting and easy to carry by one.

4.4 Improve the Environmental Adaptability of Acoustic Detection

Acoustic detection technology under the condition of uniform propagation medium, isotropic noise field and plane wave signal should develop towards acoustic detection technology that employs nonplane wave, non-Gaussians, non-stationary signals and environment processing of noise's actual characteristics. It also transits from stable platform detection methods to non-stationary platform detection methods in order to access and occupy more information and knowledge thus improving the sound detection performance.

4.5 Detection of Cooperative Methods

The ability of detection cooperative with radar, and other means should be developed. Organic combination of radar, photoelectric, acoustic, and other detection means should be realized. Learn from each other, confirm each other, then cooperative all-new battlefield target detection system which covers the whole airspace, full range and whole target is formed in the true sense, thus effectively completing battlefield reconnaissance warning.

5 Conclusion

Modern war is high-tech war, as well as comprehensive information war. Reconnaissance early warning plays the key role in the air defense operations. It is the first to bear the brunt while functions throughout the war. Faced with challenges from (ultra) low-altitude aircrafts, western military powers are exploring new technologies to confront. With the development of modern science and technology, new detection principles and detectors are also generated constantly. Acoustic detection, which is all passive and comprehensive, is attracting more attention. We should develop sound detection technology and apply it to reconnaissance warning equipment for future air defense combat. We can use this acoustic detection technology to make up for blanks in detecting (ultra) low-altitude aerial targets from acoustic frequency. In this way, we can improve our ability of reconnaissance and early warning, which is an urgent demand in modern air defense operations.

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Research on the Building of Training Field of Complex Electromagnetic Environment

Shujie Zhang, Binliang Lu, Yan Sun and Honglei Li

Abstract It is fairly challenging for the CPLA forces to minimize the gap between military training and real combat. Building of training field of complex electromagnetic environment is the precondition to polish the competency of combat command of commanding officers of various levels and that of real combat of units of various levels under complex electromagnetic conditions. In the article, building complex electromagnetic environment scientifically to attune to the needs of real combat, building training field combining real-plus-virtual training environment to attune to the needs of military training, building the comprehensive military drill platform for units by strengthening four attributes of training field are discussed. It is of some guiding significance for units to build training field of complex electromagnetic environment.

Keywords Complex electromagnetic environment · Training field

1 Introduction

It is fairly challenging for the CPLA forces to minimize the gap between military training and real combat, improve the competency of real combat and win operations under complex electromagnetic conditions. The complex electromagnetic environment building is purposed to provide close-to-real-combat training support conditions, and is beneficial for units to upgrade real combat training quality and obtain optimal training result. It is the precondition to polish the competency of combat command of commanding officers of various levels and that of real combat of units of various levels under complex electromagnetic conditions [1].

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2 Building Complex Electromagnetic Environment Scientifically to Attune to the Needs of Real Combat

The units have attached great importance to military training under complex electromagnetic conditions, gathered considerable experiences, and made material achievements. However, there still exists a big gap between the training status quo and the needs to win operations under information conditions, such as the failure of commanding officers to cognize and be adapted to operation under complex electromagnetic conditions, and the poor competency of operating personnel to get control of complex electromagnetic environment. The main reason is referred to the inadaptability of infrastructure building to the development of training, namely, the configuration of complex electromagnetic conditions does not attune to the needs of combat and training, and consequently resulting in the difficulty in steady and precise training.

Whether training reflects the needs of real combat or not, and whether the awareness of complex electromagnetic environment and ECM capabilities of commanding officers and operating personnel can be improved or not, to a large extent, are determined by whether the complex electromagnetic environment of training field is in line with real conditions of future battle space. Complex electromagnetic environment building should therefore highlight the needs of full factors, multiple types, and high density by all possible means in order to reflect the needs of real combat and improve training quality.

It is desirable to take the frequency band and features of such equipment as communication devices, early-warning radars and fire control radars into account to determine the types of complex electromagnetic environment, in accordance with the types of electromagnetic interference. Electromagnetic interference is generally categorized into natural geographic environment, mutual interference of electronic devices of friend units, hostile interference environment, and civil electromagnetic radiation environment [2]. Not all aforementioned electromagnetic environments constitute threat to operations unless they use the same frequency or signal as our equipment and are relevant to our equipment, or the radiation energy or signal strength goes beyond the safety limit of our equipment. Therefore, the training field complex electromagnetic environment configuration should stress electromagnetic environment that constitute practical threat to units in real combat, such as natural geographical environment, hostile jamming environment against our wireless command communication, the guiding environment of enemy precision air strike, the hostile jamming environment against our radars (including early-warning radar, fire control radar and so on), enemy self-defense aerial electronic jamming, as well as civil high-power radiation environment [3]. The means of hostile jamming against our radars is categorized into pulse modulation jamming, laying jamming, frequency sweep jamming, range deception, angle deception, dummy target deception, combined jamming, and so on [4].

It is desirable to determine the strength of complex electromagnetic environment in accordance with the rating standards of electromagnetic environment. Set electromagnetic environment into 4 levels and 10 sublevels as general level (sublevels 1–3), mild level (sublevels 4–5), moderate level (sublevels 6–7) and serious level (sublevels 8–10) based on such indexes as spectrum occupancy, noise level relative increment and jamming signal power [5]. Spectrum occupancy is understood as the ratio of occupied spectrum of military, civil, and jamming signals to available spectrum; noise level relative increment refers to the increment of average background noise level relative to that before building complex electromagnetic environment; jamming signal power means the difference between the peak power of original signals and the field intensity peak power of self-interference, mutual interference and hostile jamming. The combination and superposition of those 3 indexes (variables) shall result in electromagnetic environment of differing strengths and complexity.

3 Building Training Field Combining Real-Plus-Virtual Training Environment to Attune to the Needs of Military Training

It is a must to build environment facing the challenge of training and task-rehearsal in broader band of spectrum along with the development of high-tech weapons and equipment, the expansion of battle space and the change of operational environment, in order to attune to the needs of military training and improve the competency of winning real combats. However, it is hard to realize merely based on the current situation and future development due to the uncertainty of imaginary threats, namely, the complexity and uncertainty of hostile jamming and the uncertainty of natural geographical environment. And it is impractical to obtain many such ideal sources of threats even if building training environment of electromagnetic threats by all possible channels to acquire or replicate the sources of threats of imaginary enemy. Therefore it is necessary to build training field of networked complex electromagnetic environment combining real troops and weapons, virtual training, and war games, which integrates equipment, technology, and procedures of the recon and early-warning system, C2 system, firepower system, and comprehensive support system into training of complex electromagnetic environment.

The complex electromagnetic environment combining real troops and weapons, virtual training, and war games may satisfy the needs of military training and promote immediate production of combat effectiveness [6]. Real troops and weapons means to train real troops with real weapons and equipment in complex electromagnetic environment which is close to real combat; virtual training is understood as to train real troops with simulation systems; war games means to train real troops with simulation systems in simulated environment based upon a specific scenario. Combine those 3 training means with built-in training system to ingeniously integrate real troops, simulators and war games into a complete training system. Such training environment built in training field of complex electromagnetic environment may on the one hand effectively solve the problem of joining training which combines recon and early-warning, command and control, and firepower, and the problem of shortage of training resources, on the other hand, it integrates training participants into a vivid complex electromagnetic environment in visual, hearing, and tactile senses.

The point of strength to build such real-plus-virtual complex electromagnetic environment lies in

To develop threat source simulators of new types. A threat source simulator is a broad-band and program-controlled system of high flexibility, using precise threat-replicating devices and reprogrammable core-module system which simulates various threat radiation system, and avails training field with almost real complex electromagnetic environment according to real needs of battle space.

To promote the interoperability and compatibility of training field building [7]. The training network based on built-in systems characterized in improved between the interfaces of weapons/equipment and those of training devices in the training field, and the interoperability and compatibility among various training devices in the training field itself.

To highlight the features of real combat of training field. There are 3 ways to realize it. First, to provide real-time feedback to ensure the lifelike effects. In order for units to feel the atmosphere of real combat of complex electromagnetic environment and acquire real-time feedbacks, we should link the training system with hostile threat source system and realize interoperability with built-in devices on real weapons and equipment, for training participants to feel almost real combat effect, meanwhile to lay foundation for training assessment. Second, to stress the diversity of targets and the flexibility of configuration. Simulated targets should include fighter planes, UAVs, anti-radiation missiles and so on, on the other hand, the method to configure simulated targets should be flexible so as to satisfy the needs of differing training space and specific training tasks, and to provide instant and accurate tactical background for real troops of different echelons. Third, to combine real and virtual means so that electronic confrontation and firepower are better featured in real combat. Comprehensively reflect the striking effect of helicopters, UAVs and fixed-wing aircrafts, and give prominence to vividness of operation in all such combat proceedings as recon, searching, tracking, electronic confrontation, sequential prioritizing, firing, destroying, and assessment.

4 To Set up the Comprehensive Military Drill Platform for Units by Strengthening Four Attributes of Training Field

The goal of building of training field of complex electromagnetic environment ought not to be limited in electronic confrontation training, but meet the demands of full-element and full-spectrum training to improve the training efficacy of tactical joint training.

To strengthen the attribute of versatility of training field guided by the principle of based-on-competency. The principle of based-on-competency is understood as to resist all possible hostile targets adopted by potential enemies by advanced means of combat under complex electromagnetic conditions, other than some certain enemy or air strike weapon. The training field of complex electromagnetic environment is thus required to facilitate units to take actions against multiple crises in diversified terrain and electromagnetic conditions. Therefore, on the basis of probable tasks, we should optimize training field building and expand the function of training field so that it supports multithreading, namely, to meet the demands of multiple training in one single training field.

To strengthen the attribute of suitable-for-joint-training with full-element joint training as the main training pattern. The training field of complex electromagnetic environment shall not only support the training of communication devices, early-warning radars, and fire control radars, but support the training of all equipment of units as well. In addition, it should strengthen the coordination, cooperation, and connection with outer combat forces to improve the training capacities of tactical joint training while fulfilling regular training tasks.

To strengthen the attribute of flexibility of training field with modulated function expansion as the standard. In order to meet the demands of tactical joint training, the training field should be able to integrate multiple simulated training subsystems into a big system of multiple functions for multiple training tasks by combining the function modules of the training field. A training field of modulated functions is suitable for diversified tasks and complicated environment, which not only facilitates targeted training and adaptability training, but also networked joint training. Regroup the supporting facilities of combat system by means of system technological integration to set up control system clusters for various functions, so as to form the training field technological system group suitable for given tasks. Then, configure the training field building-block-like control system cluster for differing tactical actions in order to provide close-to-real-combat training background of complex electromagnetic environment.

To strengthen the attribute of practicality of training field by stressing confrontation and real-time assessment. Training field building should stress the characteristics of confrontation and real-time assessment in order to promote the vividness of training and real combat confrontation [8]. Therefore, with regard to target setup, training field should massively apply effect emulators to simulate electromagnetic interference effect as well as battle field audio and visual effects; with regard to effect judgment, training field should assess training effect scientifically by joining built-in training devices to control systems and target systems in order to collect and record multiple data.

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Research on the Law of Biochemical Degradation of Solidified Sludge Based on 3D Fractal Dimension

Pei Wang, Fei Xue, Jinxiang Yi and Fei Xu

Abstract At present, landfill is the main way of sludge disposal in China. For the solidified sludge contains a lot of organic matter, the biochemical reaction will happen in the landfill, and the micro-structure of solidified sludge will has a great change. In order to reveal the law of biochemical degradation and the microscopic mechanism of solidified sludge, this paper designs organic matter biodegradation test under conditions of aerobic, anaerobic condition and leachate adding. Through 3D fractal dimension, it presents an obvious staggered characteristic of biodegradation of solidified sludge. It comes to the results that the biodegradation of solidified sludge is fastest and most thorough under leachate condition.

Keywords Solidified sludge · GIS · Microstructure · Fractal dimension

1 Introduction

With the rapid increase of population, the fast pace of urbanization and the continuous improvement of living standards, the output of sewage has increased dramatically [1]. Solidified sludge is a relatively homogeneous matter which contains sludge and solidified agent [2]. Since sludge contains lots of organic matter and microorganism, the biodegradation would begin after landfill. Li et al. [3] studied the influence of microbial activity on sludge strength under different curing conditions.

In the process of biodegradation, the composition and microstructure of the sludge would change, which leads to the settlement of sludge landfill, so it is necessary to study the change rule of microstructure of sludge in order to understand

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the macroscopic mechanical properties of the sludge. Analyzing the micro-structure from micro-perspective contribute to reveal the variation regulations of sludge and solidified sludge. In current, relevant researches have made it possible to estimate porosity and other structure parameters through understanding images based on GIS [4]. Chew et al. [5] found that the change of the engineering properties of marine clay is caused by the change of the microstructure by means of SEM, XRD, EDS and other modern analysis methods. Meanwhile, some other researches show that fractal dimension is an important parameter to characterize distribution and complexity of the internal morphology of soil effectively [6, 7].

This paper designs organic matter biodegradation experiments under different conditions (aerobic condition, anaerobic condition, and leachate condition) to quantitatively analyze the variation of microstructure morphological parameters based on 3D fractal dimension. Based on SEM images, the law of solidified sludge biodegradation under different conditions is studied through transformation rules, and microstructure parameter is quantitatively analyzed by GIS methods.

2 Materials and Preparation

Dewatered sludge from a sewage treatment plant of a certain city in China is taken as origin material; $32.5^{\#}$ ordinary portland cement is applied as solidified agent. Sludge is divided into 3 samples, mixed with 15 % cement of their weight. Sample 1 is used to study the law of microstructure of solidified sludge under aerobic conditions; same amount of fresh leachate from Tianziling landfill is added into the sample 2 (200–400 ml every time), which is to studied the law of microstructure of solidified sludge under aerobic condition and leachate condition. To cut off the air and reduce water evaporation, sample 3 is sealed with plastic wrap in order to research the law of microstructure of solidified sludge under anaerobic condition.

All samples are maintained in the basement of greenhouse in which temperature varies little in 4 seasons. At different stages of biodegradation, SEM images are taken for each sample. Appropriate and representative pictures are selected for microscopic mechanism research among all SEM images.

3 Research Methods

3.1 Fractal Theory

Surface area-volume method is derived from fractal theory of Mandelbrot [8], if research object is an isolated island and other closed curve or surface, it is feasible to use the surface area-volume method to calculate fractal dimension which describe its complexity and irregularity.

For the geometry object of which the three dimensional structure is irregular and rough, B.B. Mandelbrot put forward to use the fractal surface area $A(\varepsilon)$ to replace the smooth surface area A and fractal volume $V(\varepsilon)$ to replace the smooth volume V. To improve calculation efficiency, ε is taken as 1; D is the fractal dimension; a_0 is constant associated with curved shape of the island. So relationship above is promoted as the following:

$$\log[V] = \frac{3}{D}\log[A] - \log\left(a_0^3\right) \tag{1}$$

K is the linear portion of slope, and 3D fractal dimension can be calculated as formula (2):

$$D = \frac{3}{K} \tag{2}$$

3.2 *Extraction of 3D Fractal Dimension of Solidified Sludge Based on GIS*

To study micro-structure of solidified sludge, SEM images should be well-selected. In this essay, the magnification of SEM images, which is tested by Wang et al. [4], is set to 2000× for global view, and 3000× for unit extraction. Figure 1 shows the SEM image of biodegradation under aerobic condition. In order to select representative areas, SEM samples are cropped of different stages of biodegradation by Photoshop. Selected and extracted particles should be obvious, and the surface of which should be intact. In order to calculate the surface area and volume, the area was filled with black whose gray value is 0 which is out of particles in the cropped image. The cropped images are saved as separate image files as shown in Fig. 2.

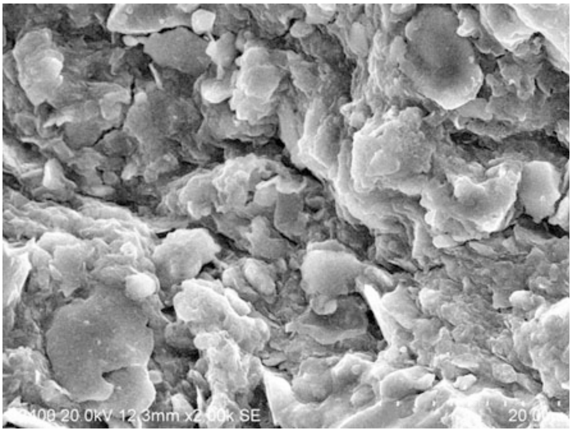

Fig. 1 SEM image of solidified sludge under aerobic condition

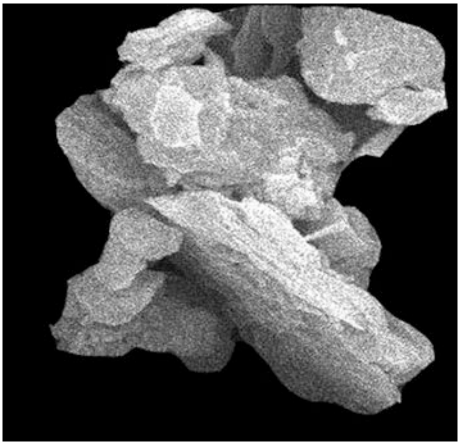

Fig. 2 Sketch map of cropped pattern

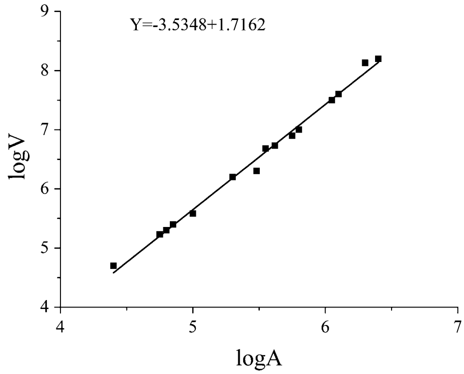

Fig. 3 The log[*A*] − log[*V*] curve line of a SEM image

To ensure the authenticity of fractal dimension results, 15 samples are chosen for each stage, and DEM models are established by 3D Analyst tool of ArcScene module. Then, surface area and volume of particles are calculated.

The results of surface area and volume are plotted in double logarithmic coordinates in Fig. 3. In Fig. 3, log[*V*] − log[*A*] curve line presents a significant linear characteristic. As shown in fitting equation, the slope *K* is 1.7162 and the correlation coefficient *R* is 0.9826, which indicates that solidified sludge particles present good fractal characteristics. Finally, 3D fractal dimension can be calculated according to the formula (2), and it gives that D (3D fractal dimension) equals 1.7428.

In the same way, 3D fractal under other conditions of different biodegradation stages are calculated, and listed in Table 1.

Table 1 3D fractal dimension at different stages under various conditions

Time/Week	Aerobic condition	Leachate condition	Anaerobic condition
0	1.7428	1.7386	1.7320
2	1.7734	1.7752	1.7608
6	1.8492	1.8604	1.8246
14	1.9356	1.9526	1.8607
26	1.9542	1.9762	1.8662
42	1.9648	1.9884	1.8693

4 Analysis of Result

In Fig. 4, it gives out the change trend of 3D fractal dimension under different conditions with time respectively.

As shown in Fig. 4, 3D fractal dimension of solidified sludge under different conditions have presented phased change trends. The general change trend of 3D fractal dimension with time is upward. All trend lines in Fig. 4 can be categorized in 3 stages, according to the value of slope (representing biodegradation rate). In Fig. 4, there is obvious rise in the first stage, representing the beginning of biodegradation. At the beginning of biodegradation, the amount of microbe is limited, so the microbial activities are not dynamic. Only small and simple organic matters are decomposed to gas and water. With the outflowing of gas and water, the internal structure of solidified sludge is damaged, increasing the fractal dimension of solidified sludge.

In the second stage, all curves become steeper, meaning the acceleration of biodegradation rate. In this stage, the hydrated reaction rate between sludge and cement accelerates, affecting pH, water content, nutrients and oxygen content of solidified sludge. In this way, the reproduction and metabolism of microbe in all conditions have been promoted. More gas and water has been generated due to this

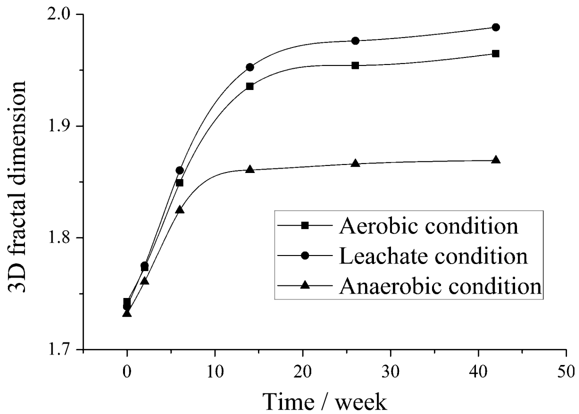

Fig. 4 Relationship between 3D fractal dimension and time under different conditions

phenomenon, resulting in the rapid increase in fractal dimension of solidified sludge. When reflected on SEM images, more flocculent materials can be found, as well as the fractal dimension.

As biodegradation goes on, the basicity of sludge increases, with the activity of which decreases. Meanwhile, the organic matter and water inside solidified sludge has been consumed gradually, lowering the biodegradation. Reflected on SEM images, the volume of flocculent body, and solidified sludge particle increases. The change of solidified sludge structure becomes stable, lowering the increase of fractal dimension till stable.

5 Conclusions

Estimating 3D fractal dimension of solidified sludge quantitatively is relatively simple and effective, based on GIS. In this essay, conclusions can be draw to as below:

1. From micro-perspective, the small particles of solidified sludge assemble to larger ones, generating large amount of pore, as hydration reaction goes on. And this is considered to be the origin reason of strengthening solidified sludge intensity.
2. There is a significant periodical change pattern in 3D fractal dimension of solidified sludge. As biodegradation goes on, pore volume gradually increases, gathering small particles in solidified sludge to flocculent body. Using quantitative analysis, phase characteristics of solidified sludge biodegradation can be presented directly.
3. 3D fractal dimension are used to reflect biodegradation of solidified sludge quantitatively. Under different control conditions, change trends of fractal dimension appear similar. Degradation efficiency can be estimated by final values of fractal dimension in stable stage. As shown in Fig. 4, the degradation efficiency and rate reaches highest under leachate condition, followed by aerobic condition and anaerobic condition.

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Thermal Safety Assessment Test of Permeable Chemical Protective Clothing

Ying Li, Xuezhi Zhang, Bo Yang and Shouxin Zhang

Abstract *Objective* to study the physical parameters change rule of human body wearing permeable chemical protective clothing on full protective state in high temperature and high humidity environment, so as to provide theory basis for the thermal safety assessment of permeable chemical protective clothing research. *Methods* in high temperature and high humidity simulated environment, the subjects wearing permeable chemical protective clothing on full protective state walking on treadmill, physiological parameters of subjects was measured in real time. *Results* Through statistical analysis of the experiment test results of human body test, the rules between various physical parameters were founded, and then physiological parameter model was established by linear fitting of the experimental data.

Keywords Permeable chemical protective clothing · Thermal safety assessment · Linear fitting · Physiological parameters model

1 Introduction

Human thermal safety engineering security evaluation is a burgeoning cross discipline with comprehensive and systematic. Human thermal safety, which is based on scientific understanding of human thermal response mechanisms and rules based, study how the "Human, Clothing and Environment" system affect human thermal exchange and provide theory evidence for protecting human security in a hot environment. Through the thermal safety experiment on clothed human body, this paper mainly researches on the change of physiological parameters which can be well referenced for the evaluation of function and safety of permeable chemical protective clothing.

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2 Materials and Methods

In order to ensure the subjects' personal safety, three trained researchers monitor the subjects in whole process. Test laboratory equipped with thermal induced disease first-aid medicine and oxygen generator.

2.1 Subjects

There were thirty-five male subjects participated in the test. General physical fitness was established with each subject before the test. Before the test, all subjects had trained on treadmill and familiar with the whole test procedure. Physiological characteristics of the subjects who participated in this test are summarized in Table 1.

2.2 Conditions in the Test Room

The temperature was 35 ± 1 °C, relative humidity was 60 ± 5 %, and wind velocity 1 ± 0.3 m/s.

2.3 Test Procedures

The experimental steps are as follows:

1. Subjects drank 350 ml electrolyte beverage half an hour before test started, and was forbidden to drink or eat during the test.
2. Intelligent electronic body scale (KCC150 METTLER, America) was used to measure weight before and after the test.
3. The rectal temperature (Tre) and skin temperature (Tsk) was measured using a temperature test instrument ("4000A", YSI, America). According to ISO 9886-2004 [1] eight points skin temperature requirement, eight measurement points were distributed in human body.

Table 1 Summary of physical characteristics of the subjects

Subject characteristics	Mean	Std. dev.	Min	Max
Age (years)	23	1.6	18	25
Weight (kg)	68.6	5.1	56.5	73.2
Height (cm)	173.6	4.2	167.5	178.5
Surface area (m^2)	1.814	0.07	1.631	1.906

4. The subjects were dressed in permeable chemical protective clothing on full protection state.
5. Subjects were walking on the treadmill with the speed 5 km/h and no slope (moderate exercise load). The treadmill (Jaeger, Germany) was connected to a computer, and calibrated in accordance with the manufacturers' instructions. The test protocol was developed by means of the software supplied with the treadmill.
6. The metabolic rate (M) and heart rate (HR) were measured by cardiopulmonary exercise testing instrument ("Oxycon Pro" Jaeger, Germany).
7. The test was terminated by the test officer when the test subject felt exhaustion, its rectal temperature reaches 39 °C, or its heart rate reaches 180 for a minute, whichever occurred first.

2.4 Data Collection and Statistical Analyses Methods

The test required real-time measuring body temperature (rectal temperature and skin temperature), heart rate, metabolic rate, and naked weight before and after the experiment, specific requirements were as follows:

1. Rectal temperature and the skin temperature data was recorded by tester once every 5 min.
2. The heart rate and metabolic rate data was automatically recorded by cardiopulmonary exercise testing instrument once in every 30 s.

Study on values of physiological parameters within a unit time.

3 Results and Discussion

3.1 Body Temperature Change Rule and the Linear Analysis

Rectal temperature and average skin temperature changing time curve are shown in Fig. 1, and their calculation formulas are formula 1 and formula 2.

$$T_{\mathrm{re}} = \frac{\sum T_{\mathrm{re},i}}{n} \tag{1}$$

$$T_{\mathrm{sk}} = \frac{\sum \left(0.07T_{\mathrm{sk1},i} + 0.175T_{\mathrm{sk2},i} + 0.175T_{\mathrm{sk3},i} + 0.07T_{\mathrm{sk4},i} + 0.07T_{\mathrm{sk5},i} + 0.05T_{\mathrm{sk6},i} + 0.19T_{\mathrm{sk7},i} + 0.2T_{\mathrm{sk8},i}\right)}{n} \tag{2}$$

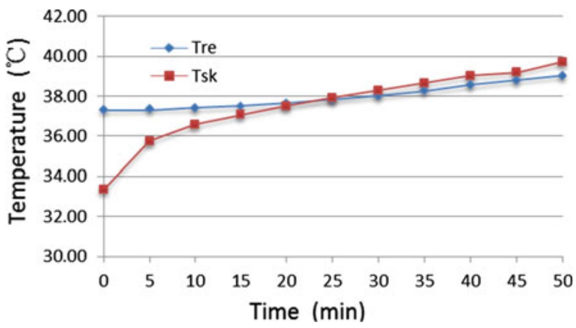

Fig. 1 Rectal temperature and average skin temperature change with time

$T_{re,i}$ The rectal temperature of every 5 min, °C
i Time point (0, 5, 10, …)
n Number of people
$T_{skm,i}$ The skin temperature of every 5 min, °C

Figure 1 shows that the temperature rise rate of average skin is greater than that of the rectal temperature. The average skin temperature rise rate reduced after more than 36 °C. About 25 min into the experiment, the value of average skin temperature is equal to that of rectal temperature. That is to say, the human body temperature reaches the internal and external equilibrium point at that time, and the value is 37.9 °C by calculating. 25 min after experiment, the value of average skin temperature is greater than that of rectal temperature. The variables rectal temperature and average skin temperature data linear fitting with independent variable time get the formula 3 and formula 4.

$$T_{re} = 0.036t + 37.067 \quad (R^2 = 0.9534) \tag{3}$$

$$T_{sk} = 0.1034t + 34.953 \quad (R^2 = 0.8768) \tag{4}$$

Then this paper makes average skin temperature as independent variable and rectal temperature as variable data get formula 5 by data linear fitting.

$$T_{re} = 0.4575T_{sk} + 20.67 \quad (R^2 = 0.9081) \tag{5}$$

3.2 *Heart Rate Change Rule and the Linear Analysis*

Heart rate changing time curve is shown in Fig. 2, and its calculation formula is formula 6.

$$\text{HR} = \frac{\sum \text{HR}_i}{n} \tag{6}$$

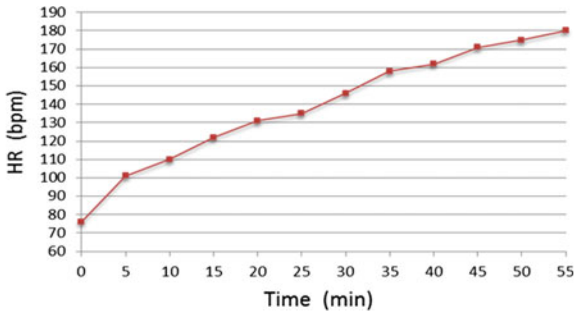

Fig. 2 Heart rate change with time

HR_i The heart rate of every 5 min, bpm;

Figure 2 shows that experiment began and within 5 min the heart rate rised rapidly and then rising rate reduced. About 35 min after the test, the heart rate rise rate reduced once again. Du et al. [2] found that in moderate intensity exercise test, heart rate rising rapidly at the test begins 3 min after that the heart rate changes within a certain range which is a relatively steady state. 30 min after the test beginning, heart rate has increased at a certain rate. But this paper results show that in the high temperature and high humidity environment, the subjects wearing chemical protective clothing under full protection state and who are walking at a moderate intensity, their heart rate changers does not appear relatively steady state. That is because the thermal load of clothing led the body's metabolism rising, so the heart rate changer cannot reach a relatively steady state.

The heart rate data linear fitting with time gets the formula 7.

$$\mathrm{HR} = 1.8098t + 87.897 \quad (R^2 = 0.9741) \tag{7}$$

Heart rate is very sensitive and easy to measure physiological parameter. So, this paper makes heart rate as independent variable and makes average skin temperature and rectal temperature, as variable data get formula 8 and formula 9 by data linear fitting.

$$T_{\mathrm{re}} = 0.0182\mathrm{HR} + 35.526 \quad (R^2 = 0.8951) \tag{8}$$

$$T_{\mathrm{sk}} = 0.0559\mathrm{HR} + 30.058 \quad (R^2 = 0.9371) \tag{9}$$

3.3 Metabolic Rate Change Rule and the Linear Analysis

Metabolic rate changing time curve is shown in Fig. 3, and its calculation formula is formula 10.

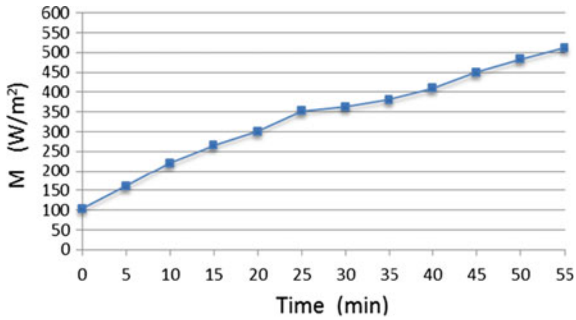

Fig. 3 Metabolic rate change with time

$$M = \frac{\sum M_i}{n} \tag{10}$$

M_i The metabolic rate of every 5 min, W/m^2

Figure 3 shows that metabolic rate increases with the time, about 25 min after the experiment beginning, metabolic rate rising rate are reduced, but it does not appear the steady state. Normally the body dressed in good heat transfer performance uniform keeps on moving in medium load, 10–20 min after the experiment beginning, the metabolic rate is kept a relatively steady state and that is hardly affected by the environment [3]. But this paper results show that in the high temperature and high humidity environment, the subjects wearing chemical protective clothing under full protection state who are walking at a moderate intensity, their metabolic rate changers did not appear in relatively steady state. That is because the thermal load of clothing led the body's metabolism rising, so the metabolic rate changer cannot reach a relatively steady state.

The metabolic rate data linear fitting with time get the formula 11.

$$M = 6.9839t + 141.19 \quad (R^2 = 0.9751) \tag{11}$$

This paper makes heart rate as independent variables and makes metabolic rate, as variable data get formula 12 by data linear fitting.

$$M = 3.8073\text{HR} - 180.89 \quad (R^2 = 0.9744) \tag{12}$$

The relationship between the human metabolic rate and heart rate in GB/T18048—2008 [4] is shown in formula 13. The formula established conditions are the subject (about 20 years and 70 kg weight) dressed in good heat transfer performance uniform and keep on moving in medium load.

$$M = 3.8\text{HR} - 210 \tag{13}$$

Some study showed [5, 6] that when the environment temperature is 20–39 °C, the influence of metabolic rate by temperature can be ignored. So the difference between formula 12 and formula 13 is caused by clothing. Through the discussion, this paper draws the following conclusions: under high temperature and high humidity environment, people dressed in chemical protective clothing under full protection state keeps on moving in medium load, whose metabolic rate is improved 30 W/m^2 than that dressed in good heat transfer performance uniform.

This paper makes average skin temperature and rectal temperature as independent variables and make metabolic rate as variable data get 14 and formula 15 by data linear fitting.

$$M = 182.23T_{re} - 6601.7 \quad (R^2 = 0.8633) \tag{14}$$

$$M = 63.545T_{sk} - 2068.4 \quad (R^2 = 0.9415) \tag{15}$$

4 Conclusions

Through statistical analysis of the experiment test results of human body test, the rules between various physical parameters was founded, and then physiological parameter model was established by linear fitting the experimental data. By analyzing the test data, it shows that the subjects dressed in chemical protective clothing under full protection state keeps on moving in medium load, although the human body movement under constant load but due to thermal stress of external environment and the clothing thermal resistance, their body temperature, heart rate, and metabolic rate cannot reach a relatively steady state; moreover, their metabolic rate is improved 30 W/m^2 than that dressed in good heat transfer performance uniform.

5 Compliance with Ethical Standards

The study had obtained approval from the State Key Laboratory of NBC Protection for Civilian ethics committee.

All subjects participated in the experiment signed the informed consent.

All subjects participated in the test were voluntary and could withdraw from test at any stage.

All relevant ethical safeguards had been met in relation to subject protection.

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Visualization of Sound Field in Semi-closed Room Using Finite-Difference Time-Domain Method

Dongdong Lu and Xiangyang Zeng

Abstract This paper illustrates the visualization method of transient sound propagation in 3-dimensional semi-closed sound field in which a rectangular shape of room is modeled by applying the finite-difference time-domain (FDTD) method. As a direct time-domain simulation the technique of FDTD owns unique advantage in solving acoustic problems in closed and semi-closed rooms. To ensure the accuracy of the FDTD, some attention is paid in this paper on the key problems such as: numerical stability, numerical error, boundary condition, and the excitation signal. This paper uses slicing to visualize the 3-dimensional semi-closed sound field, and that validity is proved by the visualization of a 2-dimensional semi-closed sound field.

Keywords Visualization · Finite-difference time-domain (FDTD) · Semi-closed room · Boundary condition

1 Introduction

To examine and understanding such complicated phenomena of acoustic for example: reflection and reference, visualization of sound field is so significant not only from the overview of practice engineering, but also from the overview of noise control engineering. In the past, various kinds of visualization method were contrived and applied in room acoustics. These methods can be roughly divided into two categories. One is based on geometric acoustics such as ray tracing method and image source method, and another is based on wave acoustics such as finite element method and boundary element method. Among these wave acoustics method the authors have been researching the application of the finite-difference time-domain method in room acoustics. In the FDTD algorithm, the particle velocity and the

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sound pressure are computed directly in discrete time steps, therefore transient sound phenomena can be animated. In this paper, FDTD method is used to visualize a special sound field—a semi-closed room in 3-dimension.

2 FDTD Algorithm

The sound wave in the 3-dimension sound field can be described by the following wave equations. Equations (2.1), (2.2), and (2.3) are the momentum equations in ***x***-, *y*-, and *z*-dimensions, respectively; and Eq. (2.4) is the continuity equation [1, 2].

$$\rho_0 \frac{\partial u_x(x,y,z,t)}{\partial t} + \frac{\partial p(x,y,z,t)}{\partial x} = 0 \tag{2.1}$$

$$\rho_0 \frac{\partial u_y(x,y,z,t)}{\partial t} + \frac{\partial p(x,y,z,t)}{\partial y} = 0 \tag{2.2}$$

$$\rho_0 \frac{\partial u_z(x,y,z,t)}{\partial t} + \frac{\partial p(x,y,z,t)}{\partial z} = 0 \tag{2.3}$$

$$\frac{\partial p(x,y,t)}{\partial t} + \rho_0 c^2 \left(\frac{\partial u_x(x,y,t)}{\partial x} + \frac{\partial u_y(x,y,t)}{\partial y} + \frac{\partial u_z(x,y,t)}{\partial z} \right) = 0 \tag{2.4}$$

where p is the sound pressure; ρ_0 is the medium density; $c$is the propagation speed of wave; $u_x u_y$ and u_z are the particle velocities in x-, y-, and z-dimensions, respectively.

The time and spatial derivatives of an arbitrary function f, $\partial f/\partial x, \partial f/\partial y$, $\partial f/\partial z$ and $\partial f/\partial t$ can be written by the central finite difference forms as $(f(x+\Delta x/2) - f(x - \Delta x/2))/\Delta x$, $(f(y+\Delta y/2) - f(y - \Delta y/2))/\Delta y$, $(f(z+ \Delta z/2) - f(z - \Delta z/2))/\Delta z$ and $(f(t+\Delta t/2) - f(t - \Delta t/2))/\Delta t$ respectively. Here Δt is the discrete time steps, and Δx, Δy and Δz are the discrete spatial steps. This paper using staggered grid system discrete the three dimension ($\Delta x = \Delta y = \Delta z$), as shown in Fig. 1a, the following equations are obtained for a discrete system.

$$\begin{aligned} u_x^{n+1}(i+1/2,j,k) = {} & u_x^n(i+1/2,j,k) \\ & - \frac{\Delta t}{\rho_0 \Delta x}\left(p^{n+1/2}(i+1,j,k) - p^{n+1/2}(i,j,k)\right) \end{aligned} \tag{2.5}$$

$$\begin{aligned} u_{\mathrm{y}}^{n+1}(i+1/2,j,k) = {} & u_y^n(i+1/2,j,k) \\ & - \frac{\Delta t}{\rho_0 \Delta y}\left(p^{n+1/2}(i,j+1,k) - p^{n+1/2}(i,j,k)\right) \end{aligned} \tag{2.6}$$

$$\begin{aligned} u_z^{n+1}(i+1/2,j,k) = {} & u_z^n(i+1/2,j,k) \\ & - \frac{\Delta t}{\rho_0 \Delta z}\left(p^{n+1/2}(i,j,k+1) - p^{n+1/2}(i,j,k)\right) \end{aligned} \tag{2.7}$$

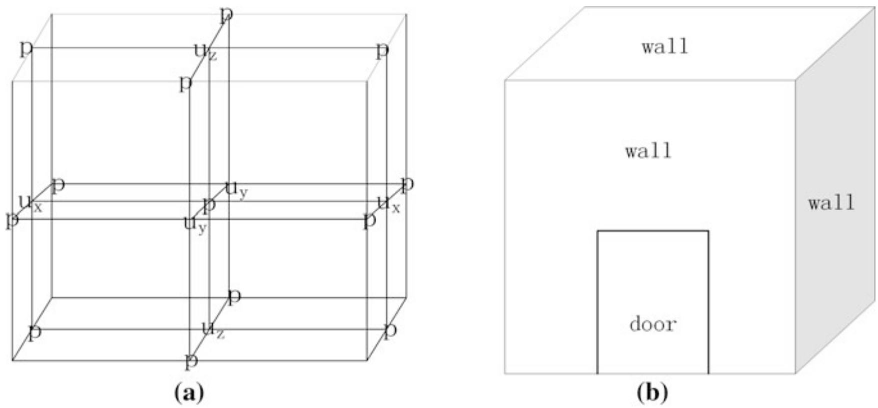

Fig. 1 **a** Staggered grid cell system for 3-dimensional sound field; **b** 3-dimensional schematic view of a semi-closed room

$$p^{n+1/2}(i,j,k) = p^{n-1/2}(i,j,k) - \rho_0 c_0 \Delta t \left(\frac{u_x^n(i+1/2,j,k) - u_z^{n+1}(i-1/2,j,k)}{\Delta x} + \frac{u_y^n(i,j+1/2,k) - u_y^{n+1}(i,j-1/2,k)}{\Delta y} + \frac{u_z^n(i,j,k+1/2) - u_z^{n+1}(i,j,k-1/2)}{\Delta z} \right) \tag{2.8}$$

where, $\Delta x \Delta y$ and Δz are the discrete spatial steps, indices n, $n-1/2$ and $n+1/2$ denote time steps.

Details on the FDTD method have been reported on other occasions. Here only the stability conditions and the numerical dispersion need to take into consideration. When taking the discrete time into consideration the stability condition is reported by Eq. (2.9)

$$\Delta t \le \left(\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2} + \frac{1}{\Delta z^2} \right)^{-1/2} \tag{2.9}$$

At the same time, when using the numerical method to calculate the sound field, in order to avoid numerical dispersion, the frequency must be taken into consideration. Details on the numerical dispersion also have been reported on several occasions, here, to meet the need, set the grid size as the wavelength of 1/10-1/20 [3].

3 Absorbing Boundary Condition

Since the basic leapfrog scheme is space centered, numerical boundary conditions are required at the boundaries of the grid. These numerical boundaries are set to cut the computational domain. The purpose of these numerical boundary conditions is set to absorb the acoustic energy on the boundaries from all angles, so these conditions are sometimes called absorbing boundary conditions. Much research has been performed on absorbing boundary conditions. In this paper, the sound field is described as Fig. 1b, in which, the boundary conditions consist of wall and door, while the door can be closed and opened. In order to insure the sound field is semi-closed, the door is set open.

3.1 Absorbing Boundary Condition at the Wall

In room acoustics, the sound wave transmission in the sound field, when the sound wave reaches the boundary, part of the wave is absorbed by the walls, while, the other waves reflect back. Based on that phenomena, the absorption coefficient can be applied to establish contact between calculation area and the boundary [4].

The normal component of particle velocity on the boundary is expressed by Eq. (3.1).

$$u|_{\text{boundary}} = \frac{p}{z} \tag{3.1}$$

where u is the normal component of the particle velocity on the boundary; p is the sound pressure; z is the normal acoustic impedance on the boundary.

Assuming the incident sound is a plane wave, the absorbing coefficient of the wall can be expressed by Eq. (3.2).

$$\alpha_\theta = 1 - \left|r_p\right|^2 = 1 - \left|\frac{z_n \cos\theta - \rho_0 c_0}{z_n \cos\theta + \rho_0 c_0}\right|^2 \tag{3.2}$$

where θ is the angle of the incident sound wave and the normal direction of the wall; α_θ is the absorbing coefficient of the wall; r_p is the reflection coefficient of sound pressure; z_n is the normal acoustic impedance on the boundary. The Eq. (3.2) can be simplified as Eq. (3.3)

$$z_n \cos\theta = \rho_0 c_0 (1 + \sqrt{1 - \alpha_\theta})/(1 - \sqrt{1 - \alpha_\theta}) \tag{3.3}$$

When iterative calculation using FDTD method, sound speed of three direction perpendicular to each other and a sound pressure is needed. In room acoustic the incident angle is 90°. At the same time, to simplify the problem, it was assumed that the normal acoustic impedances on the boundary consists only the real part. So the Eq. (3.3) can be simplified as Eq. (3.4).

$$z_n = \rho_0 c_0 (1 + \sqrt{1 - \alpha_\theta})/(1 - \sqrt{1 - \alpha_\theta}) \tag{3.4}$$

In calculation, the p can be represented by the sound pressure at the center point of the cell-grid $p(i, j, k)$, the following expressions are derived by x-components of the particle velocity on the boundaries. The y- and z-components are similarly to the expressions in x-.

$$u_x^{n+1}(1/2, j, k) = -p^n(1, j, k)/z_n \tag{3.5}$$

$$u_x^{n+1}(i_{\max} - 1/2, j, k) = p^n(i_{\max}, j, k)/z_n \tag{3.6}$$

3.2 *Absorbing Boundary Condition at the Door*

When the room acoustic is semi-closed, the absorbing coefficient at the door is 0, while the normal acoustic impedance is endless, that means the boundary condition at the walls cannot be applied any more.

The boundary condition at the opened door needs special processing, so that the sound wave maintains the characteristics of propagating toward, without significant reflection. Dealing with the same problem in the Maxwell equations, PML (Perfect Matched Layer) absorbing boundary condition and Mur absorbing boundary condition can be selected. In this paper, we select Mur boundary condition. Details on the Mur boundary condition have been expressed on several occasions, here will not repeat. The boundary condition of the door can be expressed as Eq. (3.7) [5, 6].

$$\begin{aligned} p^{n+1}(i,j,k) = & -\frac{1}{3}p^{n+1}(i-1,j,k) + \frac{7}{6}(p^n(i-1,j,k) + p^n(i,j,k)) \\ & - \frac{1}{3}p^{n-1}(i,j,k) + \frac{1}{12}\begin{pmatrix} p^n(i-1,j+1,k) + p^n(i,j+1,k) \\ + p^n(i-1,j-1,k) + p^n(i,j-1,k) \end{pmatrix} \\ & - p^{n-1}(i-1,j,k) \end{aligned} \tag{3.7}$$

4 Excitation Signal

When dealing with the Maxwell equation, the boundary conditions generally set to Mur boundary or PML boundary, in that case the excitation signal does not require special considerations. Generally, Gaussian signal and sinusoidal signal are always selected as the excitation signal.

In room sound field, with the boundary condition of PML or Mur, when the sound wave arrives the board, the sound wave keeps the characteristic of propagating forward, without reflection and scattering. In this case both the Gaussian pulse signal and the sinusoidal signal can be satisfied, without special treatment. While the sound boundary having absorption, due to different materials in the central frequency of different octave band having different acoustical adsorption coefficient, the excitation signal must be a narrowed band signal. As Gauss signal is a wideband signal, the Gauss signal is not fit any more. In this paper, we choice a single-frequency signal with the frequency of 1000 Hz as the excitation signal.

5 Sound Field Visualization

In the field of construction engineering, the classic building shape is rectangular (also called "shoe-box" style), such as concert halls, cinemas, and other compartments. So in this paper, we select the rectangular as a research object. In this paper, set the material of the walls as concrete. The absorbing coefficient of the concrete at the central frequency of 1000 Hz is $\alpha_\theta = 0.02$.

In this paper, as shown in Fig. 1b, the calculation by the FDTD method is performed for a 3-dimensional space of 5 m wide, 5 m long, and 5 m high, in which a sound source and the boundary condition is set. The sound source is set at the center of the semi-closed room.

For visual display the sound spread of semi-closed sound field, this paper presents both the 2-dimension and 3-dimension situations.

Figure 2 is the pressure distribution of 2-dimensional semi-closed room sound field. In Fig. 2a sound wave just reached the boundary without reflection, before which the sound wave keep normal transmission. In Fig. 2b the sound wave reached the wall, without reaching the corner. The sound wave reflected on the walls, while the sound wave kept transmission on the opening door without

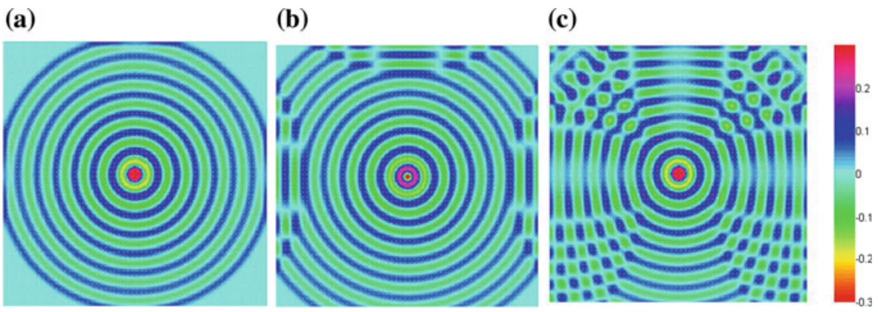

Fig. 2 **a** 2-dimensional semi-closed room acoustic pressure distribution at 10 ms; **b** 2-dimensional semi-closed room acoustic pressure distribution at 15 ms; **c** 2-dimensional semi-closed room acoustic pressure distribution at 80 ms

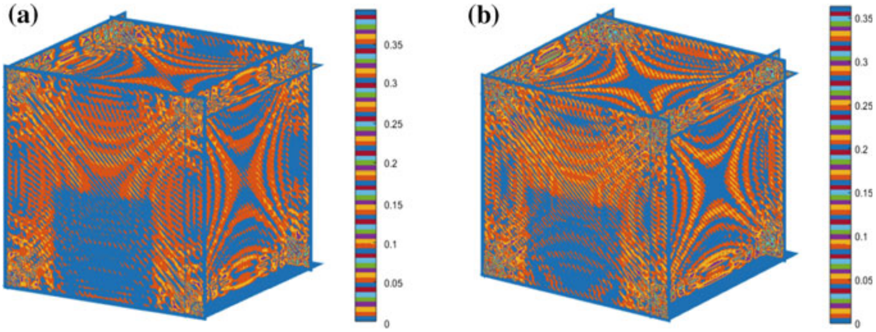

Fig. 3 **a** 3-dimensional semi-closed room acoustic pressure distribution at 100 ms; **b** 3-dimensional semi-closed room acoustic pressure distribution at 200 ms

reflection. In Fig. 2c the sound field in a relatively stable state, the pressure distribution was more complicated than the sound pressure distribution in Fig. 2a, b. In Fig. 2c the sound wave kept transmission on the opening door without reflection while at the other part of the 2-dimensional semi-closed sound field the sound wave reflected.

In 3-dimension sound field, sound pressure is a 4-dimensional scalar in the 3-dimensional sound field; so space slicing is adopted to visualize the 3-dimensional sound field. In order to clearly understand the internal sound pressure distribution, the right and the upper part of the slice are 0.5 m distance from the real sound field boundary, respectively. In Fig. 3 at the position of the door, no sound wave spreads out, which is decided by the Mur boundary condition. At the same time, on the other walls when the sound wave achieving the walls the sound wave was reflected and continue to propagation.

6 Conclusion

In this paper, the 3-dimensional sound field visualization of semi-closed room was researched using FDTD method. This paper is just to simulate the phenomena of the sound wave transmitted in semi-closed room. As a result, it has been found that this kind of visualization technique is very effective to describe the semi-closed sound field.

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Auto-Body Structure Noise Analysis Based on Modal Analysis Method

Zhongliang Wei, Minghui Chen, Fang Xie, Qun Wang, Liang Ling, Sijuan Zheng and Li Li

Abstract Take a certain engineering vehicle as an example, use the application of the finite element analysis method, establish the finite element of the vehicle and passenger compartment cavity model, comparative stiffness calculation results, and test results verify the accuracy of the model. Focuses on the application of modal analysis method and acoustic mode, establish the acoustic-structural coupled finite element model, calculating modal participation factors, and the plate body structure contribution, structure analysis of sensitivity, noise source identification of main vehicle. The main noise source to take corresponding improvement measures, can effectively restrain the noise, to verify the correctness of the analysis method.

Keywords Auto-body · Modal analysis · Structure sensitivity analysis · Noise analysis

1 Foreword

The engineering vehicle takes the large bearing and high speed as the traction to increase the dynamic performance and reduce its own load so that the auto-body is thinner and the components are lighter. The box is often with thin-shell structure. If driving in the harsh environment, like on the macadam pavement or off-road, the auto-body vibration and the noise in the vehicle, especially, the LF structure noise will be normally increased under the premise of increasing the dynamic performance and fuel economy [1]. Auto-body is the main component of the vehicle with the purposes of bearing and platform. The noise, vibration, and harshness (shortened as NVH) shall be strictly controlled during the design stage. It is significant to study the influence of the auto-body structure vibration to the interior noise [2]. With the division of low frequency and high frequency for the interior noise, they

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shall be considered to be restrained respectively during the auto design stage. The sound absorption material has an obvious effect to restrain the high frequency noise but a poor effect to restrain the low-frequency noise [3]. The requirement for the equipment layout in the active sound control is very high and the signal synthesis is complicated, so the active sound control has been always difficult to be popularized and applied in the vehicle [4]. The volume of the middle-and low-frequency noise is not high, but it will cause discomfort and increase the load if people stay in this noise environment for a long time. It has a large influence to the driving safety [5]. Therefore, this paper studies and analyzes to reduce the noise through the structure improvement.

2 Structure Modal Analysis

2.1 Auto-Body Structure Finite Element Modal Analysis

The finite element equation for the auto-body structure could be expressed as [6]:

$$M_i\ddot{x} + C_i\dot{x} + K_i x = F_i \tag{1}$$

In this equation, M_i is the auto-body structure mass matrix; $\ddot{x}$ is the acceleration of the structure node; C_i is the structure damping matrix; $\dot{x}$ is the speed of the structure node; K_i is the structure stiffness matrix; x is the displacement of the structure node and F_i is the external force applied on the structure.

The finite element mesh for auto-body will be created on Hypermesh software platform. Shell63 and Solid185 mesh cells will be used for auto-body with the total cell quantity of 128,730 and the total node quantity of 113,842, of which the triangle cell percentage (the ratio of the total quantity of the triangle cells and the total cell quantity) is 5 %. Cweld cell will be used for auto-body welding spot. The total quantity of the cweld cell is 5240. Cbar cell will be used for bolt. By comparing the analog rigidity computation with the experiment result for the auto-body model, the error is small, being able to satisfy the analysis requirement. The rigidity computation result and the experiment result are as Table 1.

The vehicle structure modal parameters reflect the natural vibration characteristic of the auto structure. The vehicle structure has an important influence to the interior noise as well as to the stability during driving. It is one of the vibration forms with the largest influence to the structure. The first-order torsional mode and the first-order pitch mode of the auto-body are the important parameters for auto

Table 1 The rigidity value from computation result and experiment result

Performance	Computation result (N/mm)	Experiment result	Rigidity value (%)
Bending stiffness	75,436.5	72,403.95	4.02
Torsional stiffness	76,389.4	73,349.1	3.98

design, indicating the performance of the structure resisting the torsion at the low-frequency resonance as well as the superposition performance of vibrational coupling. The vibration mode frequency with large hazard shall be staggered with the pavement and the excitations to the greatest extent during the design.

2.2 Finite Element Modal Analysis for Acoustic Cavity

In the analysis and calculation for acoustic fluid, air is with mass and elasticity as well as could be compressed. It will expand after the compression and then be compressed again to form the sound wave with pressure. Suppose the acoustic fluid does not flow and has no viscosity, one-dimensional acoustic wave equation as per equation of continuity, dynamic equation, and ideal gas equation [3]:

$$\frac{\partial^2 p}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} \tag{2}$$

The acoustic wave equation for three-dimension equation system is:

$$\nabla^2 p = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} \tag{3}$$

In this equation, c is the sound velocity in air; p is the sound pressure and ∇ is the Laplace operator. Discretize the cavities in the vehicle to infinite elements without consideration of the damp; the sound wave equation could be expressed as:

$$M_i\ddot{p} + K_i p = F_i \tag{4}$$

In this equation, M_i is the mass matrix of acoustic cavity; $\ddot{p}$ is the second derivative for the sound pressure of the acoustic cavity to time; K_i is the stiffness matrix of the acoustic cavity; p is the sound pressure of the acoustic cavity and F_i is the generalized force transmitted by the structural unit to the fluid.

The acoustic cavity in the finite element also has the modal frequency and vibration mode, which is known as acoustic mode. The acoustic cavity in the vehicle will produce acoustic resonance at the acoustic mode frequency to form the typical acoustic mode. The acoustic cavity unit will be created on LMS Acoustic software platform and the acoustic mesh will be created with the structural model. The usable acoustic cavity mesh will be generated by using acoustic cavity generation function through the closed structure so as to ensure the consistency of the both boundary surfaces and improve the coupling calculation accuracy. After the calculation, there are 84,118 units in the acoustic cavity model in total. The modal frequency and vibration mode of the acoustic cavity are as Fig. 1. X-axis, Y-axis, and Z-axis of the vehicle coordinate system are corresponding to the longitudinal, horizontal, and vertical directions.

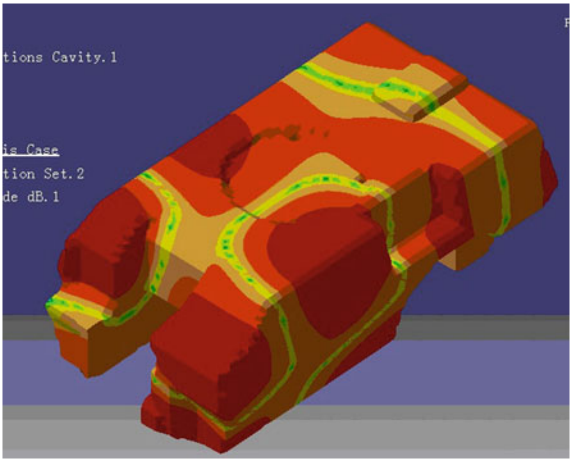

Fig. 1 The thirteenth rank vibration model of cavity (159.48 Hz)

2.3 Modal Analysis for Acoustic-Structure Coupling

The road excitation of the auto-body will cause the vibration of the auto-body wallboard vibration, by which the radiation sound is produced to act on the passenger compartment. And the sound wave will be reacted on the auto-body wallboard after the wave is amplified or reduced by the acoustic cavity of the passenger compartment to form the radiation sound and the sound pressure distribution in the passenger compartment to be transmitted to the ears of the driver and the passengers. Without consideration of the damp influence, the dynamic equation of the coupling system is [7]:

$$\begin{bmatrix} M_{ii} & 0 \\ M_{ji} & M_{jj} \end{bmatrix} \begin{bmatrix} \ddot{x} \\ \ddot{p} \end{bmatrix} + \begin{bmatrix} K_{ii} & K_{ig} \\ 0 & K_{jj} \end{bmatrix} \begin{bmatrix} x \\ p \end{bmatrix} = \begin{bmatrix} F \\ F_g \end{bmatrix} \tag{5}$$

In this equation, M_{ii} is the structural mass matrix of the cabin; M_{ji} is the mass matrix of the acoustic-structure coupling; M_{jj} is the acoustic cavity mass matrix of the cabin; K_{ii} is the stiffness matrix of the cabin; K_{ij} is the coupling stiffness matrix of the cabin and K_{jj} is the acoustic cavity stiffness matrix of the cabin.

The auto-body structure shall be closed for the calculation of the sound pressure distribution in the cabin. By manual filling the plate gap of the model, the nodal line (zero sound pressure position) is at the driver's place after the calculation, which could guarantee the noise reduction at the driver's place effectively.

3 Prediction Analysis for Sound Pressure Response in the Cabin

To get the sound pressure response curve of the cabin, excitation shall be applied on the auto-body and the load could be got with experiment and simulation. There is no sample vehicle for the experiment during the product design process normally, so the primary simulation could use the force curve got with dynamic calculation.

3.1 Acquire the Boundary Conditions

Drive the vehicle on the grade D road for dynamic simulation to get the exciting load for the action part. For easy calculation, the time domain signal is normally required to take the frequency domain transformation so as to get the load spectrum under the frequency domain environment. The load spectrum of right and back suspension applied on the auto-body is shown as Fig. 2.

3.2 Sound Pressure Response Analysis

The action system load spectrum shall be taken as the structural excitation to get the vibration responses of the structural points through the structural response analysis. The vibration responses will be taken as the noise simulation boundary to take the coupling noise simulation with the acoustic modal so as to get the noise response

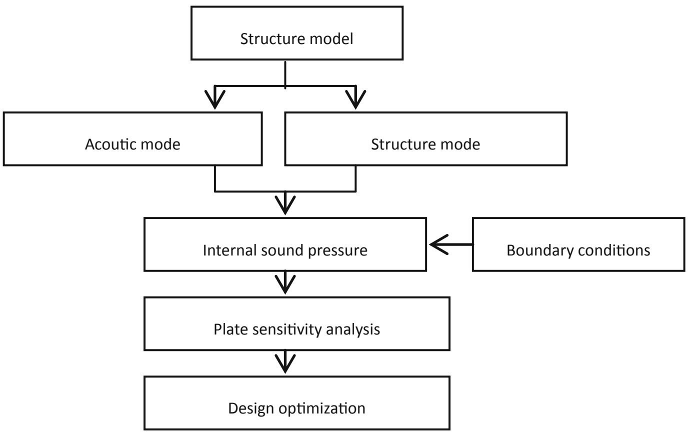

Fig. 2 The simple flow of noise simulation

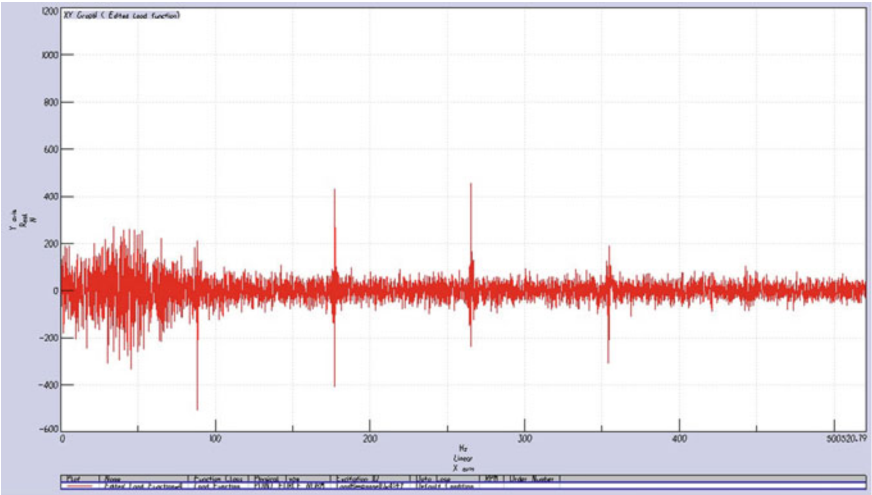

Fig. 3 The load curve of right and back suspension

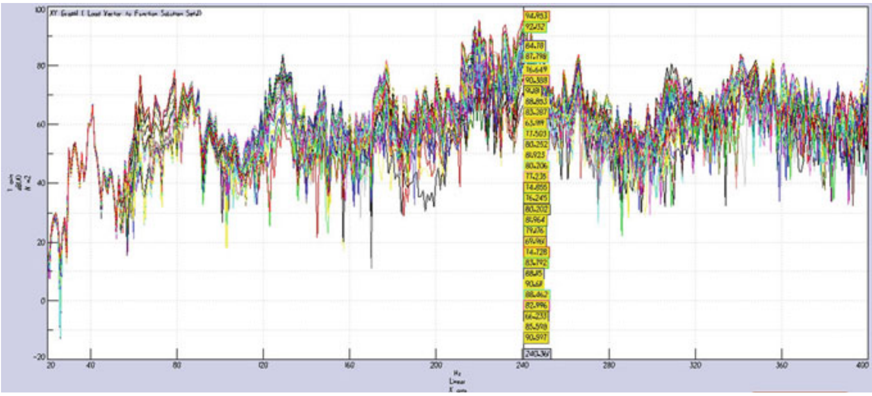

Fig. 4 The frequency domain curve of noise in cabin

values for the points in the cabin. The noise frequency domain curve at the driver's head is shown as Fig. 4 after calculation (Fig. 3).

There are resonance peak 1 and resonance peak 2 at 218 and 240 Hz with the relatively consistent values fluctuating near 95 dB. Under the load excitation, the response to the above two frequencies is severe. It is the main noise in the cabin.

The noise in the cabin could be reduced obviously if the above noise is eliminated. The influence of the space occupied by the seats and the sound absorption materials is not considered for the above situation.

4 Structure Sensitivity Analysis

The middle-and low-frequency noise in the auto-body is mainly related to the structural vibration of the auto-body, while the different plates of the auto-body have different sensitivities to the sound pressure of the points in the internal space of the passenger compartment. Therefore, defining correctly the relation between the structural vibration and the noise in the vehicle could restrain the structural vibration of the auto-body effectively and reach the objective to control the noise in the vehicle.

Based on Eq. (5), dividing the auto-body plates into n units, then at some point i on the auto-body plate, the sound pressure at the point i in the passenger compartment caused by the vibration is:

$$p_{i,j} = \sum_{r=1}^{n} \frac{\phi_{\mathrm{ir}}\phi_{\mathrm{jr}}}{K_r + j\omega C_r - \omega^2 m_r} F_j \tag{6}$$

In this equation, φ_{ir} is the r-order sound pressure modal at the point i; φ_{jr} is the r-order vibration modal at the point j; K_r is the r-order modal stiffness of the coupling system; ω is the circular frequency; C_r is the r-order modal damp; m_r is the r-order modal mass of the coupling system and F_k is the input force at the point k. Then, the sound pressure at the point i could be expressed as the vector superposition of the sound pressure caused by all vibration units. The total sound pressure p_i at the point i is:

$$p_i = \sum_{k=1}^{n} p_{i,k} \tag{7}$$

p_i represents the acoustic contribution of all unit vibrations to the node i in the cavity

The acoustic contribution factor of the plate vibration is defined to be the acoustic contribution of a specific plate to the point i. Divide the acoustic contribution p_{hi} of the vibration of the structural unit point h to the cavity unit i by the total acoustic pressure at the point i to get the sensitivity factor:

$$t_{ci} = \frac{p_{\mathrm{hi}}/|F_k|}{|p_i/F_k|} \tag{8}$$

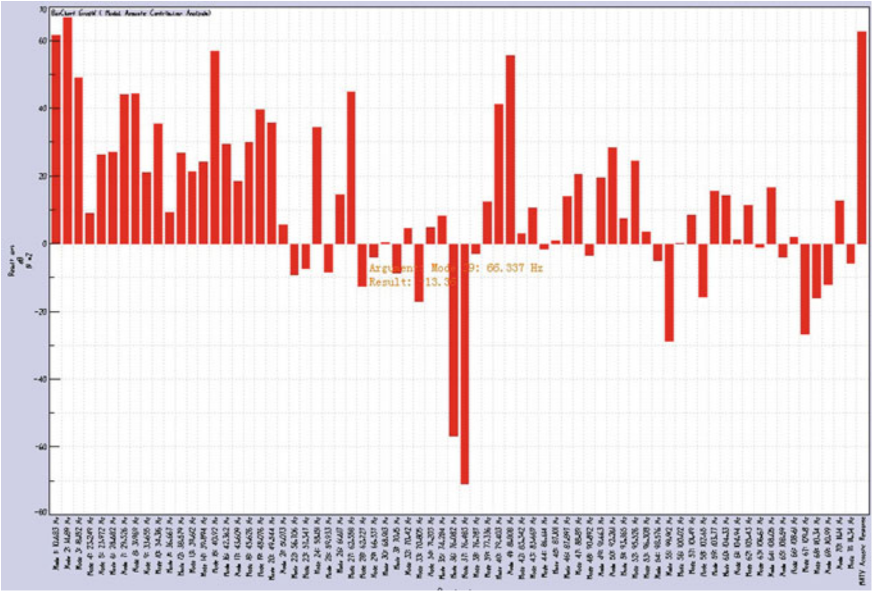

Fig. 5 The contribution chart of cabin field

In this equation, $p_{\mathrm{hi}}/|F_k|$ is the sound pressure transfer function of the plate and $|p_i/F_k|$ is the sound pressure transfer function. The acoustic sensitivity could be explained to be the contribution of every plate to the auto-body sensitivity. This definition provides a direction to reduce the auto-body sensitivity, which is helpful to improve the design (Fig. 5).

Among the analysis results of the plate sensitivity, the positive sensitivity means that the noise in the vehicle could be reduced by restraining the vibration; while the negative sensitivity means the restraining the vibration will not reduce the noise in the vehicle but will increase the noise in the vehicle. The contributions of the plates at the resonance peak are shown as the above figure. Restraining or strengthening the plate vibrations reasonably could reduce the noise effectively.

As per the plate sensitivity analysis results, the thicknesses of the auto-body plates with high interior noise sensitivity are modified and added with reinforcing ribs, U-shaped reinforcing rib is added in the middle of the support plate at the cabin bottom, the thickness of the boards at the both sides of the auto-body is increased by 2 mm and U-shaped reinforcing rib is added for the ceiling, and then the sound pressure response analysis is taken again. The sound pressures at 218 and 240 Hz are reduced obviously, which reduce to 84 dB with the reduction of 10 dB. There is no change almost at 129 and 340 Hz. There are slight increases at some different parts. But it is obviously that the noise in the compartment is reduced obviously (Fig. 6).

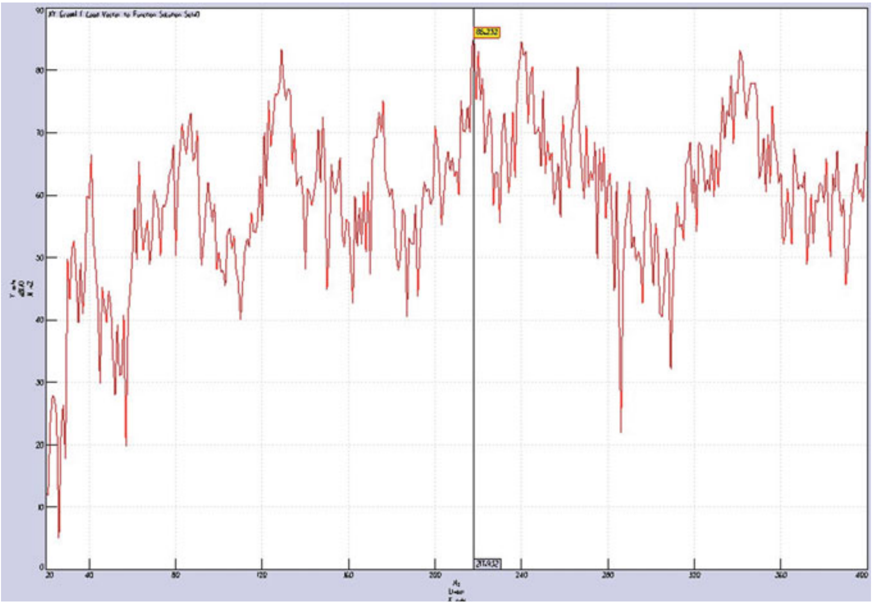

Fig. 6 The improved noise frequency domain curve of cabin reference

5 Conclusions

Taking a certain engineering vehicle as an example, this paper creates the acoustic cavity infinite element models for the auto-body structure and the passenger compartment, based on which the finite element model is created for the acoustic-structure coupling system; the modal characteristics of the acoustic cavities for the auto-body structure and the passenger compartment are analyzed respectively, the acoustic-structure coupling system modal and the system vibration characteristic are analyzed as well. The distribution characteristics of the interior noise and the noise frequency are got through the analysis of the noise frequency response curve. The plates with high sensitivity will be found through the noise sensitivity factor analysis for the field points to propose the improvement measures. The two noise peaks are reduced obviously as per the calculation results, which verify the correctness of the analysis method.

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Analysis of Factors and Countermeasures for Astronaut Space Disorientation

Xiuqing Zhu, Guohua Jiang, Yuqing Liu, Bohe Zhou, Ming An, Xuewen Chen and Fuchao Hu

Abstract In the manned spaceflight, since the gravitational "down" cues provided by gravity are absent and visual cues to orientation are often ambiguous, the altered gravity environments affect astronaut's sense of self-orientation and can lead to spatial disorientation and space motion sickness, affect the operational performance of astronauts, eventually threat astronaut's life and result in mission failure. Several types of representation of disorientation based on different situations are described, the influencing factors of disorientation according to human physiology and cognition are discussed, the research methods and progresses currently are summarized, and several possible countermeasures, such as pharmaceuticals, virtual reality, galvanic vestibular stimulation and artificial gravity, are analyzed.

Keywords Manned spaceflight · Microgravity · Disorientation · Space sickness

1 Introduction

Astronauts often feel the spatial disorientation and disturbance of location awareness, and this situation mostly occurs before and after orbit injection and returning to earth. The main reason is the conversion of gravity environment. The space disorientation occurring in the conversion of gravity environment will threaten the safety of the astronauts and spacecraft and success of mission.

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Spatial disorientation refers to the phenomenon that the astronauts cannot feel the attitude and movement of themselves, spacecraft or surrounding environment, which can easily cause space motion sickness, misoperation and other dangerous situations [1, 2]. The sense of self-orientation is the result of input information of many sense organs processed and integrated by central nervous system, including vision, vestibule, proprioception, touch and other sensory information. Combined with human's memory and cognitive mechanism, astronauts judge the attitude and orientation of body in the space. In the microgravity environment, lack of the reference of gravity, it is incident to astronauts to have trouble of spatial disorientation.

When astronauts experience the adaptive process of zero-gravity environment and then return to earth with gravity from orbit, they are also affected by gravity readaptation, including gait variance, reduction of balance ability and decrease of accuracy of situation awareness [1]. For example, when space shuttle which is controlled by human, returns to the earth, disorientation may lead to the risk of landing operations. In the landing mission to asteroids and Mars in the future, this may affect the landing operations and operational capability after landing of astronauts.

2 Disorientation in the Space Mission

In the space mission, astronauts will experience the gravity conversion process when entering orbit and returning, which may lead to sensory disorder phenomenon and cause illusion so as to result in the occurrence of disorientation. In the different stages of flight mission, there are several types of representation of disorientation [2].

2.1 Inversion Illusion Under Microgravity

Inversion illusion is the vestibular proprioceptive illusion and is the first space disorientation encountered by astronauts after entering orbit. Astronauts described such a strange feeling: Although the visual orientation in the module prompts them that they are always in the visually upright posture, they still feel themselves in the inversion state. Fixing astronauts on the seat can ease this illusion. The illusion is quite common and will appear in several minutes after astronauts are in the weightlessness and then last for several minutes and even few hours, but few people will have this illusion last until the second day. Further research shows that inversion illusion is related to the inner ear otolith weight loss, rising of visceral position and combined action of nasal and facial hyperemia.

2.2 Visual Reorientation Illusion

Astronauts on the space station and space shuttle move between many modules frequently, increasing the chance of visual orientation illusion. After changing the body position and attitude, astronauts often find that the floor, ceiling and the walls in the module often exchange position. Although they know the changes of body position, they still consider that the object below the body is floor and that parallel to the body is walls and that above the head is ceiling. The asymmetry layout and familiar objects in the fixed position in the module can prevent or reduce this illusion. When astronaut sees the inverted peer beside him, sometimes he will suddenly feel that he is in the inverted state.

2.3 Extravehicular Activity Acrophobia

For extravehicular activity, when astronauts work in the payload bay of space shuttle or fixed at the end of robot arm, all of them have acrophobia suddenly and feel themselves falling to the ground, which is similar to the acrophobia that people may have when standing at the edge of the cliff or the top of tall buildings. An astronaut described that he felt himself falling to earth at that time and accompanying anxiety and fear even made him lose operational capability. He had to tightly grasp an object so that this fear is reduced a little. Although the systematic analysis of this phenomenon has not yet conducted, obviously, with the further expansion of space activities and increase of extravehicular operations, extravehicular activity (EVA) acrophobic vertigo will become a serious problem.

2.4 Readaptation to Returning to Gravity Environment

After the space mission, returning to gravity environment needs readaptation. We often see that the gait of astronauts returning to earth is not stable and they even need to be helped out of the module. This is because that the sense organs need to readapt to the gravity environment and the coordination and sense of direction of the body shall be adjusted [1]. In the process of landing of spacecraft, astronauts shall perform mission operations; especially, the space shuttle needs astronauts to control the shuttle landing, which has severe requirements on their sense of direction and operational capability. They must deal with the body adaptation and cognitive regulation in the condition of gravity conversion. For the future landing missions, such as Mars, without the support of auxiliary personnel on the ground, astronauts must rely on themselves and restore their body movement and work capabilities as soon as possible.

3 Analysis of Influence Factors

3.1 Theoretical Research on Physiological Effect

The researches show that the disorientation and motion sickness caused by conversion of gravity environment are mainly caused by the adjustment and readaptation of physiological senses. Scientists have proposed several hypotheses, mainly including sensory conflict and fluid shift [1].

Sensory conflict, this theory assumes that there is a neural signal memory. In the environment of 1 g, the linear or angular acceleration caused by human motion transmits the signal into the neural memory for storage through eyes, otolith and semicircular canal and also inputs the signal to the comparator for comparing with original stored information. If two kinds of information are not consistent, the felt conflict is caused, resulting in motion sickness. The mismatch signal is stored in the memory, and the original signal is changed. This process will repeat in the next movement. In the environment of weightlessness, the otolith weight will disappear. The lymph in three semicircular canals will also lose weight. At this time, even if the movement like ground motion happens, the signal transmitted to the memory is not the same and has conflict with storage signal originally formed on the ground, so that sensory conflict will cause disorientation and motion sickness. This new signal gradually changes the original signal in the memory, and two kinds of signals gradually match with each other so that there will be no stimulus conflict any more. This theory explains the reason for the disappearance of space motion sickness 7 days later in flight.

Fluid shift is redistribution of body fluid. Astronauts said when they got into the state of weightlessness and felt head congestion most serious, the motion sickness is the most obvious. When the symptom of head congestion relieves, the motion sickness will also decrease; when doing lower body negative pressure exercise in space, the blood is from the head to the lower limb. At this time, motion sickness symptoms will decrease. On the one hand, blood rushing to the head changes the original blood circulation of the brain, resulting in changes in the status of cells of cerebellum; on the other hand, the lymph of vestibular semicircular canal may also change, which is a kind of abnormal stimulation to the vestibular organ, so the motion sickness is caused.

3.2 Influence of Cognitive Factors

Cognitive factors also play an important role in the direction judgment of people and mainly realize direction judgment through the visual perception to cognitive information processing. In particular, in the environment of weightlessness, visual perception plays a more important role. Perspective taking and ability of mental rotation have important effect on the direction judgment of people and are often used to judge a person's ability of orientation perception. Researches show that people who get higher scores in the test of perspective taking and ability of mental rotation spend less reaction time in the mission of direction judgment and gain higher performance, which can be the reference index for personnel selection.

3.3 Experimental Research Methods

The exact mechanism of spatial disorientation and motion sickness is still not completely clear, and a large number of scientific experiments and theoretical analysis are needed. The main experimental methods adopted at present include the application of spaceflight, weightless plane and ground centrifuge and other experimental environment for study. The experimental objects include humans and other animals. In addition, simulation modeling method is used for theoretical analysis.

Spaceflight test is the most ideal experiment environment. In the 1980s and 1990s, the USA used payload bay of space shuttle to carry out physiological experiments for many times to study the effect of spaceflight on nervous physiology. In the early 1980s, Spacelab1 of space shuttle was used for a series of correlation experiments. Four payload specialists took part in the human trial to evaluate the vestibular and visual response of people in the space and explore changes of sensory and motor function. Test data include test results and observation before, during and after the flight [3]. In the early 1990s, the mission of space shuttle STS-90 was to conduct Neurolab project of scientific research on brain and nervous system [2], and about 26 neuroscience experiments were conducted. Besides human physiological experiments, mice, opsanus pardus, cricket and other animals were used to conduct experiments for researching the changes of vestibular organs under microgravity. Mir Space Station and International Space Station have provided ideal platform for studying the physiological effect of long-term weightlessness on humans.

For many scientists, there are few chances for spaceflight experiments. Weightless plane can also be used for some short-duration weightless experiments. Weightless plane has weightless and overweight alternately, and the time of weightless is very short. Scientists used weightless plane to conduct mouse spatial orientation test. They detected the physiological reaction of direction cells of the mice head by implanted electrodes and found that when the mice were on the walls and ceilings, they also had the physiological reaction of disorientation [4].

Conversion of gravity environment includes microgravity (space orbit), low gravity (Moon, Mars surface), normal gravity (earth surface) and supergravity (spacecraft launching, returning process) and others. The conversion of these gravity environments can cause neurophysiological responses and adaptive changes. Using centrifuge on the ground can cause the gravity environment of over 1 g to simulate the conversion from normal gravity to supergravity. Scientists used centrifuge tests to study the perception error to spatial orientation and reduction of operational capability of humans in the environment of supergravity and established error evaluation model.

In order to reduce experimental costs and realize the quantitative analysis of data, establishing a simulation model for human orientation analysis by the method of mathematical modeling, conducting analysis research and comparison analysis with real test results and constantly refining simulation model have become an important research means, quantificationally predicting directional sensory deviation of astronauts. The established model takes into account the gravitational cues, gravireceptor deviation, visual vertical direction, symmetry of environmental structure, polarization cues, introspective tendency and other factors and evaluates the direction judgment of subject through weighting parameters and vector calculation, which can be used for mission analysis and personnel performance prediction.

The research on the directional physiological reaction mechanism of people in different gravity environments is very important for studying preventive measures or measures for reducing disorientation. The researches show that spatial disorientation causes physiological symptoms and vestibular perception plays a leading role. The adjustment of the central nervous system runs through the whole process of adaptation. Scientists have used a variety of animals to conduct invasive tests to study the response changes of vestibular organs to microgravity environment and changing process of physiological mechanism. Mastering changing mechanism of physiological mechanism has a great significance for guiding the selection of special personnel and early targeted treatment or training.

4 Analysis of Coping Strategies for Disorientation

In order to overcome the effect of spatial disorientation and motion sickness on performance of astronauts, the researchers have conducted many tests and explored many kinds of coping measures to cope with different situations. Some of these measures have been applied to the practical missions and have some practical effect. Some may also cause side effects. Some measures are not mature and still in the experimental process.

4.1 Application of Pharmaceuticals

At present, the pharmaceuticals are used to treat symptoms of motion sickness caused by disorientation. We mostly use scopolamine + dextroamphetamine for oral administration. There are side effects, such as dry mouth and sleepiness. In the American spaceflight plan, intramuscular injection of promethazine is recommended to treat moderate to severe space motion sickness, but the application effect is not ideal. Different individuals have different feelings when using it, and even the sleepiness, slow response and other side effects caused by the pharmaceuticals are greater than the influence of space motion sickness.

4.2 Physical Adjustment and Constraints

Researches show that in the adaptive process of gravity conversion, the rotation of head will increase the stimulation to vestibule, and occurrence of motion sickness, especially the rotation of head in the directions of pitching and rolling, will cause more intense stimulation. Therefore, in order to avoid the occurrence of disorientation and motion sickness, in the adaptive process of gravity conversion, it is necessary to avoid head movement as much as possible. Physical restraint can reduce motor stimulation, so in the launching and returning stages, astronauts must be fixed on the seats and keep head still to reduce the induction of motion sickness. Some tests have proved that pressure stimulation in a particular direction can improve the direction awareness of astronauts; for example, increasing pressure stimulation under feet can improve direction perception.

4.3 Layout and Marks in the Module

Multi-function docking adapter MDA of Skylab of the USA has a cylindrical inner surface. Control panel and other systems to operate space telescope are installed on the walls in different directions. The MDA is designed to make an efficient use of wall space; therefore, it is a module without a single visual vertical axis. As a result, astronauts dislike working there and they feel that it is like a maze [2]. In fact, even in the weightless environment, people also need to determine their own orientation so as to infer the target orientation for movement or operation. So it is required that environment design of module should have clear polarity information to determine the direction easily. In addition, adding emergency indicators and location indicator diagram is also the feasible method for improving information about direction judgment.

4.4 Virtual Reality Training

For the training in the virtual reality environment, on the one hand, through the changes of virtual scenes, simulate a person to work in the spatial environment in different viewpoints and body attitudes to improve the cognitive ability to direction and attitude; on the other hand, through the arbitrary change of visual scenes, the vestibular and proprioception have no changes, can simulate the conflict process of visual perception and neural physiological perception to improve readaptation efficiency of nervous system, improve tolerance to sensory conflict and reduce adaptation period [5].

4.5 DC Vestibular Stimulation Training

DC vestibular stimulation is to conduct electrical stimulation to vestibular organs by setting surface electrode on the head and simulate the effect of gravity conversion on the vestibular organs of astronauts and can be used for testing the response of body to vestibular stimulation to study the reaction characteristics and response mechanism of human body in the condition of vestibular stimulation. This method is widely applied to aerospace, aviation physiology and stress response tests. And it is also used in personnel stress adaptation and simulation training [6].

4.6 Artificial Gravity

Artificial gravity mainly adopts the method of centrifugal rotation. There are different designs, such as rotation in the module, rotation partly module and rotation of the whole module. According to different design proposals, the length of rotational centrifuge arm is different. The future application shall be designed combined with the overall structure of spacecraft. Besides the overall consideration for g value, rotation period, structure and size of centrifuge and other factors, the problem of adopting intermittent artificial gravity or continuous artificial gravity shall be solved. Among them, how to arrange the gravity migration and conversion procedures, effect of Coriolis acceleration caused by rotation and the adaptability of people to the rotating environment in the space and other problems shall be solved. At present, the experimental results and data are not enough to support the actual aerospace applications and are still not mature in the engineering realization. But artificial gravity can provide the most adaptive gravity environment for people, which is the most anticipated solution.

5 Conclusion

In the manned spaceflight mission, due to the conversion of gravity environment, the physiological reaction and adaptive regulation of astronauts often cause physical sensory disorders, resulting in spatial disorientation and motion sickness. This phenomenon affects job performance of astronauts and may lead to safety problems and mission failure. Studying relevant physiological mechanism and coping mechanisms, preventing and overcoming disorientation and motion sickness caused by gravity conversion process and adopting effective preventive and coping methods are of great importance for astronaut safety and success of mission.

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Study on the Strategy of Disinfectant Using in China's Space Station

Hong Yin, Yikui Zhao and Kanyan Xu

Abstract *Purpose* Disinfectant is widely used in the International Space Station to help control the microbe level in the cabin environment. However, the long-term use of disinfectant with a single formula can generate microbial drug resistance and reduce the germicidal efficacy. Here, we try to find a method for the usage of disinfectant in China's future space station to prevent the resistance induction. *Method* We conducted the resistance induction experiment, using the minimum inhibitory concentration (MIC) as determinant to study the drug resistance of *Candida albicans* induced by compound disinfectants as well as disinfectants with a single formula. *Conclusion* Both the alternate use of disinfectants with different germicidal components and the use of compound disinfectant can effectively prevent or alleviate the induction of microbial drug resistance.

Keywords Disinfectant · Drug resistance induction · *Candida albicans*

1 Introduction

According to the overall conception of the space station engineering, China's space station is expected to be built in 2020–2022. After that, China's space station will provide the access to the long-term orbit work for up to six crewmembers. In the space station, astronauts can carry out various scientific and technological experiments, including some large-scale, interdisciplinary research, and the replenishment work will be performed by cargo spaceship [1]. Since the personnel and materials will enter the space station frequently, the tellurian microbes will be inevitably brought into space station and breed abundantly under the long-term closed environments in the cabin, and thus may cause the corrosion of the materials and even affect the health of the astronauts.

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The housekeeping subsystem of International Space Station (ISS) supports routine cleaning using a portable wet/dry vacuum cleaner and six kinds of wipes to prevent microbe contamination [2]. At present, the disinfectant provided by NASA is a single-chain quaternary ammonium compounds (QAC's) (4250Z) [3]. 4250Z is the second generation product of QAC's. It is the mixture of four kinds of alkyl dimethyl benzyl ammonium chloride and two kinds of alkyl dimethyl benzyl triethyl ammonium chloride, mainly used for surface disinfection, food preservation and water treatment, etc. It has strong disinfection ability to bacteria, fungi, viruses and algae. However, just like the resistance to antibiotics, the long-term use of disinfectant with a single formula can lead to microbial drug resistance. From the 1950s to the present, people have found that many strains have produced resistance to QAC's, biguanides, metal ions, phenols, alcohols and iodines and other disinfectants [4].

The designed service life of China's space station is ten years, so it is necessary to setup a reasonable use strategy of disinfectants to prevent microbial drug resistance. Studies have shown that alternate use of different types of antibiotics can reduce the microbial drug resistance to antibiotics to a certain extent [5]. In this study, we have performed the drug resistance induction experiment of the microbes to disinfectants using *Candida albicans* as the testing object. We take MIC value as the basis of judgment and observe the change of drug resistance after alternate use of different disinfectants. Our results show that the alternate use of disinfectants with different effective components or the use of compound disinfectant can effectively prevent or alleviate the microbial drug resistance.

2 Materials and Methods

2.1 Determination of MIC Against Disinfectants

The MIC of value *C. albicans* (ATCC10231) against disinfectants is determined by 96-well plate dilution method and light absorption photometry (microplate reader BIO-RAD 680) [6].

1. Preparation of *C. albicans* culture: Single colony of *C. albicans* is inoculated in 10 ml Sabouraud's liquid medium and cultured overnight (30 °C, 150 rmp). The concentration of the culture is adjusted to OD_{600} 0.17–0.18 by spectrophotometer (UNIC2100), and the concentration of the culture is about 10^7cfu/mL.
2. Add 100 μL double Sabouraud's liquid medium in column 1–12 of row A, B, C, F, G and H on a sterile 96-well plate.
3. Add 100 μL disinfectant (320 mg/L) in the first column of every row; mix well and draw 100 μL solution to the second column; conduct double dilution in

turn; draw 100 μL from the last column and discard. Use the sterile water to replace disinfectant in the column 9 and 10 as positive control, use the sterile water to replace the culture in the column 11 and 12 as negative control. The disinfectant is the same for every three rows.

4. Add 100 μL *C. albicans* culture into column 1–10 of row A, B, C, F, G and H and mixed well.
5. Grow the culture for 24 h, test the OD value at 560 nm by spectrophotometer.
6. Take the average value of every three rows of disinfectants as the effective light absorption value of this disinfectant and take this light absorption value as the vertical ordinate and the effective concentration of each column of the disinfectant as the horizontal ordinate to draw a line graph. The concentration of disinfectant that makes the surviving curve of *C. albicans* dropped dramatically is the MIC value of *C. albicans* against the disinfectant.

2.2 Drug Resistance Induction and Elimination

1. *C. albicans* is cultured overnight in Sabouraud's liquid medium with disinfectant concentration of 1/2 MIC (30 °C, 150 rpm). After centrifugation (6000 rpm, 3 min), precipitates are moved to new liquid medium with 1/2 MIC disinfectant and subcultured.
2. Repeat the operation describe in (1) for 20 continuous passages.
3. Determine the MIC value of the strains after passage to the disinfectants.
4. Take the strains after passage as the original strain to new Sabouraud's liquid medium with a different disinfectant, conducted 20 passages again and then determine the MIC value of the previous disinfectant.

3 Results

3.1 MIC Value of C. Albicans *Against Various Disinfectants*

The MIC value of *C. albicans* against HTSW-WP-02 is showed in Fig. 1. From this figure, we found that the surviving curve of *C. albicans* dropped dramatically when they were treated with 10 mg/L HTSW-WP-02, so the MIC value of *C. albicans* against HTSW-WP-02 is 10 mg/L. The MIC value of *C. albicans* against PHMB, 4250Z and benzethonium chloride (BZC) is 80, 40 and 80 mg/L, respectively. HTSW-WP-02 is a product of Shenzhou Space Biology Science & Technology Co., Ltd.

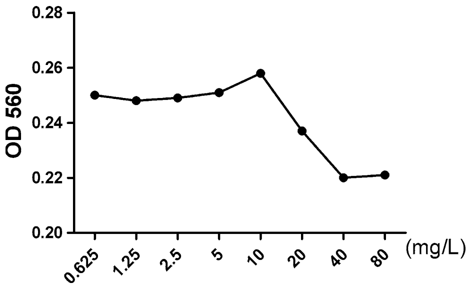

Fig. 1 Determination of MIC value against HTSW-WP-02

3.2 *Induction and Elimination of Drug Resistance to Disinfectants with Single Components*

We transferred *C. albicans* continuously for 20 generations in Sabouraud's liquid medium with PHMB and measure the MIC value; we found that the MIC value of *C. albicans* against PHMB was 320 mg/L, four times of the original MIC value. We took this culture for passage as the original strain, transferred continuously for 20 generations in culture medium with BZC and 4250Z, respectively, to reduce the drug resistance to PHMB. The MIC value against PHMB was reduced to 160 mg/L (Fig. 2).

Next, we tried to reduce the drug resistance to BZC by PHMB and 4250Z treatment. After transferred continuously for 20 generations in Sabouraud's liquid medium with BZC, the MIC value of *C. albicans* against BZC was 160 mg/L, two times of the original MIC value. We then took this culture for passage as the original strain, transfer continuously for 20 generations in culture medium with PHMB and 4250Z, respectively, to reduce the drug resistance to BZC. The MIC value against BZC was reduced to 40 mg/L and 80 mg/L, respectively (Fig. 3).

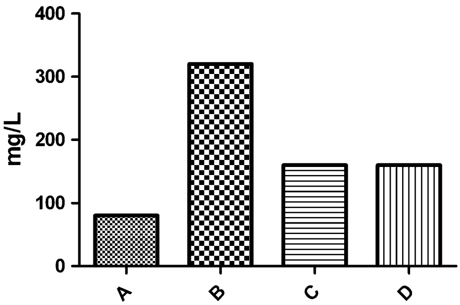

Fig. 2 Induction and elimination of drug resistance to PHMB. **A** MIC value of original strain against PHMB; **B** MIC value of *C. albicans* after induction with PHMB; **C** MIC value of *C. albicans* after reduction of drug resistance to PHMB by BZC; **D** MIC value of *C. albicans* after reduction of drug resistance to PHMB by 4250Z

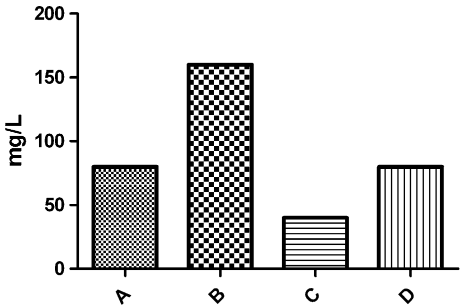

Fig. 3 Induction and reduction of drug resistance to BZC. **A** MIC value of *C. albicans* original strain against BZC; **B** MIC value of *C. albicans* after induction with BZC; **C** MIC value of *C. albicans* after reduction of drug resistance to BZC by PHMB; **D** MIC value of *C. albicans* after reduction of drug resistance to BZC by 4250Z

The results showed that long-term use of disinfectant with a single formula will make its MIC value increase, indicating that *C. albicans* has produced a certain drug resistance to the disinfectant. The alternate use of the disinfectants with different effective components can significantly reduce the drug resistance of *C. albicans* to the original disinfectant.

3.3 Results of Induction of Drug Resistance to Compound Disinfectant

We then studied the induction of drug resistance to compound disinfectant. Both 4250Z and HTSW-WP-02 are compound disinfectants. After transferred continuously for 20 generations in liquid medium with 4250Z and HTSW-WP-02, respectively, the MIC value of *C. albicans* against 4250Z or HTSW-WP-02 was the same as before, which meant that no drug resistance was induced.

4 Discussion

The use of disinfectant is an important method to prevent the space station from microbial contamination, especially those caused by fungi. This study took *C. albicans*, the common fungi representative in microbial killing test as the research object and studied its drug resistance to PHMB, BZC and two kinds of compound disinfectants.

PHMB and BZC are recognized disinfectants with broad spectrum sterilization, low toxicity and low corrosion. PHMB is a guanidine disinfectant, it interacts with phospholipid and destroys the phospholipid bilayer to increase cell membrane permeability and destroy its integrity, which will lead to the death of microbes [7–10]. Similar to guanidine disinfectants, BZC also combines with the cell membrane, changes its permeability and causes the flow-out of intracellular materials, which will lead to the death of cells [11].

In recent years, with the increasing knowledge about drug resistance to disinfectants, it has been found that the long-term use of disinfectants with a single effective component can cause an increase in microbial drug resistance to disinfectants. Microbial drug resistance can be classified as inherent drug resistance and acquired drug resistance. The inherent drug resistance is the nature of microbes and mostly caused by special structure or performance of the microbe itself. For example, the lower sensitivity of fungi to disinfectants is related to its natures such as the glucan component of its cell wall, the thickness of cell wall and the porosity. The acquired drug resistance refers to a resistance that sensitive microbes acquire to the disinfectant by various means in the process of long-term interaction with the disinfectants [11].

This study carries out MIC determination after continuous use of PHMB and BZC and finds that the drug resistance of *C. albicans* to these two kinds of disinfectants has been significantly increased, indicating that *C. albicans* has produced acquired drug resistance. After the replacement of disinfectants for continuous passage, the drug resistance of the *C. albicans* strains to the original disinfectants has been reduced to a certain extent, indicating that the acquired drug resistance observed in this study is not genetic and stable. This result is similar as the result obtained by Meng et al. [12], studying on the drug resistance to antibiotics using bacteria as the research object. The strategy for alternate use of disinfectants with different effective components can help preventing long-term operating space station from being contaminated by microbes.

In this study, the continuous use of two kinds of compound disinfectants leads to no drug resistance in *C. albicans*. The reason may be that the mixture compound of different disinfectants can make the number of acting sites increasing and the germicidal mechanism more complex; so the microbe needs more genetic variation to produce drug resistance. 4250Z is a compound product consisting of six single-chains QAC's, and is widely used for surface disinfection, food preservation, water treatment, etc. However, in our corrosion test, we find that this disinfectant has a slight corrosion on carbon steel and aluminum (unpublished result). HTSW-WP-02 is a compound product newly developed by Shenzhou Space Biology Science & Technology Co., Ltd.; it has basically no corrosion on four kinds of test materials in the corrosion testing, while has the same sterilization efficiency and safety performance as 4250Z has (unpublished result), and therefore it is suitable for use in a long-term closed environment.

As the China's space stations will carry out a long-term operation in a closed environment, it is necessary to prevent the microbes from producing drug resistance to the disinfectants which is used in the surface cleaning and sterilization in the cabin. Through this study, we provide two proposals which can solve this problem: One is the use of compound disinfectants, the other is the alternate use of disinfectants with different effective components, and these two proposals can also complement each other.

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Part IV
Research on the Man-Machine Relationship

Research on the Correlation Between the Viewing Screen Layout of In-Vehicle Information Terminal and Crew's Mental Workload

Weiping Liu, Zheng Zhang, Junfeng Nie and Binhe Fu

Abstract The ergonomic study on the viewing screen layout of In-Vehicle information terminal is essential to improving the reliability of armored vehicle's man–machine systems. Based on the ergonomic experiment platform of armored information system, a series of experiment was conducted in which 32 subjects performed the information entering task in three kinds of viewing screen layout of In-Vehicle information terminal. The mental workloads of each experiment condition were evaluated and compared. Results indicated that the layout view screen had a significant impact on crew's mental workload. The research results can provide a reference for In-Vehicle information terminal design and display.

Keywords Viewing screen · Layout · Information display · Mental workload

1 Introduction

The viewing screen is a significant part of man–machine interaction, and now, the size and layout of the viewing screen are key points in ergonomic study [1]. Due to the finitude of crew's working space, the mental workload of information processing is enormous. Thus, it is necessary to optimize the viewing screen layout of In-Vehicle information terminal.

Research to date has evaluated the effect of the viewing screen layout on user performance. National Aeronautics and Space Administration (NASA) has carried out a large number of researches on man–machine interaction, including display luminance, display content and installation site of the view screen. Dominessy conducted an experiment to analyze the relationship between the viewing screen layout and goal acquisition of pilots [2]. By summarizing former studies, a research on the design and the layout of the view screen was conducted, which was on the

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basis of a newly established mental workload evaluation model and synthesized three representative methods in mental workload measurement [3, 4]. These results provide information on pilot performance, but there is no research focus on armored vehicle crew's mental workload. So the aim of the present study is to carry out an ergonomic experiment to investigate the correlation between the viewing screen layout of In-Vehicle information terminal and crew's mental workload to select the optimum layout.

2 Method

2.1 Subjects

The 32 subjects included in the experiment were aged 22–25 years (mean = 23.2, SD = 0.98), and studied engineering. They were right-handed and healthy with no history of seriously deformity and illness. Data were collected for all subjects, but 2 of these were removed from the analysis due to obvious lack of effort.

2.2 Experimental Apparatus

The experimental was performed on the ergonomic experiment platform of armored information system. There were three kinds of layout for the viewing screen of In-Vehicle information terminal (Fig. 1), namely at a 60° angle from crew's sight on the left side, the layout setting in vertical director of crew's sight, at a 60° angle from crew's sight on the right side.

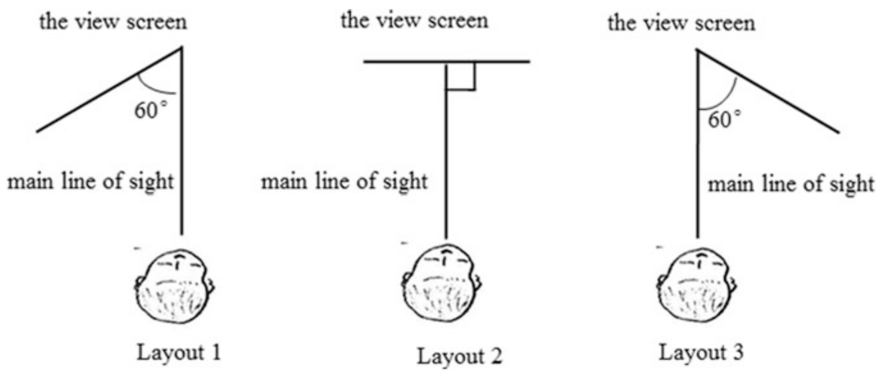

Fig. 1 Three kinds of layout of the viewing screen

2.3 Procedure

Prior to the experiment, subjects were given 10 min to familiarize themselves with the platform and experimental task. Then, there was a tester who set the layout of the viewing screen of In-Vehicle information terminal. During the experiment, subjects were asked to sit in a chair for 5 min, and then, they had to perform 10 times of the information entering task in each layout of the viewing screen. Their ECG signals in each experiment condition were collected by the MP 150 multi-channel physiological instrument. After experiments, they needed to complete a NASA-TLX questionnaire to evaluate subjective mental workload in different layouts.

2.4 Variables

Independent variables were layouts for the viewing screen. Dependent variables were classified into three aspects, namely psychological indexes, physical indexes and subjective evaluation indexes.

2.4.1 Psychological Indexes

From the aspect of psychological indexes, the response time in three reaction modes (simple reaction, choice reaction and understanding reaction) were used to assess the operating speed in different experimental conditions. The error rates of three reaction modes were used to assess the operating veracity in information processing.

2.4.2 Physical Indexes

Heart rate variability (HRV) was selected as the physical index. With the growth of subjects' mental workload, HRV would increase, while if the mental workload of subjects rises, HRV will also appear an upward trend. In this paper, low frequency (LF, 0.04–0.15 Hz), high frequency (HF, 0.15–0.40 Hz) and LF/HF were selected as indexes to reflect the change of HRV [4].

2.4.3 Subjective Evaluation Indexes

The National Aeronautics and Space Administration-Task Load Index (NASA-TLX) was used to evaluate subjects' mental workload. This subjective assessment scale included mental demand (MD), physical demand (PD), time demand (TD), the effort level (EL), operational performance (OP) and frustration level (FL) [5]. To confirm the weight of above aspects, 6 experienced experts were invited and the final factors' weight was gained by the expert scoring (as shown below).

$$(\mathrm{MD}, \mathrm{PD}, \mathrm{TD}, \mathrm{EL}, \mathrm{OP}, \mathrm{FL}) = (0.233, 0.100, 0.244, 0.078, 0.278, 0.067)$$

3 Results and Discussions

Data from 2 subjects were removed due to obvious lack of effort. Descriptive statistics and variance analysis were used to analyze and to examine the significant difference of experimental data of subjects in different layouts of the view screen. The significance level was set at $P < 0.05$ for all statistical tests.

3.1 *Psychological Indexes*

The average values and standard deviations of response time and error rate are shown in Table 1.

From the descriptive statistics of response time and error rate in different reaction modes, layout 2 and layout 1 had the minimum and maximum values, respectively, and the data of layout 3 were between the above two.

With the consideration of actual situation of the information entering task, all subjects were required to remember the information on the view screen and then press buttons with their right index fingers. Thus, it was easier for them to complete the task and to ensure the operating veracity when the view screen was set on the vertical director of crew's sight or the right side, rather than setting on the left side.

The results of variance analysis indicated that both of the simple reaction time, choice reaction time and understanding reaction time were significantly affected by the layout of the view screen ($P = 0.000 < 0.05$, $P = 0.002 < 0.05$ and $P = 0.014 < 0.05$, respectively). Also, the error rates of above three kinds of

Table 1 Response time (ms) and error rate (%) in different layouts (M ± SD)

Index	Layout	Simple reaction	Choice reaction	Understanding reaction
Response time	Layout 1	982.25 ± 100.67	1849.10 ± 217.09	2863.05 ± 249.62
	Layout 2	796.14 ± 102.36	1571.28 ± 224.51	2363.97 ± 252.64
	Layout 3	876.20 ± 115.02	1603.08 ± 196.40	2483.12 ± 263.15
Error rate	Layout 1	0.43 ± 0.03	2.23 ± 0.23	2.01 ± 0.27
	Layout 2	0.40 ± 0.06	1.99 ± 0.15	1.88 ± 0.24
	Layout 3	0.41 ± 0.10	2.09 ± 0.12	1.92 ± 0.18

Table 2 HF (ms^2/Hz), LF (ms^2/Hz) and LF/HF in different layouts (M ± SD)

Layout	LF	HF	LF/HF
Layout 1	1069 ± 447	972 ± 329	1.10 ± 0.48
Layout 2	858 ± 206	876 ± 308	0.98 ± 0.25
Layout 3	967 ± 314	937 ± 297	1.03 ± 0.29

respond modes in different layouts had remarkable difference ($P = 0.000 < 0.05$, $P = 0.000 < 0.05$, $P = 0.001 < 0.05$, respectively).

3.2 Physical Indexes

The average values and standard deviations of HF, LF and LF/HF are shown in Table 2.

The average values of HF, LF and LF/HF in three kinds of layouts (Table 2) were different. In layout 2, the LF and LF/HF indexes were low, which showed that sympathetic activity was slightly inhibited and vagal activity was enhanced, and the tension degree of subjects was not high. The physical indexes proved that the layout 2 was superior to the other layouts in reducing crew's mental workload, which was consistent with the result of psychological indexes.

The results of variance analysis indicated that HF, LF and LF/HF were significantly affected by the layout of the view screen ($P = 0.000 < 0.05$, $P = 0.003 < 0.05$, $P = 0.023 < 0.05$, respectively). It demonstrated the sensibility of HRV in evaluating subjects' mental workload.

3.3 Subjective Assessment

The results of subjects' subjective assessment in different layouts are shown in Table 3.

From the Table 3, layout 2 and layout 1 had the highest and lowest level of NASA-TLX, respectively, and the data of NASA-TLX in layout 3 were between the above two. The results of subjects' subjective assessment were consistent with the results of psychological indexes and physical indexes.

Table 3 Subjective assessment of subjects in different layouts (M ± SD)

Layout	MD	PD	TD	EL	OP	FL	NASA-TLX
Layout 1	53 ± 3.41	45 ± 4.18	55 ± 4.27	49 ± 3.05	50 ± 3.52	40 ± 3.01	50 ± 5.11
Layout 2	46 ± 3.63	31 ± 1.98	48 ± 3.25	41 ± 2.82	57 ± 4.10	33 ± 4.54	45 ± 5.02
Layout 3	51 ± 4.95	42 ± 3.12	50 ± 4.11	43 ± 2.67	54 ± 3.79	36 ± 3.08	47 ± 4.63

In layout 2, subjects were less likely to be frustrated and they tended to pay less attention, time and effort to complete the experimental tasks compared with other layouts. However, subjects were hard to adapt to the layout 3, the operating speed and accuracy could not be ensured, and they needed to pay a great deal of attention and effort to complete the experimental tasks.

4 Conclusions

According to the above results and experimental conditions, we can arrive at the following conclusions:

1. It was practicable to use the ergonomic experiment to compare crew's mental workload in different layouts and to use psychological indexes, physical indexes and subjective evaluation indexes to construct evaluation index system of mental workload.
2. Considering psychological indexes, physical indexes and subjective evaluation indexes comprehensively, the layout 2 was optimal layout in reducing crew's mental workload.
3. Due to crew's operating habits, the layout 1 was inferior to the layout 3. Thus, it was proper to choose the layout 2 or slightly right layout and to avoid the left side of the layout.

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On Usability Evaluation of Human–Machine Interactive Interface Based on Eye Movement

Chenhui Li, Zengjun Ji, Zhibing Pang, Shili Chu, Yonggang Jin, Jianguo Tong, Hualiang Xu and Yuxin Chen

Abstract There is not a thorough integrated index system and evaluation criterion for evaluating the interface ergonomics of equipment display; thus, we put forward an evaluation method based on eye movement evaluation method. Human-machine interaction is mainly realized by means of command interface, graphic interface and multimedia interface, etc. Presently, it is developing toward virtual reality and multiple channel user interface. The authors address the usability evaluation of human–machine interactive interface. First, they define the concept of the usability of human–machine interactive interface. Then, they elaborate how to construct and analyze the usability evaluation index and elaborate the expert evaluation method and usability test theoretical technique. Finally, they analyze the hotspot of research and tread of development of usability evaluation.

Keywords Human–machine interactive interface · Eye movement tracking · Usability · Method of evaluation

1 Introduction

In recent years, the development of human–machine interaction technology "centering on human" embodies the increasingly importance of the factor of human, which makes the method of interaction more close to its natural form, so that the user may utilize his/her natural skills instead of his/her special learning. This reduces the load of cognition and thus enhances the work efficiency. What is an ideal human–machine interaction technology? What is the human–machine interface like in the future? How to evaluate the usability of the human–machine interactive interface? These questions gradually become the focus of discussion. Normally, the usability of human–machine interactive interface refers to the effectiveness, work efficiency and

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user's satisfaction of a specific interface. From the perspective of human–machineinterface, the theoretical basis to correlate the usability with the easiness and friendliness of the interface is the research of human–machineinteraction [1]. Here, the usability of the human–machineinteractive interface is defined by the authors as follows: In a specific environment of application, the interface of a system can demonstrate a feature of adaptability to the user. The feature is depicted by such indexes as the effectiveness, work efficiency, user's satisfaction and easiness, etc.

The human eyes are the organic interface to express the sense of vision. To track and analyze the gaze of the human eyes may obtain the information sensed by the human eyes. Initially, eye movement tracking was mainly applied in the research of psychology and physiology, but, due to the limitation of the sensor technology and information processing technology at that time, eye movement tracking technology developed very slowly. With the development of optical sensor technology and the increase in realtime processing capability of complex information, eye movement tracking technology undergoes a rapid development and its application field expands continuously, especially the study that eye movement tracking technology is utilized to evaluate the usability of human–machine interactive interface has already made considerable progress.

2 Eye Movement Tracking Technology

The principle of eye movement tracking technology goes as follows: sense the movement of human eyes with optical-electrical sensors or other sensors, calculate the direction and angle in which the eyeballs gaze with a microprocessor, and thus track the line of sight [2]. Eye movement tracking technology may be realized in either of the two ways: hardware and software. The eye tracking devices used with the eye movement tracking technology realized by hardware fall into the following categories: compulsory and incompulsory ones, wearable and inwearable ones, contact and uncontact ones. Such ways request the user to wear a special helmet and contact lens, or a support to fix the head and a video camera on top of the head, etc., to obtain the data of the point of sight through a sight sensor. These ways feature high accuracy but much interference to the user. Currently, the accuracy of eye movement tracking and the limitation/interference to the user is a pair of contradictions difficult to balance. In order to diminish the interference to the user, the way to track eye movement by means of software is suggested. The principle goes as follows: first, capture the image of human eyes or face with a video camera; then, detect, locate and track the human eyes or face in the image with the image processing algorithm, estimating the gazing point on the screen by the user. The software has two ways to represent the gazing direction: direction of head and direction of eyes.

The eye movement tracking system capture the image sequence of human face (or eyes) with a video camera; then, locate the human eyes by analyzing the image; finally, track the line of sight by geometric algorithm. The key techniques are shown in the following.

2.1 Capture the Image of Human Face/Eyes

Human face/eyes capturing device consists mainly of the CMOS image sensor, infrared LED array light source and corresponding embedded digital signal processing system. With the illumination by the active infrared light source, the pupils may reflect the infrared light to produce the red eye effect. Compared with other human eyes detecting technique, this method is simple in algorithm, efficient in location and intensive in antijamming capability.

The core of the device is a camera. Around the camera are two arrays of infrared LED light source, one is placed on the main light axis of the camera and the other off the axis, but they are in the same plane. The hardware circuit designed specially may make the two infrared light sources to be switched on or off alternatively as required, so that the difference between the light pupil image and the dark pupil image received by the image sensor is a clear pupil image. If an infrared light filter is applied in front of the lens of the camera to remove all the light except the infrared light, the signal–noise ratio may be increased dramatically [3].

2.2 Locate Human Eyes

To locate human eyes is actually to locate the pupils of the human eyes. It is possible to track the gazing point of the human eyes after determining the location of the human eyes. After the light and dark pupil images are obtained, subtract them to obtain the difference image. During the time interval between the two images are taken, the head of the user may displace slightly, which may cause some noise in the difference image besides the distinctive pupils. Some methods such as threshold value processing, oval detection algorithm, support vector device or neutral network may be employed to remove these noises, so that the accurate location of the pupils may be obtained.

After the location of the pupils is obtained, suppose that the head of the user does not displace greatly, the Kalman filter may be used to predict automatically the next approximate location and scope of the human eyes, so that the human eyes may be rapidly located. If the Kalman filter fails to track, it is necessary to determine the location of the human eyes again by means of the difference image of the light and dark pupil images.

2.3 Track Gazing Point

The final objective to track the gazing point is to obtain the location of the human eyes' gazing point on the screen. After a clear pupil image is obtained in locating the human eyes, based on the relative position off the LED reflection point and the pupils, the location of the user's gazing point may be calculated [3]. When the reflection point is on the lower left of the pupils, the user is watching the up left of the screen; when the reflection point is on the lower right of the pupils, the users is watching the up right of the screen. The specific location of the gazing point shall be calculated quantitatively according to the distance between the reflection point and the center of the pupils.

3 Index of Usability Evaluation

In order to realize the design concept centering on the user by enhancing the usability of the system, it becomes one of the important tasks in the usability project to analyze and evaluate the usability of the system objectively, uniformly and quantitatively. But, the usability of the system features that it cannot be directly measured, which dictates that the building of the index system for the usability evaluation is the precondition of the usability evaluation.

At present, in the research field of the usability quality index system, there are the five-element system of usability suggested by Nielsen and the three element system suggested by the ISO9241-11 Standard. In accordance with the standard, usability includes three basic indexes, i.e., efficiency, reducibility and user's satisfaction. The index system constructed by disassembling the three basic index is recognized widely, and the average rate of recognition reaches up to 89.7 %; for example, the usability index system widely applied in China is a combination of the performance data index (including time data, quantity and ratio data) and the preference data index (user's satisfaction); the evaluation index suggested by Nielsen includes five basic indexes, i.e., use efficiency, easiness, sustainability, error rate and satisfaction. With an increasing attention paid to the new standard related to the application of internet, the dimension of content is introduced into the usability index of website, producing the usability index system focusing on content and the usability index system focusing on user [4].

While the quality index system of the system usability is being constructed, besides the above-mentioned standard, addition or subtraction may be conducted with the core indexes to shape the evaluation index system adapted to oneself. Nevertheless, this must be in accordance with the actual conditions of the interactive interface, and the requirements of designers and users, while considering fully the subtraction of indexes. For example, when Olsina et al. [5] are studying the usability of current codes, they regard visitability as one of the usability factors, considering the use requirements to websites by special users (the blind). In ISO13407 and IEC300-3-9, the safety for the human being to use is taken into the study of the usability of special systems (such as nuclear power plants and medical facilities) [6]. The deep understanding of the relativity of the usability index helps to filter the usability evaluation index. In the meantime, it helps the researchers to observe more fully the usability of interactive interface and apply to data analysis and explanation. In the website usability evaluation, karat et al. find the less a user clicks the mouse, the more time of attention he obtains, and the satisfaction is thus increased. While analyzing the usability evaluation cases, Erik et al. find that the mechanism for the relativity to be produced among indexes is complex, which is closely related to the field of application, the experience of user and the use background of product. But, in the usability research cases, the difference of appearance, even tolerance, may exist between the usability indexes, especially between the objective data indexes (such as time, ratio) and subjective data indexes (the users' satisfaction obtained by means of questionnaires and interviews). Tractinsky et al. find that, if the time to operate the interface is fixed, there is some difference among the users' subjective tolerance to the interface. In the usability evaluation of weapons and equipment, there is a clash between higher redundancy of operation and higher users' satisfaction [1], and overexplanation of some indexes may cause a wrong evaluation of the usability of the interactive interface. The incongruence, even tolerance, probably existed among the usability indexes, requires that the usability researchers to understand fully the usability evaluation data and pay attention to the fusion strategy and method of various index data.

4 Conduct Usability Test of Interactive Interface with Eye Movement

From the perspective of evaluation principle and theoretical basis, the method of evaluation for the human–machine interactive interface falls into two categories: expert evaluation method and usability test method. The expert evaluation method is exercised by usability experts or ergonomics experts. In accordance with the usability design principle, design experience of same products or guidance of product demand, they evaluate the usability quality of the human–machine interactive interface. Its advantage lies in easiness to operate, flexibility and high efficiency. Studies show that the cost–efficiency ratio can reach up to 1:48, and it can detect effectively the confrontation between the usability principle and the standard in the interface design.

The usability test method tries to simulate the use behaviors of the actual system through a series of operations and programs. It is a test method built on the basis of cognitive psychology. As the preventative of the user, the test personnel participate in the test of the actual product or the prototype of the product. The test is conducted along the script of the design, and the test personnel tries to find out the problems which affect the use of the product by observing the behavior of the user and understanding the comment of the evaluation of the user, and thus increase the experience level of the user. Based on the purpose and way of evaluation, the usability test falls into two types: feedback search and performance measurement; based on the development stage of the product, the usability test falls into four types: explorative test, evaluative test, confirmative test. The usability is of great significance for improving the design of the product. A great number of research indicate that the two central elements to transform usability into application are interactive design and usability test, which are to guarantee the users' experience of the product corresponds with their expectation. The usability test can find most of the places to be improved in the interface, by means of such basic psychological methods as observation and communication, and with the help of qualified professional personnel and advanced experimental facilities/means. At present, the usability test is mainly conducted in for websites, information system software interfaces, electronic product, etc. The usability test for weapons/equipment human–machine interface is simple in method and few in content.

In the traditional usability test, the user's satisfaction is obtained after the user's experience is complete, so that the accuracy, timeliness and quantitativeness of the result are obviously not enough. The reasons lie as follows: The first is the difference between expectation and evaluation; the second is the loss or attenuation of some experience; the third is that all human beings are partially disguised. In order to overcome the problems with the traditional test method, such as strongly subjective, fewer samples and low external efficiency, eye movement tracking technique is introduced, especially for the visual evaluation of the user's interface, which helps to enhance the user's cognition processing.

From the perspective of technical principle, the usability test method based on eye movement tracking technique mainly examines the user's gazing behavior, search index and processing index, etc. The features and advantages of the method are direct, highly efficient and can discover the strategies that the user may adopt on the interface. During the human–machine interaction, the eye movement or a normal visual observation is not smooth and continuous; instead, it consists of trains of alternative gazings and eye jumps. Gazing is the line of sight stops for a while at some location. Usually, such a stop is understood to acquire information from the interface or conduct the internal processing. Eye jump refers to the eye's rapid hop between two gazing points. The duration is short, and the scope varies between 1 and 40°; sometimes it may even reach up to more than 400°. During a gaze there are also rapid and microwave movements of the eye with a scope less than 1°, referred to as the physiological tremble. The behavior of eye movement may be used to discover the spatial location of the user's attention and interest on the human–machine interface; for example, Loftus et al. find that the user's eyes gaze most the unexpected, protruding and important areas, and the attention is concentrated to acquire the most information.

There have been many successful cases for the usability test based on eye movement tracking technique. For example, Curell et al. apply the eye tracker to conduct the usability research for the search engine and suggest how to balance navigation and information tasks and how to distribute attention for search pages; Terenzi et al. employ the eye movement tracking technique to explore the effect that the information space and location may produce on the design of the interface layout. Eye movement tracking measures on the basis of the user's eye movement, so the method is mainly suitable for evaluating the visual user's interface. For example, when designing and developing the display control interface of equipment, the eye movement data may be used to determine what layout and shape rouse more the user's attention and interest. Presently, there are two difficulties for the eye movement tracking technique to be employed in the usability test. One, eye movement tracking facilities may interfere the testee's man-machine interactive behaviors. The noise data produced can affect the effectiveness of the conclusion of the usability evaluation, or even result in a wrong test. Two, the traditional usability test and the usability test based on the eye movement tracking technique have their respective advantages. It is likely to enhance the evaluation effect and efficiency by fuzing the data obtained by these two methods, but these multiple-sourced and versatile-structured data challenge the data fusion process, and the involved fusion algorithm has to be studied further.

To cope with the redundancy and noise existed in the usability test by way of the user's eye movement data, we monitor the real time change of feeling by collecting the user's physiological data, and thus test and analyze the usability problems existed in the human–machine interactive interface. The user's physiological data involved are ECG, respiratory rate and Galvanic skin response, etc. The comprehensive test method employs the user's physiological data and eye movement tracking. Its key loop is to identify the pattern of feeling of the physiological signal, i.e., to fetch out the pattern of features from the collected physiological signals, and match them with the data of eye movement in order to identify the user's status of feeling. In nature, identification of physiological signal feeling is a problem of pattern identification, which is to seek the optimized data set and optimized identification ratio representing most corresponding status of feeling. The theoretical basis is that the status of feeling is closely related to the physiological signal; the physiological signal and eye movement data may vary with the status of feeling.

At present, it has the following features to identify the user's physiological signal. One, the focus of attention is the correct rate of identification, and the study for the feature pattern of feeling status is not enough; two, the applied feature selection algorithm is easy to reach a local extreme value; third, selection of feeling features is an NP problem, the algorithm of which increases exponentially with the number of features. Therefore, to address the above-mentioned problems, we combine the eye movement tracking technique with the intelligent pattern identification method, and regard solving the optimized feeling feature subset in the feeling identification as the compound optimization to seek the optimized feeling feature eye movement pattern and the optimized rate of identification. This is difficult and hotspot in current research, and a certain progress has been made therein.

5 Conclusion

Generally speaking, among the present evaluation methods, the expert evaluation method is high in efficiency and easy to operate, but its problem is that it is too subjective. On the contrary, the usability test method employing the eye movement tracking technique introduces eye movement data and psychological/physiological data into the usability evaluating process of human–machine interactive interface, its conclusion is more objective and easy to explain, and in the meantime, it can cope well with such problems as “false negative” and “false positive” in the test process. With the combination of eye movement tracking technique and the physiological monitoring technique, new breakthrough and development will be seen in the field of usability evaluation of human–machine interactive interface.

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On Application of Human–Machine Work Optimization in Equipment Operation

Zhibing Pang, He Wei, Pengdong Zhang, Hong He, Honglei Li, Chenghui Li and Cheng Jin

Abstract *Purpose* The purpose of the study was to improve and optimize the current human–machine work way for some equipment, optimize the basic path of the operation specialty, and enhance the unit's actual operation capability of the equipment. *Method* Employ the method of optimizing operation time and other relative optimization tools; analyze and explore the current work way for some equipment; find the operation steps which are not safe, efficient, and economic in the human–machine work; and suggest an optimization scenario for improvement. *Result* Find out all sorts of problems existed in the current work that are not reasonable, parallel, and have a rather long waiting time, and analyze the specific reasons for these problems. *Conclusion* After experimental analysis and repeated operation experiments, the authors suggest an optimization scenario to increase effectively the human–machine work efficiency for this equipment. After being tested and compared with experiments, the suggested scenario is proved to be active and effective.

Keywords Work optimization · Equipment operation · Application · Study

1 Introduction

Human–machine work optimization is suggested for the operator's own energy cannot be saved. If the energy cannot be effectively consumed in a specific time, there will be a waste; if the energy is over-consumed, it will lead to fatigue [1]. Human–machine work optimization is a rule of thumb, which may shorten the work

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time, avoid operation fatigue, and increase the human–equipment combination efficiency. Human–machine work optimization records and analyzes the work of the operator and the weapon/equipment in the same time, improves the complex and awkward actions, cancels the dangerous and unnecessary actions, and seeks a scientific work way so that the work process is more reasonable and smooth, and the human–machine combination is more coordinated and efficient.

2 Principle of Human–Machine Work Optimization

2.1 Principle of Parallel Work

Parallel work is an economic work way suggested for running the multiple operators/single machine or multiple operators/multiple machines system. The following three points should be considered: firstly, parallel of weapons/equipment. Both daily training and combat operations are the operations based on weapons/equipment. Without the parallel of the work objects, there will not be any basis for economy; secondly, parallel of operators' actions [2]. Operators should make full use of their action parts; for example, when they divide actions for their two hands, the difficult and the easy ones should be cooperated; the hand/foot coordination work and the operations with the two hands acting simultaneously should be stressed. Researches show that if the two hands act along symmetrical but opposite paths, there will be the highest work efficiency; thirdly, parallel of preparations. It is mainly manifested in that operators divide their jobs to prepare, previous actions are taken as the preparation for next actions, training programs are made simultaneously with the preparation of equipment, etc.

2.2 Principle of Saving Actions

The key to human–machine work optimization is to simplify actions. The basic viewpoint for simplifying actions is to combine unnecessary actions, cancel dangerous actions and improve wrong actions, and thus reduce the necessary basic actions to the utmost [2]. Unnecessary actions can lead to not only the waste of resources but also fatigue of operators easily, degrading the work efficiency; dangerous actions can threaten seriously the safety of operators; and wrong actions can probably lead to failure of equipment. Therefore, the analysis of reasons for the operation action is the basis to simplify actions. Hence, we should consider the operator's own physiological and psychological features, obtain fully the tempo of actions, and arrange reasonably the work break so that it may be rich of flexibility, and the transition of actions may be free and natural too.

2.3 Principle of Comfortable Work Posture

Comfortability of work posture is required by the physiological conditions of the operator, the running features of equipment, and the post-work. Firstly, the work posture conforming to human physiological conditions helps to reduce fatigue and increase work efficiency. The operator should correct his/her unnatural work postures and reduce the mental tension and physical consumption as specified by his/her physiological balance feature, and thus try to sustain the work as long as possible [3]. Secondly, the work posture should be adapted for the structure and performance of equipment. Therefore, on the premise of safety, it helps to observe, exert force, and adapt for space, etc. Thirdly, the work posture should be adapted for the requirements of post-work. It should meet the requirements to locate precisely, operate, and exchange information rapidly.

2.4 Principle of the Highest Whole Work Efficiency

The core of human–machine work optimization lies in the highest whole work efficiency [4]. Researches indicate that a system is not definitely optimized even if all of its constituent parts are optimized. The work efficiency of a system is an organic combination of the optimized work of all parts instead of the sum of them. Therefore, when we conduct the human–machine work optimization research, we should pay more attention to the total efficiency of a system while analyzing some specific action optimization. It is advised to analyze and solve problems with the concept of viewing a system as a whole.

2.5 Principle of Time Optimization

Time optimization requires taking measures to shorten the total time for finishing a work as much as possible when a certain amount of personnel, material, and financial conditions are given. The main method for time optimization is to save time on the key branch. Thus, in the overall planning graph, time optimization should be developed with reducing the duration of the key branch as the center. The main methods and measures are [5] as follows: firstly, in accordance with the evaluation standard and practical experience, check and analyze whether the duration of the key work corresponds to reality and adjust it to the minimum value as required if it is too loose; secondly, make a proper use of the flexible time to exploit fully the potential of the non-key branch. The personnel and material resources on the non-key branch may be used to support the work on the key branch so that the time on the key branch may be shortened and thus the total time of human–machine work may be shortened; thirdly, improve the work way and replace the sequential work with parallel work and/or crossed work so that the duration of the key branch can be shortened. Parallel work is to divide a job into several independent jobs and conduct them simultaneously. Crossed work is to disassemble the continuous steps which are conducted alternatively; fourthly, allocate properly the limited resources or increase more resources to shorten the work time.

3 Optimized Analysis of a Certain Equipment Conducting Deployment

A certain equipment conducting deployment means the necessary preparations for the combat vehicle converting from march state into combat state after entering the position according to the higher instruction. Each operator should have a close coordination under the unified command to achieve rapidness, accuracy, and safety. The equipment is deployed by the commanding officer (No. 1 operator), operating personnel (No. 2 operator), and driver (No. 3 operator) in coordination. The squad staff is in “Fall in, rear of vehicle” formation and wait for “Deploy!” command. At the command, each operator begins to work according to their division of duty.

3.1 Optimize Working Procedure

The discordance in organizing the working procedure easily results in the appearance of slow work [6]. In deployment of a certain equipment, the computer in the vehicle needs 30–60 s in normal starting. It will need a little longer time in cold weather conditions. In the current process, No. 1 operator needs 57.6 s for pulling out working pedal ladder and electric cabin ladder and placing wooden block before starting the computer. The procedure is improved by directly entering the cabin to start the computer after pulling out electric cabin ladder. In this way, No. 1 needs only 7.5 s. Compared with the current one, the improved one advanced the time by 50.1 s in starting the computer. By optimizing the procedure, reduce the waiting time of the operator, enhance the time efficiency, and avoid slow work or cessation to wait for succeeding work.

3.2 Modify Working Mode

By modifying the working mode, the parallel work and crossed work were employed instead of sequential work to shorten the total working time. Firstly, in the current operation, Nos. 1 and 3 place the wooden blocks separately. And the total time needed was 57.6 s. In the modified one, Nos. 1 and 3 coordinate each other in placing the wooden blocks. No. 1 is responsible for the left rear and right rear leveling legs of the vehicle. No. 3 is responsible for the left front and right front leveling legs. They totally need 33.2 s and save 24.4 s. By this way, No. 3 need not run to the electric cabin and report to No. 1 as "Wooden block, done." Secondly, the way which No. 3 opens the communication cable box in the current operation is modified into the one which No. 1 starts the computer, then opens the communication cable box by taking advantage of getting out of the cabin, and takes out the earth wire. Thirdly, the way which No. 1 gets out of the cabin and enters the cabin to start navigation display controller and raises the antenna in the current operation mode into the one which No. 3 does those actions after finishing his duties to reduce the actions of No. 1. By modifying the working mode, the unnecessary running actions were canceled and the operating burden of the operators was reduced.

3.3 Exploit the Potential of Non-key Work

Exploit the potential of the non-key branch. Highlight the coordination between operators and shorten the duration of the key branch. Firstly, change the current "Fall in, in rear of the vehicle" into "Fall in, in front of the vehicle." This method facilitates the coordination of the operators and starts the work at the same time. Thus, No. 1 may start the computer earlier and No. 2 releases the locking mechanism as early as possible. Secondly, No. 3's face-to-face reporting "Done" is replaced by whistling to reduce the waiting time of No. 1, and the unnecessary running of No. 3 is avoided. Exploit the working potential of the non-key work and reduce the operating burden of the operator so as to enhance man–machine working efficiency and shorten the total man–machine working time.

3.4 Make Additions to Ensure Operating Safety

According to the textbook of Power Unit, it is written that two operators should be coordinated in striking the pike. In its chapter concerning erecting missile, there is a warning that before erecting, it should be done to check whether the locking mechanism is fully released. Therefore, it is put forward that firstly No. 2 reports "Locking mechanism, done!" and connects one terminal of earth wire with the earth bolt of power wire board. After fulfilling his duty and whistling, No. 3 takes out the hammer from power unit cabin and strikes the pike in coordination with No. 2; secondly, by increasing the actions of No. 2, the missile-erecting safety was ensured. After connecting the earth wire, No. 2 runs to the place 5 meters away from the vehicle facing the door of the electric cabin and observes. Once any problem is occurred, it was reported to No. 1 as soon as possible.

Table 1 Comparing the effects before and after deployment optimization

Operators	Analysis of flow	Operation time in current flow work (s)	Operation time of optimized flow work (s)	Difference (s)	Current utilization ratio (%)	Utilization ratio after optimization (%)
No. 1	Operate	112.6	101.4	−11.2	34.5	36.8
	Wait	213.9	174	−39.9		
No. 2	Operate	85.6	94.2	109.4	26.2	34.2
	Wait	240.9	181.2	−59.7		
No. 3	Operate	84	115.8	31.8	25.7	42.4
	Wait	242.5	159.6	−82.9		

4 Conclusions

In order to see directly the difference before and after optimization, the authors count and analyze the work of each operator as shown in Table 1.

It is known from Table 1 that (1) the deployment time of the equipment is reduced from 326.5 to 275.4 s, saving 51.5 s; (2) when operation actions are increased, No. 2 and No. 3 operators' operation time after optimization is increased, but the waiting time of each operator is reduced, indicating that the operators' post-division is more scientific and reasonable; (3) except that there is no distinctive change in the work efficiency of No. 1 operator, the work efficiency of both No. 2 and No. 3 operators is increased.

The article takes the deployment optimization of a certain equipment as the research object elaborates the train of thought for optimizing human–machine work and clarifies the principles of work optimization. Based on the relevant method of work research, the article analyzes scientifically the process of deployment of the equipment, finds the operations which are not safe, efficient, and economic in human–machine work, and formulates a reasonable and feasible optimization scenario. The article compares and analyzes the work time of the equipment before and after optimization, and indicates that the human–machine work time after optimization is less than the current time so that the expected result is achieved. The article plays a positive guiding role in increasing the performance of human–machine combination work.

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Research on Weapon Human–Machine Interface Ergonomics Based on Visual Spatial Characteristics

Yanjun Zhang, Chenhui Li, Zhibing Pang, Xiaofei Zhai, Guangwei Feng, Honglei Li and Genhua Qi

Abstract For the faulty of current human–machine interface (HMI) ergonomic evaluation of weapon systems, the model of ergonomics assessment was established based on the spatial characteristics of human visual. In the model, the adaptability between human–machine interface design and visual features was evaluated from four aspects: The vertical vision, the level vision, visual angle and visual field, respectively. The probability of the effective operation of the operator was also observed. Experimental result showed that the model directly reflected the existing problems in human–machine interface ergonomics design, which could supply references for optimizing of human–machine interface design of weapon systems.

Keywords HMI · Eye movement · Visual space · Ergonomics

1 Introduction

In human–machine system, operator obtain working condition parameters, input parameters, operating state parameters and output parameters of the system through the human–machine interface. By analyzing the failure caused by human factors during operating weapon systems, 70–80 % of the failures are caused by human–machine interface design. Therefore, human efficiency and security of human-machine interaction system depend largely on the visual interface (such as monitor and operating panel) and the characteristics of the human visual matching degree [1]. Practice shows that the man–machine adaptability of existing equipment is far from perfect, the fault of misusing occurs frequently, resulting in a significant increase in the risk of weapons. The paper analyzes the adaptability between HMI

The article belongs to the man–machine relationship research scope.

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design layout and visual characteristics of a certain type of weapon from the visual spatial characteristics.

2 Visual Spatial Characteristics

Visual spatial characteristics include three aspects: visual angle, visual field and viewing distance [2]. Ability to distinguish object details of the visual organ is called visual angle, denoting by perspective. Visual angle is the angle of the target to be observed by two points when the light reaches the eye, which depends on the observing distance *L* and the distance *D* between two points on the target:

$$\theta = 2\arctan\frac{D}{2L} \tag{1}$$

Visual field is the spatial extent of a person's eye seeing, when his head and eye remain intact, usually represented by an angle. When the head perpendicular to the ground and the eyes are on the front, considering the eye movements, the field of vision in the vertical direction can be up to 75° to the horizontal plane of the center line; the field of vision in the horizontal direction can be up to 75° to the main line of sight of the center line. And the image is clear in the field with the vertical direction 30° below the horizontal and the horizontal direction of the main line of sight range of around 15°, which is known as the best field of view. The scope is called effective field of view in the vertically 25° above the horizon and 35° below and the horizontal direction of the main line of sight range of around 35°. Due to the gravity, in the vertical plane, the natural eye sight below horizontal is 15°.

The distance from the viewer's eyes to the object is called viewing distance. Observing various display devices and target, viewing distance should be chosen appropriate. The speed and accuracy of reading will be affected, when viewing distance is too long or too short. Usually, viewing distance should be determined according to the size, shape, lighting conditions and work requirements of the observation target. Typically, the viewing distance to observe about 600 mm and operating viewing distance of 400–800 mm is best. Additional, the angle of the head turning should not exceed about 45°, up and down should not exceed 30°, avoiding the transfer when observed.

3 Visual Spatial HMI Ergonomic Evaluating

HMI ergonomic evaluation is complicated system engineering. In order to ensure the entire process efficient and orderly, the following steps should be referenced [3], as shown in Fig. 1.

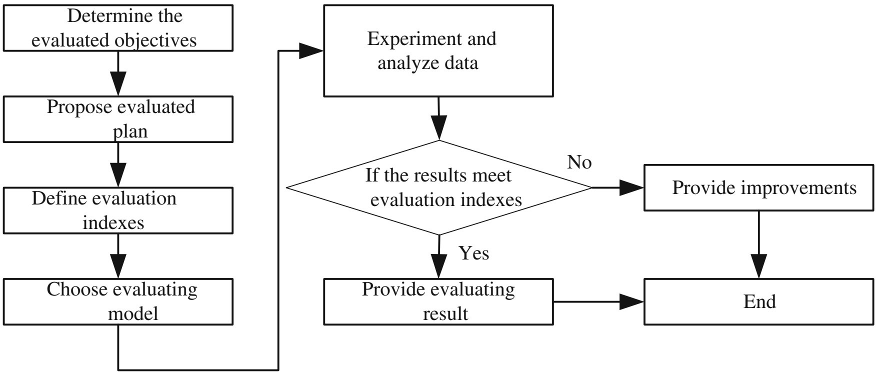

Fig. 1 Ergonomic evaluating process

The best field of view is the field with the vertical direction 30° below the horizontal and the horizontal direction of the main line of sight range of around 15°. The scope is called effective field of view in the vertically 25° above the horizon and 35° below and the horizontal direction of the main line of sight range of around 35° [4]. According to ergonomic standards, when viewing distance is less than 500 mm, the display width is not less than 3.6 mm and the line of sight is defined as 380–760 mm.

In the experiment, we need to measure the size of the man–machine interface of weapon, and the horizontal distance from the operator control panel to eyes, and calculate vertical distance from the object to the eye level. Additional, according to the national and military standard and the difference of operators' body size, we should choose the standard of double limit value product design to evaluate, i.e., the evaluation range is selected from P5–P95 male size, combined with relevant studies [5], and ultimately, the selection P90 male scales are chosen.

3.1 Vertical Field of View

As shown in Fig. 2, the expression for the vertical field of view α is as follow:

$$\alpha = \arctan \frac{h_2 - h_1}{a} \tag{2}$$

In the formula, h_1 is the eye height when operator operating, h_2 is the actual height of the object to be observed in display panel, a is the horizontal distance from eyes to the display panel and γ is the angle between actual line of sight and the horizontal line of sight, usually valued 15 °.

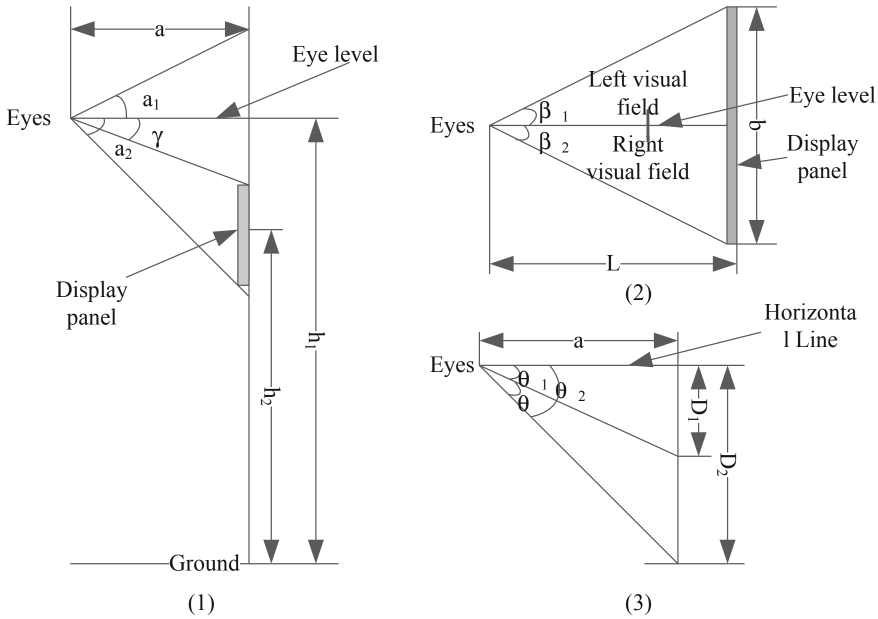

Fig. 2 Evaluating model: (*1*) Vertical visual field. (*2*) Horizontal visual field. (*3*) Visual angle

3.2 Horizontal Field of View

As shown in Fig. 2, the expression for the horizontal field of view is as following:

$$\beta_1 = \beta_2 = \arctan\frac{b}{2L} \tag{3}$$

In the formula, L is the straight distance from eyes to the object under observing when operator operating, b is the horizontal width of object under observing in display panel and β_1 and β_2, respectively are the visual field of display panel in the operator's eyes.

3.3 Visual Angle

In the paper, visual angle refers to visual acuity in a broad sense, when the object is not directly in front of the eyes (for example, below the horizontal line), as shown in Fig. 2.

According to the formula 1, the expression of θ is further deduced as following:

$$\theta = \arctan\frac{(D_2 - D_1)a}{a^2 + D_1 D_2} \quad (4)$$

In the formula, D_1 represents distance from the upper boundary of the object under observation to the line of sight, D_2 represents distance from the under boundary of the object under observation to the line of sight, then $(D_2–D_1)$ represents the height of the observed object, a represents horizontal distance from eyes to the vertical plane of the observed object.

3.4 Viewing Distance

During operation, the operator maintains a correct posture, which would not change in the body posture when operational object changes. Therefore, the viewing distance L should be defined by distance from eyes to observed object as the person sitting.

L is viewing distance in the following expression:

$$L = \sqrt{a^2 + D^2} \quad (5)$$

In the formula, *D* represents the vertical distance from the object to be observed to level of sight, a represents horizontal distance from eyes to the vertical plane of the observed object.

3.5 Effective Probability of Operator Action

We use Harold method [6] to experiment, which is used to calculate the reliability of the system, and evaluated whether the location of configuration and installation display elements are applicable to humans operation, by calculating the probability of success to perform tasks, evaluation to the whole system is obtained. Table 1 shows the probability of misreading in different regions, every 15° divided into a region from the central of sight toward the outer, which are valued by R.

Table 1 Optimum values in different visual regions

Effective visual area (°)	Misreading value *R*	Effective visual area (°)	Misreading value *R*
0–15	0.0001–0.0005	45–60	0.0020
15–30	0.0010	60–75	0.0025
30–45	0.0015	75–90	0.0030

The effective probability of person's operating can be calculated as the following:

$$P = \prod_{\mathrm{i}=1}^{n} (1 - R_{\mathrm{i}}) \quad (6)$$

In the formula, P is the effective probability of operating; R_{i} is misreading value of display and control components; n is the number of display components.

4 Application Examples

In this paper, we selected an equipment operator for the study. The operator controls three display panel, from left to right, ultra-short wave transceiver, broadband microwave relay, digital switch. Digital switch, for example, its display area is rectangular structure with dimensions of 200 mm × 250 mm.

4.1 Vertical Visual Field

According to the general experimental needs, using P90 male scale, the height h_1 is 1643 m when the operator is standing. After several measurements, the average horizontal distance a is 450 mm from the eyes of seating operator to display panel, the standard height of display components h_2 ranges from 1225 to 1775 mm. When the vehicle remains still, according to the formula 2, the operator's vertical visual field is as followed:

$$a_1 = \arctan\frac{1775 - 1643}{450} = 16.3^{\circ} \quad (7)$$

$$a_2 = \arctan\frac{1225 - 1643}{450} = -42.9^{\circ} \quad (8)$$

From the value, we can obtain the following conclusions:

1. Display above eye level is located within the effective visual field of the operator, and some buttons below eye level is located outside the effective visual field;
2. Below the line of sight of the operator, there are 16 buttons arranged in parallel, with their corresponding identity on the buttons, the spacing of buttons is small. Due to the similarity of the buttons, the operator would mix the identity, leading to error operating.

4.2 Horizontal Visual Field

After measuring the digital switch, the maximum width of the display above the line of sight of the operator is 200 mm, and vertical distance D is 132 mm, the following formula can be obtained according to the formula 3 and 5:

$$\mathrm{L} = \sqrt{450^2 - 132^2} = 460\ \mathrm{mm} \tag{9}$$

$$\beta_1 = \beta_2 = \arctan\frac{170}{2'460} = 10.2^\circ \tag{10}$$

Analysis shows that is necessary to analyze and evaluate horizontal visual field of the keyboard, because the 16-button keypad under operator line of sight is out of effective visual field. After measuring, the total length is 170 mm, the vertical distance D' from center of observed buttons to eye level is 406 mm, and then according to the formula 3 and 5, we can achieve the following formulas:

$$L' = \sqrt{450^2 - 406^2} = 606\ \mathrm{mm} \tag{11}$$

$$\beta_1 = \beta_2 = \arctan\frac{170}{2'606} = 8^\circ \tag{12}$$

From the above analysis:

1. Display and keyboard are within the optimal range of the horizontal visual field of the operator;
2. Considering the keyboard's location 42.9° below the line of sight, it is not within the effective visual field in the vertical direction, which increases the difficulty of proper operation; therefore, we believe that the parallel design of the keyboard layout could be changed.

4.3 Viewing Angle

Selecting the identity above the parallel keyboard for the study, the height of identifies text is 7 mm, when D_1 is 418 mm and D_2 is 425 mm. According to Eq. 4, when the value of a is 450 mm, viewing angle θ is as following:

$$\theta = \arctan\frac{7 \times 450}{450^2 + 418 \times 425} = 28.5' \tag{13}$$

θ is slightly larger than 26′, which is in line with the requirements.

4.4 Viewing Distance

The analysis shows that standard height of observed objects range from 1225 to 1775 mm, and then the vertical distance from observed objects to eye level go from −418 to 132 mm, according to the formula 5, we can obtain the following:

$$\mathrm{L} = \max(L_1, L_2) = 614 \text{ mm} \tag{14}$$

The minimum of viewing angle is 450 mm, the maximum is 614 mm, which are within the scope of appropriate viewing distance.

4.5 Effective Probability of Operator Actions

There are six switches and interfaces, one display and four LEDs locating on digital switch, in which six shapes and interfaces located at 42.9° below center of line of sight, and the display screen position is 16.3° above center of the line of sight. Indicator light is used to display the part information of switch, whose reliability is assumed 1 to simplify the calculations.

From Table 1, we find the misreading value of display is 0.0010 when visual angle is 16.3°; the misreading value of switches and interfaces is 0.0015 when visual angle is 42.9°. According to formula 6, we can obtain the following:

$$P = (1 - 0.0010)^3 \times (1 - 0.0015)^8 = 0.9851 \tag{15}$$

Thus, the effective probability of operating is 0.9851 during the operation of digital switch. Combining plurality of sets operational data taken, the misusing probability obtaining by digital statistical methods is 0.018, i.e., the effective probability of operating is 0.982. It can be seen that two values are close.

Summary, three evaluation indexes in four conform to the evaluation criteria, and display panel is out of the effective visual field in the vertical direction, which does not meet the evaluation criteria. Combining part of the evaluation targets, some evaluation indexes conform to comprehensive evaluation criteria. Effective probability of operations calculated by Harold method, basically reflect achievement.

5 Conclusions

This paper analyzes the assessing model based on the spatial characteristics of human visual, which ergonomic evaluate human–machine interface from visual field, visual angle and viewing distance. Experimental results show that the model directly reflects the problems of weapons in ergonomics design, which can optimize the design and rational distribution of human–machine interface of weapons.

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Application and Thinking of Motion Capture in Man–Machine Operation

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Abstract The motion capture (Mocap) technology originates from animation making for multimedia films. In the man–machine operation research, it also needs a new method to measure parameter of the body accuracy. How using this technique the research. By consulting interrelated documentation, with ideas gained from concrete practice, the paper introduced the origin, type and some application of the Mocap first. And then, the paper analyzed the Mocap technical features, foreground and advantage of the Mocap technique applied in man–machine operation. The result is that Mocap technique can be a new method to be used in man–machine operation, and contrasted to the method ever, it may be better. But, it also needs some knowledge of other subjects for better usage.

Keywords Motion capture technology · Man–machine operation · Application research

1 Motion Capture Technology

Motion capture which can record and process the motion of human or other objects is widely noted for use in animation making for multimedia films greatly. In the 1970s, the Disney Company ever tried to capture the actor's motion for improving the animation effect. In the 1980s, several research institutions in USA began to research human Mocap based on the computer. Now, in the developed country, Mocap has started the commercial; many companies sell various Mocap systems.

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2 Constitution, Classification and Theory of the Mocap [1]

Exposition from the theory, the substance of the Mocap system is to trace, measure and record the motion track of the object in the 3D space. The classic Mocap system is composed of four parts:

Sensor. It is the tracking device, which is fastened to the special position of the object. It provides location information of the motion object to the Mocap system.

Signal capture equipment. It is to capture the location signal. The type of this equipment is different from the Mocap system. For example, it is a circuit board for capturing signals which are used in the mechanical Mocap system. But, in the optical Mocap system, it is high-resolution infrared camera.

Data transmission equipment. The Mocap system needs to transmit plenty of data to the computer fast and accurately, especially the data that the system needs to show in the real time. This equipment is to do this work.

Data processing equipment. The data captured from the Mocap system are amended, processed and combined with 3D model by the data processing software or hardware. Then, the whole computer animation work is complete.

From the Mocap system developed, it has several types. Table 1 shows the theory, advantages and disadvantages of various systems.

Table 1 Various motion systems [1, 2]

Name	Theory	Advantage	Disadvantages
Machinery	Tracking and measuring by mechanical device	Low cost, high precision, real-time measurement, low for place	Many action limits because of mechanical structure
Aero acoustics	Transmitter is ultrasonic generator fixed. Acceptor is ultrasonic probe arranged triangularly	Cannot be disturbed by human body and low cost	Large delay, low instantaneity and accuracy, disturbed by noise and multiple reflections lager
Electromagnetism	It makes regular electromagnetic field, and the acceptors are installed at special place on body connected to data processing unit	Obtain information about the location and direction. Proven technique, reliability high, low cost and scaling simple	Strictness for environment, disturbed by wireless each other, high distortion factor for capturing high-speed operation
Optics	Capture by monitor and track spots on the body	Large scale, no limitation from the cable and mechanical device, used convenient, expansion easy, high sample rate	High demand for place, high cost, large work for post processing

(continued)

Table 1 (continued)

Name	Theory	Advantage	Disadvantages
Inertial navigation	Measure accelerated velocity, orientation and slant angle, etc., by inertial navigation sensor	Not disturbed by environment and block, high accuracy, high sample rate; small, light, high cost	Random error increases rapid
Video capture	Recognizing object and orientating by contrasting two photos of two cameras simultaneously	No limitation for object and range of activity, low cost, high real time	Great difficulty for achieving, algorithm is complicated, low accuracy

3 Application Fields of Mocap System Present

With the progress of Mocap technique and the cost decreasing, it can play in many fields specially.

3.1 Animation Production

The Mocap technique which can be used for animation production can improve the quality of animation production greatly. It increases the efficiency and decreases the cost, and makes the process of making animation more visual and the result livelier.

3.2 New Method for Human–Computer Interaction

Expressions and actions are important expression form of human emotion and desire. The Mocap technique digitizes the expressions and actions, and provides a new method for human–computer interaction which is more convenient than keyboard and mouse. The “3D mouse” and “gesture recognition” can be come true by the technique. Operators can control the computer directly with natural action and expression, and it will be the technical basis for the computer and robot which can understand the expressions and movements of human.

3.3 Virtual Reality

Using Mocap technique in virtual reality solves the problem of human–computer interaction. In particular, in some interactive games, the maker captures the actor’s motions by Mocap technique and drives the motion of the roles in game, which gives a new feeling to the player. It also strengthens the realistic nature and interactivity of the game and improves the experience of people for virtual reality games greatly.

3.4 Robot Telecontrol

The robot can submit information collected in hazardous environment to the master. Based on the information, master makes corresponding motions which can be captured by the Mocap system. The system transmits the motion to robot in the real time and controls the robot to do the same motions. Compared with telecontrol traditional, the system can make the motion-control visual, meticulous, flexible and rapid, which will be more complex. So, it will improve the ability of robot to deal with complex situations. In the condition where the robot's automatic control is immature, this technique is very meaningful.

3.5 Sports Training and Medical Rehabilitation

Mocap technique can capture the athlete's motions. It is easy to make quantitative analysis. Combined with human physiology and physics, it is useful to improve the training method which was dependent on experience anciently, and make the athletic training theoretical and digitalit. Contrasted with the motions from a good-performance athlete, the system can capture the motions from a poor-performance athlete and improve the poor one.

In addition to this, Mocap technique can also be used in the research of ergonomics, simulated training, biomechanics, etc.

4 Application and Advantage of the Mocap System Used in Man–Machine Operation Research

Although originating from animation production, the Mocap system can play in man–machine operation also.

4.1 Quantitative Calculation of Motion Parameter of Body

The basic information which is captured from the Mocap Technique is spatial position of the body. This can be used to show the motion on screen. Though the process, it is necessary to computer the motion parameters of the body. The human figures computed by these motion parameters can be of high accuracy.

4.1.1 Quantitative Analysis of Operation Process

Through the quantitative search of specific motion, how to describe the movement range and physical state accurately is important to the impersonality and accuracy of the datum. By Mocap technique, the datum will be accurate, impersonal and systematic. It not only is a method for measurement, but also decreases the subjectivity of human in the process of measurement.

But not only that, in some difficult operating process, it has some key motions, whose operating result is important to the whole process. Quantitative measurement for the key motion, which can be contrasted specifically, can analyze the key motions effectively. It is good for a trainee to learn the key motion, so as to increase the efficiency.

4.1.2 Quantitative Analysis of Human–Machine Interaction (HMI) [3]

The research of HMI refers to two fields of man and machine. In front of equipment design, it adjusts the "machine" to adapt to the "human" usually. But, it is difficult to obtain the accurate datum in the experiment. Ever, the datum is mostly qualitative and cannot take part in the design for "machine." Using the Mocap technique in the research of HMI can capture the datum rapidly and accurately. It will be helpful to adjust the "machine."

4.1.3 Experiment with Other Equipment

The Mocap system can be used to capture the motion parameter of body accurately, which can be used with other equipment to capture more data. For example, mobile eye tracker can track the eye point of the experimenter. But in the process of experiment, it is difficult to measure the influence of the eye point moving because of body moving except the eyes. It is hard to experiment. If with the Mocap system which can computer the moving of body accurately, it is convenient for using the mobile eye tracker to evaluate HMI.

4.2 Training Method to Improving Man–Machine Operation [4, 5]

Mocap technique originates from animation production, and it must be good at virtual simulation. But as a new method, it can play in many fields.

In the man–machine operation, there exist many technological motions. They are not only large, but also complicated, which is hard for training. On the one hand, the teacher cannot teach every motion standardly, especially the motion of the finger used, which is not easy to demonstrate. So, it is hard for the trainee to learn. On the other hand, the trainee's condition, which includes receptivity, physical fitness and viewing angle, will have influence on the result.

Using Mocap system captures motion parameter of the body in the operation process and play backing by emulation technique, which are superior to skill training ever. And with the animation simulated, the trainee can observe the motion process and details constantly. So, the trainee can improve continuously, and the training quality is also increased.

In the Mocap techniques present, there is the technique with high portability and real time. It will transmit the motion information to computer rapidly. When training at special project, the teacher can do some "feedback." For example, when the trainee goes wrong, the Mocap system captures the motion information and uploads it to the master. Through evaluating, some punitive measure will be done by other equipment. This is good for trainees to obtain good, realistic and improved training efficiency.

5 Using the Mocap System Needs Some Knowledge

For using the Mocap system better, we need knowledge of two subjects.

One is sports physiology. Information captured by the Mocap system is from the human body. Familiarity with the motion of human body is of convenience to research some specific questions. Learning sports physiology not only can help the researcher realize kinetic characteristic in the motion process, but also can make the explanation more reasonable by the captured datum and result.

Two is statistical analysis technique. In the research of man–machine operation, capturing motion parameter is not the end. The next are data reduction and statistical analysis, which is the key point always. So, before the experiment, it is necessary to clarify the purpose of experiment and determine the reasonable experimental plan with the statistical analysis technique. In this way, the experiment may be good with most economical and high efficiency.

6 Conclusion

The Mocap technique can measure body parameters accurately. It can be used instead of some method which is used for man–machine operation research ever. Selecting the suitable Mocap system is convenient for the research. Meanwhile, using Mocap system needs knowledge of Sports Physiology, and learn the method of statistical analysis.

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Characteristics Analysis and Design Discussion on New Human Interface of Electric Vehicle

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Abstract As the energy supply for vehicle is becoming increasingly serious, electric vehicle (EV) has become a hot topic in both the auto industry and the public. During use, the current driving mileage and the battery level are the most common concerns of drivers. In recent years, the content and information which the EV's dashboard displays has greatly changed compared with traditional fuel vehicles. To promote the development of the human interface (HI) technology in China, this paper investigates the human interface of EV and comprehends the information contents and display characteristics different from traditional fuel vehicles. Meanwhile, through questionnaire, a survey on drivers' actual information demands and range anxiety is carried out. The results reveal and discuss the distinct display factors and presentation pattern of HI in EV, as well as the important information for drivers, to provide insight for the optimized layout, design, and related evaluation of HI in EV.

Keywords Electric vehicle · Human interface · Driver · Range anxiety

1 Introduction

With the increasing tension of automotive energy source, electric vehicles gradually become the focus of attention in the R&D of the automobile industry and public concern. Currently, electric vehicle in China enjoys a strong development momentum. Along with the constant issuing and great promotion of new energy vehicle subsidy policies in all cities, citizens' concern and acceptability of new energy vehicles have been boosted. Moreover, in major vehicle production and

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marketing countries across the world, such as European countries, USA, Japan, etc., electric vehicles also present an optimistic development condition. International studies on the human interface of electric vehicles are gradually launched in the process of breaking through traditional technologies [1–6].

The recognition of the mobility of electric energy has always been a great barrier to the development of electric vehicles. Franke studied the nature of electric vehicles and the condition in which other variables would impact the comfort of electric vehicles. Researchers leased 40 electric vehicles to sample users for launching the six-month field study, and carrying out qualitative and quantitative studies on the user experience. According to the results, it is possible to overcome the barriers perceived in the driving of electric vehicles through the intervention of information, training, and man–machine interface design. Besides, it is more important to provide reliable and useful information for drivers than to improve the maximum performance of electric energy mobile system [1].

The research has shown that the precision range estimated by the display instrument and charging state may impact drivers' attitude toward EV, driving experience and driving behaviors in different resource acquisition conditions. Seventy-three participants finish the 19-mile driving of electric vehicles in various road conditions, including the expressway and village roads. The results show that although the vague displayed value of the instrument may lead to severe anxiety of the residual value and it will keep the trust of drivers on vehicles [2].

Greek researchers have investigated 335 non-occupational drivers with the method of "drawing the instrument panel in memory" for figuring out the relationship between the driving experience and the instrument panel functions and patterns presented by the memory of researches, so as to explore if the drawing of drivers can reflect their impression on the effective part of the automotive interfaces. The experiment result will be of certain referential significance for the design of instrument panel [3].

Since there are some defects that may impact the driving safety in the use and interaction of voice control system, the widely-applied vehicle-mounted voice control system requires drivers to finish the speech input manually, but it would impact driving safety. Consequently, an innovative driver voice control and interactive interface installed on the steering wheel is designed to resolve the existing problems from three levels: processing terminal, input, and output [4].

Designers integrate different technologies into the internal design of automobiles, for instance, the Internet. In the future, there is no doubt that vehicles will play a crucial role in the virtual world: Through connecting to the smart phones and other mobile equipment, vehicles are now becoming another terminal of the Internet. However, compared with other mobile equipment, vehicles require designers to consider and resolve the driving safety and distraction. As for automobile manufacturers and IT enterprises, an ideal solution is to establish a simulation laboratory for launching the driving simulation experiment, which may quantize the distraction caused by different design concepts [5].

Since EV has been applied extensively, but there are various problems that cannot be ignored, for instance, traffic safety and theft issues. A real-time monitoring system specially was designed for EV, which has integrated the global satellite positioning, mobile network data, short message service, global mobile communication system, etc., and realized the anti-theft function and rescuing function of vehicles [6]. The introduction of new technologies has increased the contents displayed by the human interface of vehicles.

At present, cruising power and charging complexity of electric vehicles are the concerns of automotive consumers. However, during the application of electric vehicles, the current endurance and electric quantity changes are the main information that will be observed and perceived by drivers, which may impact the psychology and driving behaviors of drivers to a certain degree. Some recent researches focused on the drivers' range requirements and the estimation of remaining driving range of electric vehicle [7–9].

In this paper, analytic research is carried out for the human interface of mainstream domestic and foreign electric vehicles. Meanwhile, a questionnaire is utilized for acquiring actual information demand and focus of driver's attention. On this basis, the unique display factors, expression means, and related problem of the HI of EV are summarized, for offering important references to the design and development of new human interface of electric vehicles.

2 Characteristics of EV Dashboard

The dashboard of EV is used to inspect the working status of each system of the vehicle, such as vehicle speed, mileage, speeding warning, and battery warning. Through watching the dashboard, drivers can learn the working state of vehicle and decide to use and maintain the electric motor exactly and timely.

There are significant differences between the dashboard of EV and that of traditional fuel vehicle (FV) (Table 1).

Since the internal combustion engine is not the resource of energy, the instruments related to engine all disappear in EV. In the dashboard of EV, fuel gauge is replaced by coulomb meter, and tachometer and water thermometer of engine are replaced by the instruments related to electric motor. Accordingly, the differences on the contents for display provided the possibility for the interface of EV to change the traditional instrument design.

Table 1 Interface information comparison between EV and FV

Classification	FV	EV
Vehicle speed	Speedometer	Speedometer
Mileage	Odometer	Odometer
Energy	Fuel gauge	Coulomb meter
Power	Tachometer, water thermometer for engine	Instruments for electric motor
Power conversion	Not available	Energy recycle data

Currently, the key point to study electric vehicle instrument panel is the information collecting and displaying technology. For example, in the field of information displaying technology, electric vehicles tend to use LCD and touch panel instead of traditional mechanical ones. As for the technology of information collecting, the main tendency is to find the way to collect the working condition of motor and electric quantity more accurately. However, few studies concern the method of designing the instrument panel and center console. The design includes repositioning the instrument panel and displaying the information to meet the mental demands of drivers and ensure driving safety. The most efficient and safe way to operate the center console is still to be studied. The Internet technology adds more new contents and complexity to the human interaction research.

From the perspective of products, some countries of vehicle production and sales have designed and manufactured a batch of EV products with different characteristics. In recent years, for new electric vehicles represented by Tesla, BMW i, GM Chevrolet Volt, Toyota Prius, Nissan Leaf, etc., there have been great changes in the display contents and information presentation means, and the rapid development of Internet concept vehicles also brings in new information platform for the human interface of drivers.

For these new EVs, the information contents and display characteristics of the instrument panel and center console are different from the conventional vehicles, as well as the comprehensive utilization of virtual instrument, intelligent touch screen, multimedia, and internet technology. However, the human interface of domestic electric vehicles in China is relatively backward, and it is in urgent need of special R&D and improvement by aiming at the practical demands of drivers.

3 Investigation About Drivers' Information Demand

The human–machine interface of traditional vehicles is the platform where the human and the vehicle can interact with each other. There are three types of human–machine interfaces, including controlling interface, direct interface (e.g., displays and controls), and indirect interface (e.g., additional area between human and machine). The design of human–machine interface must make it profit for drivers to control the machine and acquire information from it, of which the key problem is the optimized matching between human and machine. The starting point of human–machine interface design is the information requirements and focus of drivers when driving EV.

For this purpose, a questionnaire was carried out to investigate people's expect and recognition level of cruising and charging ability of EV, and to compare them with the ones of traditional FV, and analyze the information demand and range anxiety of drivers and the mental impact on drivers. Table 2 shows the statistical results of questionnaires for 202 drivers in North China, which can provide reference for optimizing the human interface of EV. According to the results, 68 % drivers of EV pay high attention to current energy condition (electric quantity), while only 23 % of traditional vehicles do. 50 % drivers of electric vehicles pay high attention to endurance mileage and 65 % think it is very important, while the corresponding percentages of traditional vehicles are only 23 and 27 %. The percentages of EV drivers are two or three times as much as them of FV drivers.

62 % of FV drivers will not refuel until the fuel pointer approaching or entering the warning region. However, 44 % of traditional vehicle drivers will charge when electric quantity is lower than 1/2, 22 % will when lower than 1/4, and 27 % will depend on the estimated endurance mileage. The concern on energy condition is related to the distribution of gas station or charge station. Currently, the amount of charge station is far less than gas station.

The survey results of energy consuming situations are traffic congestion considered by 51 % drivers, air conditioning usage by 21 % drivers, and frequent accelerating and decelerating by 14 % drivers, respectively. In general, for drivers' consideration, the states of energy consuming of EV are similar to that of FV.

4 Discussion

Expect for accurately reflecting the working condition of vehicle, the instrument panel should also be designed based on the feature of human organum sensum. Instrument panel should fit for human's information receiving and cognitive process, and should be readable and reliable, which will relieve the drivers' body burden and fatigue level. In addition to the elements of FV, the instrument panel of EV should also contain battery management unit and electric motor control unit. The units should be properly arranged in order to meet the drivers' visual characteristic and psychological need. However, the way to design new human–machine interface for electric vehicles and evaluate it should be further studied.

From the results of questionnaires, it can be known that current electric quantity and endurance mileage should be the most concerned information. And the position of charge point also should be displayed for drivers timely. Like FV, the traveling speed of EV is still significant information for driving. Some information related to safety and fault of vehicle also should be comprehended by drivers. Besides, the

Table 2 Comparison of drivers' attention on information of energy and mileage

Questions about	Results	
	Electric vehicles	Traditional vehicles
Attention on energy conditions	68 % high; 27 % general; 2.5 % low; 2.5 % unconcerned	23 % high; 53.5 % general;16 % low; 7.5 % unconcerned
Attention on endurance mileage	50 % high; 33 % general; 14 % concerned; 3 % unconcerned	23 % high; 53 % general; 15.5 % concerned; 8.5 % unconcerned
Importance of endurance mileage	65 % very high; 29 %high; 4.5 % general; 1.5 %unconcerned	27.2 % very high; 46 % high; 22.3 % general; 4.5 % unconcerned

status of electric motor and battery should be general information for EV drivers to check occasionally.

Table 3 shows the information displayed on the human interface. The information is divided into three levels according to the importance, operating frequency, and attention of drivers, which includes high attention, general attention, and low attention. The table provides the reference for designing of human interface. Figure 1 is an arrangement of instrument panel based on drivers' attention allocation and human's visual features.

According to Fig. 1, the high-attention information are arranged in the optimal field of view (e.g., vehicle speed and residual electric quantity), while general-attention information in the general field of view (e.g., information of electric motor).

Besides, nearly half of drivers think they will charge when electric quantity is less than half. The concern on energy condition is related to the distribution of charge station. Therefore, the location information of charge station should be shown for EV drivers timely. According to drivers' consideration, the most energy consuming usually happens in the situations of traffic congestion, air conditioning,

Table 3 Classification and attention of information on HI of EV

Information category	Specific unit	Attention level
Driving	Speed	High attention
Mileage	Endurance mileage	High attention
	Traveled distance	General attention
Battery	Residual energy, charge–discharge, voltage, temperature, state of charge	High attention Different attention levels
Electric motor	Revolving speed, voltage, current, temperature, overheating	Different attention levels
Safety/fault	Door, safety belt, airbag, fault	High attention
Energy utilization	Braking energy recovery	General attention

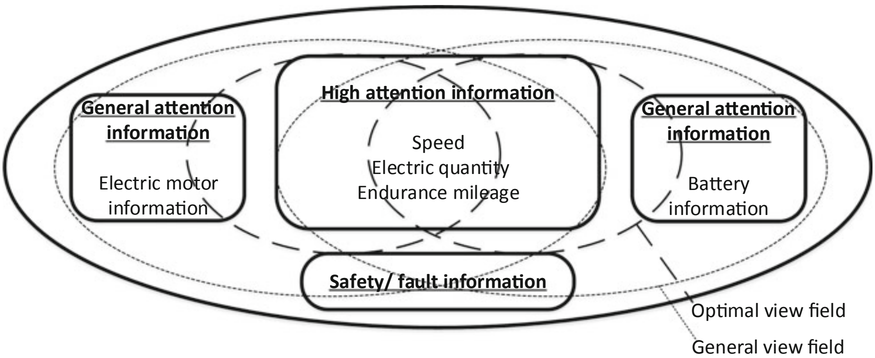

Fig. 1 Arrangement of instrument panel of electric vehicles

and frequent accelerating and decelerating. At this time, prompt information of energy consuming should be presented for drivers to release related worries.

Up to now, there are some problems remaining in the developing process of electric vehicles. For example, battery performance cannot meet the requirement of electric vehicles, which makes the endurance mileage of electric vehicles much shorter than traditional ones. What is more, it is very hard to estimate the endurance mileage of EV. Expect for the status of battery, the endurance mileage is related to many factors, e.g., working conditions, environment temperature, etc. Due to the complexity of energy consuming of EV, the prediction accuracy of endurance mileage is expected to be within 10 %. These problems also cause the need of complex human–machine interface in EV. As a result, the human interface of electric vehicles should meet the actual demand of drivers, provide better the mode of human–machine interaction, reduce the complexity of reading and controlling, and make driving more convenient and comfortable.

5 Conclusion

This paper focuses on the human interface of electric vehicle and compares the differences of information contents and display characteristics between electric vehicle and traditional fuel vehicles.

Through questionnaire, a survey on EV drivers' actual information demands is carried out. For EV, most of drivers pay high attention to current energy condition (electric quantity) and endurance mileage, while for FV, only approximately a quarter of total concerns. The drivers' concern levels for EV are two or three times as much as for FV. Therefore, in the HI of EV, current electric quantity and endurance mileage should be the most significant display information.

In addition, to reduce the drivers' range anxiety and mental stress from the energy of EV, the change situation of energy consuming and the location information of charge station should be presented for drivers. These important contents will be designed in the HI of EV to display appropriately and opportunely.

These results reveal the distinct display factors and presentation pattern of HI in EV, as well as the importance for drivers, to provide useful reference for the optimized design and evaluation of EV. In the future, based on drivers' actual demand and psychological features, the style of human–machine interface will be more readable and reliable, can meet the real demands, and release drivers' mental burden and fatigue level. Afterward, a normative human–machine interface designing and evaluating system for electric vehicle will be established and popularized in the industrial manufacture.

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The Effect of One-Color and Multi-color Displays with HUD Information in Aircraft Cockpits

Duanqin Xiong, Qingfeng Liu, Xiaochao Guo, Qingjun Zhang, Qin Yao, Yu Bai, Jian Du and Yanyan Wang

Abstract *Objective* To study the display effect of one-color and multi-color with head-up display (HUD) in aircraft cockpit and recommend the best color scheme. *Methods* Fifty-four fighter pilots participated in the experiment. In virtue of level maneuver task of dynamic simulated flight test procedure, the pilots' performance and their appraisal to the color configurations in daytime and nighttime background were explored. *Results* According to the results of simulated flight, the results of green plus magenta format were the best. By view of the subjective appraisal, the rating score of green plus magenta was superior to the other color configurations. *Conclusions* The display effect of HUD information with primary green and magenta as important parameters is the best of all color configurations. This color configuration is recommended in HUD information color coding.

Keywords Head-up display · Information · One-color · Multi-color · Simulated flight

1 Introduction

Color coding is an important coding form of visual display interface. Scientific and reasonable color coding shall be done for visual information on the display interface with mass information, so as to improve the accuracy of observation and identification of the operating personnel and make them obtain good performance in searching, counting, qualitative judgment and other tasks. It can also protect their visual and psychological functions, create a good working environment, have a sense of beauty, reduce fatigue and improve the overall efficiency of the system [1].

Head-up display is the main flight display of the modern military aircraft [2]. During the whole combat and flight process, the pilots need to obtain important information about the aircraft and the battle field through the display interface, so

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the reasonable design of its information display is particularly important. Traditional head-up display system of the cockpits display is mainly one-color (green) because of the implementation technique. During the process of actual use, the display information will be affected by the external background color and light conditions. There are no differences in colors for warning information. Therefore, the pilots generally report the one-color display is not conducive to the most effective acquisition of information in many cases, leading to the information needing to be focused on become less prominent and difficult to be identified. Moreover, the pilots also hope there will not be too many coding colors for the interface information. Too many colors will also affect pilots to observe the information.

As early as 1980s, our country and foreign countries began to explore the design of color head-up display and helmet-mounted display system and carried out relevant researches [3, 4]. At present, the advanced helmet-mounted display system of the foreign military aircraft has achieved color display. High-end civilian cars have also achieved the color head-up display system. Relevant researches have also been carried out. The color display technology of the head-up display system is mature. However, specific to the color display in formation of the head-up display in the combat aircraft, research reports have not been retrieved at present. However, some scholars have studied the color coding for abnormal information of the head-up display under laboratory conditions. The results show that red is better than yellow and green is not appropriate [5].

This study is aimed to explore the effect of one-color and multi-color displays in the head-up display systems, recommend the best color scheme for multi-color display and provide important basis for the design of color display for head-up displays.

2 Method

2.1 Test Equipment and Method

2.1.1 Task Design

The test adopts the design of 2 × 4 two-factor completely repeated measurement. Factor 1 is daytime and nighttime factor containing 2 levels of daytime background and nighttime background; Factor 2 is color factor. According to the provisions of relevant domestic and foreign standards [6], four color configuration levels are set. Each level represents a color scheme, including the same main color (green) and different target colors. The four kinds of color configuration schemes are, respectively: Scheme 1 (green + green), Scheme 2 (green + magenta), Scheme 3 (green + amber) and Scheme 4 (green + magenta + amber) which make the display frame forms one-color, two-color and three-color display settings.

This study comprehensively investigates the display effect from subjective and objective aspects. The objective aspect is to simulate the flight task with level maneuver. The subjective aspect is to ask the pilots to make subjective evaluations of excellent, good, average and poor results for the color settings of the frames.

2.1.2 Test Material and Equipment

1. One set of one-color and multi-color display flight performance test program. The test program includes the background information module, the exercise module, the test module and the data management module.
2. Two sets of simulated flight control devices (Saitek ×52), including the joysticks and the throttle levers.
3. Two laptops and two mouses. The specifications, models and their configurations are the same.

2.2 Test Method and Steps

Individual test form of man–machine conversation is adopted. The subjects shall firstly fill in the background information in the test program, then enter the exercise and accomplish 8 simulated flight tasks of dynamic program. After accomplishing each task, all the pilots need to complete the subjective evaluation for the display frame.

The test program automatically records the task accomplishment index and subjective evaluation results of the subjects.

2.3 Subjects

The subjects are 54 male pilots of fighters. Their ages are (32.78 + 5.94) years; their flying time in aircraft with head-up display is (587.00 ± 567.09) hours. Each pilot's eyesight is greater than 0.8 and does not have color blindness.

2.4 Statistical Processing

The SPSS 16.0 software is adopted for statistical processing of the test data. For difference test, two-factor completely repeated measurement is adopted.

Through data browsing and analysis, the performance indexes of the simulated flight tasks are mainly in skewed distribution. Therefore, when the descriptive statistics is carried out, the median (P_{50}) is used to represent its central tendency; when the difference significance test is carried out, each dependent variable data shall be a common logarithm with the base of 10. Then repeated measurement analysis of variance is carried out. Moreover, the relevant analysis shows that the flying time in aircraft with head-up displays is significantly correlated with each performance variables. It also shows the level of flying experience is closely related to the performance of simulated flight tasks. As a result, the flying time in aircraft with head-up displays shall be used as the covariant when the variance analysis of repeated measures is carried out, in order to eliminate its impacts.

For the analysis of subjective evaluation results, the excellent level, good level, average level and poor level are, respectively, assigned 4 points, 3 points, 2 points and 1 point. Through data browsing, the data are in normal distribution.

3 Results and Analysis

3.1 Simulated Flight Performance

According to all kinds of color configuration and the test frames under the conditions of daytime and nighttime background, the descriptive statistic results for the simulated flight performance of the pilots are shown in Table 1.

It can be seen from the results in the above table, for entering altitude difference, the P_{50} value of "Green + amber + daytime" configuration is the smallest and the P_{50} value of "Green + magenta + amber + nighttime" configuration is the largest. For rollout altitude difference, the P_{50} value of "Green + magenta + amber + daytime" configuration is the smallest and the P_{50} value of "Green + green + daytime" configuration is the largest. For entering velocity difference, the P_{50} value of "Green + magenta + amber + nighttime" configuration is the smallest and the P_{50} value of "Green + amber + nighttime" configuration is the largest. For rollout velocity difference, the P_{50} value of "Green + green + daytime" configuration is the smallest and the P_{50} value of "Green + amber + daytime" configuration is the largest. For entering heading difference, the P_{50} value of "Green + magenta + nighttime" configuration is the smallest and the P_{50} value of "Green + magenta + amber + nighttime" configuration is the largest. For rollout heading difference, the P_{50} value of "Green + magenta + amber + daytime" configuration is the smallest and the P_{50} value of "Green + magenta + amber + nighttime" configuration is the largest. For the total time of the task, the P_{50} value of "Green + green + nighttime" configuration is the smallest and the P_{50} value of "Green + amber + daytime" configuration is the largest.

By taking the flying time in aircraft with head-up displays as the covariant, the result of variance analysis for the two factors (the daytime and nighttime factor and the color factor) of the completely repeated measurement is as follows:

Table 1 Results of simulated flight performance in every color arrangement (P_{50}, n = 54)

Examination menu	Type of color configuration	Entering attitude difference (m)	Rollout altitude difference (m)	Entering velocity difference (km/h)	Rollout velocity difference (km/h)	Entering heading difference (°)	Rollout heading difference (°)	Total time (s)
Green + green + daytime (one-color)	Type 1	1069.67	2927.57	108.45	102.92	5.11	176.41	61.15
Green + green + nighttime (one-color)	Type 1	979.33	2066.77	132.27	125.54	0.96	92.69	40.53
Green + magenta + daytime (two-color)	Type 2	1071.62	2723.79	144.43	114.39	2.15	174.47	42.83
Green + magenta + nighttime (two-color)	Type 2	989.14	2142.13	154.07	139.17	0.68	102.43	58.95
Green + amber + daytime (two-color)	Type 3	977.38	2214.24	160.70	145.76	1.02	103.32	108.09
Green + amber + nighttime (two-color)	Type 3	994.69	2310.89	171.32	133.87	0.94	128.39	40.89
Green + magenta + amber + daytime (three-color)	Type 4	1022.43	1957.89	139.89	131.28	0.82	79.77	82.23
Green + magenta + amber + nighttime (three-color)	Type 4	2834.37	2903.41	106.94	113.52	78.36	179.08	62.35

- Entering altitude difference: The interaction among the daytime and nighttime factor, the color factor and the flying time in aircraft with head-up displays is significant ($F = 16.975$, $P < .05$). Regarding the color factor, the entering altitude difference of Color Configuration 4 is larger than that of Color Configuration 2. The difference is significant ($F = 6.842$, $P < .05$).
- Rollout altitude difference: The interaction among the daytime and nighttime factor, the color factor and the flying time in aircraft with head-up displays is significant ($F = 4.000$, $P < .05$). Regarding the color factor, the rollout altitude difference of Color Configuration 1 is larger than that of Color Configuration 3. The difference is significant ($P < .05$).
- Entering velocity difference: The entering velocity difference of Color Configuration 1 is less than that of Color Configuration 3, and the difference is significant ($P < .05$).
- Rollout velocity difference: The rollout velocity difference of Color Configuration 1 is less than that of Color Configuration 3, and the difference is significant ($P < .05$). The rollout velocity difference of Color Configuration 1 is greater than that of Color Configuration 4, and the difference is significant ($P < .05$). The rollout velocity difference of Color Configuration 1 is greater than that of Color Configuration 4, and the difference is significant ($P < .05$).
- Entering heading difference: The interaction among the daytime and nighttime factor, the color factor and the flying time in aircraft with head-up displays is significant ($F = 9.521$, $P < .05$). Regarding the color factor, the entering heading difference of Color Configuration 4 and Color Configuration 1 is larger than that of Color Configuration 2 and the difference is significant ($P < .05$).
- Rollout heading difference: The color factor has a significant main effect ($F = 4.538$, $P < .05$). Among them, the rollout heading difference of Color Configuration 1 is less than that of Color Configuration 2 and the difference is significant ($P < .05$).
- Total time of the task: The interaction between the color factor and the flying time in aircraft with head-up displays is significant ($F = 11.152$, $P < .05$). The interaction between the daytime and nighttime factor and the color factor is significant ($F = 22.593$, $P < .01$). The interaction among the daytime and nighttime factor, the color factor and the flying time in aircraft with head-up displays is significant ($F = 12.909$, $P < .05$). Regarding the color factor, the total time of Color Configuration 3 is longer than that of Color Configuration 2, and the difference is significant ($P < .05$).

It can be seen from the above-mentioned test results, Color Configuration 2 (green + magenta) and Color Configuration 3 (green + amber) have comparative advantages on the accuracy of accomplishing simulated tasks and the task time.

3.2 Subjective Evaluation

Results of subjective evaluation for tested pilots are shown in Table 2.

It can be seen from the results in the above table, for “Easiness of information capture” index, the average score of “Green + magenta + amber + daytime” configuration is the lowest and the average score of “Green + amber + nighttime” configuration is the highest. For “Harmony of color display” index, the average score of “Green + magenta + amber + daytime” configuration is the lowest and the average score of “Green + magenta + nighttime” configuration is the highest. For “Comfort of night flight” index, the average score of “Green + amber + nighttime” configuration is the lowest and the average score of “Green + magenta + nighttime” configuration is the highest. For “Fitness of long-time flight” index, the average score of “Green + magenta + amber + daytime” configuration is the lowest and the average score of “Green + magenta + nighttime” configuration is the highest.

By taking flying time in aircraft with head-up displays as the covariant, the result of variance analysis for the two factors (the daytime and nighttime factor and the color factor) of the completely repeated measurement is as follows:

- Easiness of information capture: The interaction between the daytime and nighttime factor and the flying time in aircraft with head-up displays is significant ($F = 13.775$, $P < .01$). The color factor has a significant main effect ($F = 4.341$, $P < .05$). Regarding the daytime and nighttime factor, the evaluation score of nighttime background is higher than that of daytime background and the difference is significant ($P < .01$). Regarding the color factor, the evaluation score of Color Configuration 2 is higher than that of Color Configuration 1 and the difference is significant ($P < .05$).
- Harmony of color display: The interaction between the daytime and nighttime factor and the flying time in aircraft with head-up displays is significant ($F = 4.323$, $P < .05$). The interaction among the daytime and nighttime factor, the color factor and the flying time in aircraft with head-up displays is significant ($F = 2.723$, $P < .05$). Regarding the daytime and nighttime factor, the evaluation score of nighttime background is higher than that of daytime background and the difference is significant ($P < .05$). Regarding the color factor, the evaluation score of Color Configuration 2 and Color Configuration 3 are higher than that of Color Configuration 1 and the difference is significant ($P < .01$).
- Comfort of night flight: The evaluation score of Color Configuration 2 is higher than that of Color Configuration 1, and the difference is significant ($P < .01$). The evaluation score of Color Configuration 2 is also higher than that of Color Configuration 3, and the difference is significant ($P < .001$).
- Fitness of long-time flight: The interaction between the daytime and nighttime factor and the flying time in aircraft with head-up displays is significant ($F = 18.109$, $P < .001$). Regarding the daytime and nighttime factor, the evaluation score of nighttime background is higher than that of daytime background and the difference is significant ($P < .001$).

Table 2 Subjective scores of pilots' appraisal to the display menu ($\bar{x} \pm s, n = 54, s$)

Examination menu	Type of color configuration	Easiness of capturing information	Harmony of color display	Comfort of night flight	Fitness of long-time flight	Integrated appraisal
Green + green + daytime (one-color)	Type 1	2.92 ± 0.92	2.88 ± 0.88	–	2.83 ± 0.84	2.88 ± 0.86
Green + green + nighttime (one-color)	Type 1	3.03 ± 0.75	3.12 ± 0.75	3.09 ± 0.73	3.09 ± 0.70	3.11 ± 0.71
Green + magenta + daytime (two-color)	Type 2	3.14 ± 0.71	3.11 ± 0.63	–	2.98 ± 0.71	3.03 ± 0.80
Green + magenta + nighttime (two-color)	Type 2	3.18 ± 0.64	3.16 ± 0.60	3.33 ± 0.76	3.24 ± 0.66	3.31 ± 0.64
Green + amber + daytime (two-color)	Type 3	3.05 ± 0.73	3.11 ± 0.76	–	2.96 ± 0.72	3.03 ± 0.77
Green + amber + nighttime (two-color)	Type 3	3.24 ± 0.72	3.14 ± 0.72	3.05 ± 0.67	3.11 ± 0.72	3.12 ± 0.77
Green + magenta + amber + daytime (three-color)	Type 4	2.85 ± 0.76	2.77 ± 0.86	–	2.75 ± 0.93	2.83 ± 0.84
Green + magenta + amber + nighttime (three-color)	Type 4	3.12 ± 0.75	3.05 ± 0.83	3.14 ± 0.81	3.07 ± 0.92	3.20 ± 0.80

- General evaluation of frame effect: The interaction between the daytime and nighttime factor and the flying time in aircraft with head-up displays is significant ($F = 15.583$, $P < .001$). The interaction between the daytime and nighttime factor and the color factor is significant ($F = 6.599$, $P < .05$). The interaction among the daytime and nighttime factor, the color factor and the flying time in aircraft with head-up displays is significant ($F = 6.195$, $P < .05$). Regarding the daytime and nighttime factor, the evaluation score of nighttime background is higher than that of daytime background and the difference is significant ($P < .001$). Regarding the color factor, the evaluation score of Color Configuration 2 is higher than those of Color Configuration 1 and Color Configuration 3 and the difference is significant ($P < .05$).

It can be seen from the results of difference significance test of subjective evaluation. The evaluation score of night background is generally higher than that of daytime background. Regarding the color configuration, two-color displays relatively receive better reviews of the pilots. Among them, the evaluation score of Color Configuration 2 (green + magenta) is higher than other color configurations.

4 Conclusion

The study is mainly to investigate the display effect of different color configurations and provide important basis for the colorization of information with head-up display system. The test has designed simulated flight tasks which require the subjects to follow the instructions and accomplish the simulated level maneuver flights with the best data maintaining status and the shortest flight time. The deviations between the actual entering and rollout altitude, velocity and heading of the subjects when accomplishing the simulated tasks of different color configurations and required flying altitude, velocity and heading are mainly selected as the performance indexes. The smaller the flight deviation is, the better the task is done. In the case of same deviation, the shorter the total time is, the better the task is done. By comparing the above-mentioned performance indexes, we can infer the display effects of different color configurations. In addition, the higher the subjective evaluation score of the subjects for the frames of a certain color configuration, the more reasonable the subjects think the color configuration of the display frame is.

According to the data of simulated flight performance indexes, from the perspective of the results of descriptive statistics and variance analysis of Table 1, the display effect of the nighttime background is generally better than that of the daytime background. The reason may be the nighttime outside background has little interference on head-up display information. Whatever the color configuration of the design of the display information is, the display effect of the nighttime background has significant advantages compared with that of the daytime background. From the perspective of color configuration, in general, the simulated flight performance indexes in case of two-color (green + magenta, green + amber) display are generally better than those of one-color (green) display and three-color (green + magenta + amber) display. The color configuration of "Green + magenta" has the best effect.

For the perspective of the subjective evaluation scores and statistical results of significant difference in Table 2, they also show that the evaluation score of the nighttime background is generally higher than that of the day background. From the perspective of color configuration, the review of the subjects on two-color configuration is also generally better than the one-color configuration and three-color configuration.

Taking the data and results of the subjective and objective researches into consideration, under the conditions of this test research, it may be concluded as follows:

- The display effect of nighttime background is better than that of daytime background;
- The display effect of two-color display is better than that of one-color and three-color display;
- The display effect of green + magenta is better than that of other color configurations.

For the head-up display system, we can preliminarily conclude that two-color display shall be adopted in the colorization of information display, among which the main color is green. The parameter color needing to be focused on is magenta.

It is still necessary to note that the colors selection in the study is mainly based on the provisions of American standards, and only three stipulated colors have been selected (green, magenta and amber) to test the frame configuration. The alert color has not been involved yet. If there are suitable conditions, the study can be extended. In addition, the conclusions of the study can be only used as a preliminary recommendation. If it is to be applied in the engineering, it still needs further to be researched and verified with head-up display system.

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Part V
Research on the Man-Environment Relationship

Thermal Protective Performance Tests of Firefighters Clothing

Chenming Li, Yuhong Shen and Yafei Guo

Abstract *Objective* The firefighters clothing is the basic equipment for firefighter. Most of the firefighters clothing performance test methods are focused on textile materials. To pay more attention to overall thermal protective performance, flame-manikin method is described. *Methods* Three material samples are tested by TPP method, and three kinds of firefighters clothing are tested by flame-manikin system. The firefighters clothing is made by the material sample, respectively. *Results* The TPP test results show that the protective performance of Sample C is best and the results of three samples are similar. However, the flame-manikin tests show that the burn injury of Clothing A is less than that of Clothing C and a significant difference is found between the other two conditions. *Conclusions* The TPP test is only a material test, which cannot mimic style, structure and degree of ease. The style of clothing has very important influence on the flame-resistant protective performance of clothing.

Keywords Firefighters clothing · TPP · Flame-manikin

1 Introduction

The firefighters clothing is the basic equipment for firefighters. The main function of this clothing is to resist flash fire and radiation damage and keep safety of firefighters [1, 2]. Investigations show that fire fighters can be exposed to intense heat flux levels as high as 4×10^4 J/(m^2 s) for relatively short periods of time. Thermal protective performance (TPP) test method, vertical combustion test

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method, limiting oxygen index method and radiant protective performance (RPP) method are mainly used to test and evaluate flame-resistant performance of clothing. These methods can only be used to evaluate the protective performance of textile materials but not to mimic overall protective performance when wearing clothing. With the development of manikin, the technology of flame-manikin testing attracts more and more attention. The flame-manikin testing method simulates the flame resistant clothing exposed to flash fire, and estimates the second-degree and third-degree burn injury on skin. The flame-resistant performance of clothing was determined according to the burn area. This paper compares the thermal protective performance of firefighters clothing by TPP method and flame-manikin method [3, 4].

2 Experiments

2.1 Subjects

Three different materials of firefighters clothing used in the study are provided in Table 1. Samples A, B and C meet the standard GA10. All samples were conditioned in (20 ± 2) °C, (65 ± 5) %RH for over 24 h before testing.

2.2 TPP Test

In the 1986, thermal protective performance (TPP) test method was introduced and it is one of the most commonly used material thermal protection test methods now. The principle of TPP test is to set the fabric sample and test sensor into the radiant and convective heat environment, simulate the human skin exposed to fire and measure the heat flux through the sample to cause second-degree burn to the skin [5].

A standard TPP tester TPP-I is used, and tests are according to standard GA10-2014. The samples are exposed to both radiant heat source and convective heat source of 84 kW/m^2 ± 4 kW/m^2 (2 $cal/(cm^2\ s)$ ± 0.1 $cal/(cm^2\ s)$).

During testing, the temperature rise curve is recorded by the sensor, the higher the temperature, the more the heat through the sample. The heat tracing curve is compared with Stoll's curve, called a second-degree burn curve. The Stoll's curve shows the second-degree burn of skin as a function of time and heat. The TPP value is the cross-point of those two curves [6].

$$\mathrm{TPP} = F \times T \tag{1}$$

where F is heat flux [2 $cal/(cm^2\ s)$] and T is time to second-degree burn (s).

Table 1 Materials of tested samples

	Sample A			Sample B			Sample C		
	Material	Weight (g/m^2)	Thickness (mm)	Material	Weight (g/m^2)	Thickness (mm)	Material	Weight (g/m^2)	Thickness (mm)
Outer shell	93 % Nomex 5 % Kavlar 2 % conductive fibers	210	0.40	100 % Aramid	200	0.38	100 % Nomex	220	0.42
Water barrier	PTFE membrane	175	0.55	PTFE membrane	175	0.55	Retardant silicone/Aramid mat/PTFE membrane complex	240	2.33
Thermal barrier	100 Aramid	150	1.08	100 % Aramid	130	2.07			
Innermost layer	50 % Nomex 50 % FR VISCOSE	120	0.33	50 % Nomex 50 % FR VISCOSE	120	0.33	50 % Nomex 50 % FR VISCOSE	120	0.33

2.3 Flame-manikin Test

When human exposes to fire, the skin burn injury degree depends on two factors: One is the heat flux of fire, and the other is exposure duration. To mimic overall protective performance when wearing clothing, the flame-manikin test system is used, which is developed by QRI. The system mainly includes manikin system, fuel and delivery system, control system, data acquisition system and computer software system. Tests are according to standard GB/T 23467, the heat flux is 84 kW/m^2 (2 cal/(cm^2 s)), and the exposure time is 8 s.

In order to calculate the skin temperature of different depths, the thermal wave model of bioheat transfer (TWMBT) is applied. For practical purposes, 1-D heat transfer is assumed, as

$$\begin{aligned}&\frac{\partial}{\partial x}\left(k_{\mathrm{skin}}\frac{\partial T}{\partial x}\right)+\omega_{\mathrm{b}}\rho_{\mathrm{b}}C_{\mathrm{p,b}}(T_{\mathrm{b}}-T)+q_{\mathrm{m}}+q_{\mathrm{r}}\\&\quad+\tau\left(-\omega_{\mathrm{b}}\rho_{\mathrm{b}}C_{\mathrm{p,b}}\frac{\partial T}{\partial t}+\frac{\partial q_{\mathrm{m}}}{\partial t}+\frac{\partial q_r}{\partial t}\right)=\rho_{\mathrm{skin}}C_{\mathrm{p,skin}}\left[\tau\left(\frac{\partial^2 T}{\partial t^2}\right)+\frac{\partial T}{\partial t}\right]\end{aligned} \tag{2}$$

where ρ_{skin}, $C_{\mathrm{p,skin}}$ and K_{skin} are physiological parameters of human skin (density, specific heat and thermal conductivity), ρ_{b}, C_{b} and ω_{b} are physiological parameters of blood (density, specific heat and perfusion rate), q_{m} and q_{r} are volumetric heat due to metabolism and spatial heating, T_{b} is artery temperature, and T is human temperature [7, 8].

The estimation of tissue burn injury in this test method is based on Henriques model. Lot of materials show that, when the temperature of skin is at 44 °C, it takes about 3 h for the non-recovery burn injury to occur. When the temperature of skin reaches 70 °C, the non-recovery burn injury occurs immediately. The total skin burn damage can be evaluated by following model:

$$\Omega=\int_0^t P\exp\left(\frac{-\Delta E}{RT}\right)\mathrm{d}t,\quad (T\geq 317.15\ \mathrm{K}) \tag{3}$$

where Ω is a quantitative measure of burn damage at any depth in the skin, P is frequency factor, e is natural exponential (2.7183), E is the activation energy for skin, R is the universal gas constant (8.315 J/kmol K), T is the absolute temperature at the basal layer or at any depth in the dermis, and t is total time for which T is above 44 °C (317.15 K) [9].

At the basal layer (epidermis/dermis interface), if $\Omega > 1.0$, second-degree burns will result. If $0.5 < \Omega < 1.0$, first-degree burns will occur. At the epidermis/dermis interface, if $\Omega > 1.0$, a third-degree burn injury will occur [10].

3 Results

3.1 TPP Test Results

The TPP test results are shown in Table 2.

The outer garment of firefighters clothing is used to resist flame and heat. After tests, the outer shell of sample A is carbonization, the outer shell of sample C is carbonization and shrinkage. This is because the proportion of Nomex in the outer garment of Sample C is the largest. When Nomex suffers high temperature, it will be carbonation and increase the thickness [11]. The thermal barrier of both Samples A and B are Aramid, the thicker the fabric, the higher the TPP value shown in Table 2. The thermal barrier of Sample C is retardant silicone and Aramid mat. There is more air in this barrier than that of Samples A and B, so the TPP value is highest.

3.2 Flame-manikin Test Results

The Flame-manikin test results are shown in Table 3.

In Table 3, the results show that the burn injury of Clothing A is less than that of Clothing C and a significant difference is found between the other two conditions. However, in Table 2, the TPP value are similar. Because the TPP test is only a material test, it cannot mimic style, structure, degree of ease, etc. By analyzing the test process record, it is found that the fire gets into the inner of the Clothing C from the bottom of the clothing because it is very loose in the bottom and inner. So it continues to burn for 3 s when the flash fire is extinguished.

Table 2 TPP test results

Sample	Time to second-degree burn (s)	TPP value (cal cm^{-2})
A	20.7	41.4
B	19.6	39.2
C	21.4	42.8

Table 3 Test results of different clothing

Clothing	Second-degree burn injury area percentage (%)	Third-degree burn injury area percentage (%)	Total burn injury area percentage (%)
A	9.7	3.6	13.4
B	16.4	6.8	23.2
C	14.7	4.9	19.6

4 Conclusions

From this work, some recommendations can be made. In material tests, the TPP value of Sample C is highest. However, in flame-manikin tests, the overall protective performance of Clothing A is best.

These results show that the style of clothing has very important influence on the flame-resistant protective performance of clothing. Therefore, we should take into account the design of the clothing.

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Research on Connection Between Wind-Chill Factor and Human Perception in Extremely Cold Areas Experiment Environment

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Abstract To accurately hold the rules and characteristics of extremely cold environment, to study the connection between wind-chill factor and human perception in cold region experiment environment, and to provide guidance to operators in cold region, improving their acclimatization and performance; by applying the basic theory and analytical method of Man-Machine-Environment System Engineering, with work experience summery, consulting to documentation, questionnaire, and field experiment, we discussed the connection between wind-chill factor and human perception in cold region experiment environment. There is connection between wind-chill factor and human perception in extremely cold areas experiment environment. With the increase of wind-chill index, human perceives the environment to be colder and his capacity of action decreases, resulting in decline in his operating efficiency. The research on connection between wind-chill factor and human perception in extremely cold areas experiment environment is an attempt of constructive nature to explore the combination of the theory and practice of Man-Machine-Environment System Engineering, and its results will provide theoretical guidance for machine operating in extremely cold environment and practical significance in improving human acclimatization and performance in extremely cold environment.

Keywords Extremely cold area · Wind-chill factor · Human perception

1 Introduction

Extremely cold area refers to those military operation areas where the average temperature in the coldest month is under −15 °C [1]. In China, our cold region includes year-round extremely cold area and seasonal extremely cold area, about 4, 300,000 km^2 and 43.5 % of China's land territory [2]. Almost all the Northeast

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China, part of Northwest China, North China, and Xizang, can be referred to as extremely cold area.

The most distinctive features of cold region are its low temperature and high wind speed. Especially in low temperature environment with wind, air draught encourages heat loss in human body. With higher wind speed, human body cools faster and losses more heat, and there will be higher possibility for cold weather injury. In view of that, wind speed and temperature play decisive roles in the cold level of operating environment. To accurately hold the rules and characteristics of cold environment and improve human acclimatization in extremely cold areas, it is of much significance to enhance the study on the connection between wind-chill factor and human perception in extremely cold areas experiment environment.

2 Wind-Chill Effect

By speaking the wind-chill effect, we mean with human perception of chill being affected by wind, there will be sharp contrast between temperature reading on the thermometer and human perception of temperature. The connection between wind speed and human perception of temperature is referred to as wind-chill effect.

Wind-chill effect is measured by wind-chill index (chill perception index), and wind-chill index is an exponential function which explains the connection between heat loss of human body and wind speed as well as temperature under 15 °C. It indicates calories of heat loss of every meter squared human body surface exposed to environment of certain wind, temperature and humidity condition. According to experiment, with a temperature of −1.1 °C, if wind speed is 11.1 m/s (about six levels of gales), human body will perceive chill 17.2 °C less than that in same temperature without wind [3].

Wind-chill index is the superficial air temperature above exposed human skin, and it describes the comprehensive effects of air temperature and wind speed on human body. Wind-chill index can be obtained from wind-chill index table or by calculation via certain formula. The formula is:

$$K_V = (33 - T)\left(9.0 + 10.9\sqrt{v} - v\right)\left(1 + \frac{RH - 50}{100}\right)\frac{3}{4} \quad (1)$$

In this formula (1), K_V represents wind-chill index, v is the wind speed (m/s), RH is relative humidity, and T is temperature (°C). In calculation, if relative humidity is

Table 1 Connection between wind-chill index and human perception

K_V	50–200	200–300	300–600	600–800	800–1000	1000–1200	1200–1400	Above 1400
Human perception	Warm	Comfort	Cool	A little chilly	Chilly	Rather chilly	Very chilly	Extremely chilly

under 50 %, we consider $RH = 50$ [4]. Table 1 shows the connection between wind-chill index and human perception.

3 Equivalent Cooling Temperature

In the course of accessing cold stress of environment, with environment temperature factor being put into account, the wind speed at that time also need to be considered. Usually, the term "equivalent cooling temperature" is used to describe the cooling effect of wind [5]. Equivalent cooling temperature refers to the degree of cold perceived by human body in wind, which equals the air temperature value in a same degree of cold that human body perceives without wind. Its formula is:

$$T_{\mathrm{e}} = T + \frac{T - 36}{10} V \tag{2}$$

In formula (2), T_{e} is the equivalent cooling temperature (°C), T is air temperature (°C), and V is the wind speed (m/s). Table 2 shows the wind cooling effects described by equivalent cooling temperature [4].

4 Practical Tests of Temperature and Human Perception

According to the weather log of some certain area, the average air temperature in the coldest month in winter ranges from −19 to −11 °C. Its climatic feather can be summarized as dry air, low temperature, and strong dry and cold wind. In addition to that, with some certain area being surrounded by sea in three sides, there are significant monsoon, rather strong wind, and significant wind-chill effect, and its

Table 2 Wind cooling effects described by equivalent cooling temperature

Wind speed (m/s)	Air temperature (°C)						
	5.0	0.0	−5.0	−10.0	−15.0	−20.0	−25.0
Gentle breeze	5.0	0.0	−5.0	−10.0	−15.0	−20.0	−25.0
2	4.5	−1.1	−6.0	−11.0	−16.0	−21.5	−26.5
3	1.5	−4.0	−9.5	−15.5	−21.0	−26.5	−32.0
4	−0.5	−6.5	−12.5	−16.5	−24.3	−30.0	−36.0
5	−2.5	−8.5	−15.0	−21.0	−27.5	−34.0	−40.0
6	−3.5	−10.5	−17.0	−23.5	−30.0	−36.5	−43.0
7	−5.0	−11.5	−18.5	−25.5	−32.0	−39.0	−45.5
8	−6.0	−13.0	−20.0	−27.0	−34.0	−41.0	−48.0
9	−7.0	−14.0	−21.0	−28.5	−35.5	−42.5	−49.5
10	−7.5	−15.0	−22.0	−29.6	−37.0	−44.0	−51.5

Table 3 Operating environment data in 6:00 (morning) on a certain day and human perception

Wind speed (m/s)	5.1	5.3	5.1	3.9	5.7	6.1
Relative humidity (%RH)	58.5	58.7	57.6	58.1	57.9	56.4
Temperature (°C)	−12.2	−11.8	−11.6	−11.9	−11.7	−11.5
Wind-chill index	1333.8	1327.6	1294.5	1217.1	1347.3	1385.5
Equivalent cooling temperature (°C)	−24.5	−23.7	−22.3	−19.8	−26.3	−25.7
Human perception	Extremely cold	Extremely cold	Extremely cold	Extremely cold	Extremely cold	Extremely cold

Table 4 Operating environment data in 14:00 (noon) on a certain day and human perception

Wind speed (m/s)	4.4	5.1	6.4	5.9	4.6	4.3
Relative humidity (%RH)	27.1	27.7	28.3	30.7	31.0	30.8
Temperature (°C)	−6.3	−5.2	−6.5	−5.4	−4.9	−4.2
Wind-chill index	1134.9	1078.2	1184.9	1171.9	1034.7	1110.2
Equivalent cooling temperature (°C)	−13.5	−15.2	−18.1	−17.3	−14.7	−11.9
Human perception	Cold	Cold	Cold	Cold	Cold	Cold

equivalent cooling temperature usually is under −20 °C. Extremely cold area refers to the area where the average air temperature in the coldest month is under −15 °C, including year-round extremely cold area and seasonal extremely cold area [6]. Tables 3 and 4 show the environment data acquired by experiment devices in the test place in 6:00 (when the lowest temperature occurred on that day) and 14:00 (when the highest temperature occurred on that day) [7].

5 Conclusion

The atrocious weather condition in extremely cold area severely undermines human adaptability and survivability, and that requires enough attention. The research on connection between wind-chill factor and human perception in extremely cold areas experiment environment analyzed the connection among air temperature, wind speed and human perception, which provide important theoretical guidance to the research on human adaptability in extremely cold environment.

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Research on Human Factor Solution to Improve Operating Performance in Northeast Cold Region

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Abstract The research on human factor in operating performance in northeast cold region is instructive in improving operator's acclimatization and performance in northeast cold region. Applying the basic theory and analytical method of Man–Machine–Environment System Engineering and methods from work experience summery, the research on human factor in operating performance in northeast cold region is a constructive exploration to combine theory and practice together. According to work experience, to propose such solutions on human factor as cold weather acclimatization training, improving mental quality, enhancing professional skills, strengthening administrative management, and taking protective measures, to improve operating performance in northeast cold region. In research on human factor in operating performance in northeast cold region, those measures are proposed to improve operating performance in northeast cold region, provide guidance to operators in cold region, help prevent assorted diseases, keep themselves mentally and physically healthy, and improve operating performance.

Keywords Cold region · Operating performance · Human factor

1 Introduction

In China's northeast cold region, with frigid/temperate continental climate [1], its climate has such main features as temperature varies greatly between summer and winter; strong wind in plain area and deep snow in mountainous area [2]; highly variable and dry weather with raging sandstorm in spring; short-time scorching heat and rainy weather in summer; sudden drop in temperature and decrease in

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precipitation in autumn; long and cold winter featured with low temperature, high temperature differences, long frigid season, long time of cold wave and snow, deep snow cover, deep permafrost, frequent and strong wind, long ice period, short daytime and long night, and low absolute humidity.

2 Solutions on Human Factor to Improve Performance

2.1 Low Temperature Acclimatization Training

2.1.1 Organize Cold Endurance Training in a Scientific Way

As a major cause of fortuitous causality, low temperature causes frostbite and even threat to life. Therefore, it is of highly necessity to improve acclimatization training for operator in northeast cold environment. Moderate cold endurance training, to some degree, will improve human endurance in cold environment and acclimatization to cold weather; improve human proficiency in machine operating; shorten the time in which human are exposed to low temperature; succeed in fortifying human body against cold injury and maintaining high efficiency in operating.

2.1.2 Principals for Low Temperature Acclimatization Training

There are four major principals for low temperature acclimatization training: first, to proceed in regular order step by step. The temperature setting in training needs to shift from low to high gradually; the training intensity needs to be heightened gradually; the training load needs to be increased gradually; and the training time needs to be extended gradually. Second, enough low temperature stimulation. Training needs to be proceeded only when low temperature stimulation acts on human body obviously. Third, special attention to differences between people. Under adverse weather, exposure to low temperature stimulation needs to be combined with moderate exercise; excise of arms and legs needs to be intensified; special attention is paid to the protection of peripheral parts such as ears and nose by massage. Fourth, training in a persistent way. Even after getting acclimatized to low temperature, cold endurance training needs to be proceeded at least three times one week, to strengthen the training.

2.1.3 Methods for Low Temperature Acclimatization Training

Via consulting to relevant domestic and foreign documents and collecting winter operating and acclimatization training experience and practice of units in China's northeast region, for the purpose of improving human cold endurance and helping with the adequate functioning of equipments, four major methods for low temperature acclimatization training are recommended here: first, physical training. The priority for physical training in winter season is the preliminary training oriented toward long-distance running; second, cold water training. Early in summer and autumn, operators begin to wash their hands and face, and feet or bathe their extremities with cold water, to improve acclimatization process via low temperature exposure training of peripheral or exposed parts of body; third, cold air training. In more than two months, outdoor excise should be no less than 6–7 h per day, with appropriate cloth reduction; fourth, comprehensive acclimatization training. In a training period, use more than two methods to intensify acclimatization training.

2.2 Improve Mental Quality

2.2.1 Thorough Mental Mobilization

Mentality leads action. Bold action comes from tough mentality only. It is necessary to fully understand operator's mentality, lives and work and inspire them on various occasions, to fight up their spirit, to eradicate their sense of loneliness and depression resulted from long-time work in cold environment, and to help them build confidence against cold weather. Meanwhile, those in charge at all echelons need to be responsible enough, setting example for subordinates.

2.2.2 Do Well in Healthcare Education

Cold region winter healthcare education needs to be actively carried out, with lecture on disease and injury prevention in northeast cold region, to equip operators with knowledge on the danger of cold disease and injury the prevention and treatment of them, enhance their awareness of winter protection, release their mental pressure, overcome their fear, and improve their ability to protect themselves against cold disease and injury. For the effectiveness of healthcare education, the two combinations doctrine needs to be put into consideration: combination of general education and lectures on specific topics and combination of mental care and healthcare education. Specific solutions need to be formulated to improve stress response ability of operators [3].

2.2.3 Psychological Behavior Training

Considering the peculiarities of northeast cold region, effective psychological behavior training can help prevent and overcome such positive psychological factors such as apathy, anxiety, and fear, and improve psychological adaptability of the subject [4]. Generally speaking, there are three methods in psychological behavior training: First, outdoor expend training (OET) helps to overcome apathy. OET games such as trust fall, cooperated climbing, and rock climbing will help build cooperation and initiative in operators; help operators to adopt positive outlook on life; and reduce the risk of mental problems such as apathy. Second, self-control training helps to overcome anxiety. It will be organized with relaxation training method and self-suggestion training. Third, extreme training helps to overcome fear. Extreme sports such as long-distance expedition, cliff climbing, rope climbing will help overcome fear in operators toward cold environment.

2.3 Enhance Professional Skills

Research suggests that affects from low temperature are inversely proportional to operating proficiency [5]. Therefore, organizing targeted operating skills training in low temperature environment will effectively enhance human equipment operating skills in harsh environment. Pay attention to these three points: first, choose cold outdoor environment to conduct equipment operating training, to improve human adaptability to low temperature environment; second, choose weather of cold wave, strong and cold wind to operate equipments, to improve human adaptability to cold wind; third, choose snowfield with strong sunshine to conduct training, to improve human adaptability to strong sunshine.

2.4 Strengthen Administrative Management

Strengthening administrative management is the key to winter protection in northeast region. Administration departments need to put winter protection into their work agenda and formulate practical measures according to operating environment. They should be prepared early on, take the initiative, pursue strict requirements, and ensure full implementation in practice. Meanwhile, they need to inculcate and supervise implementation in operators. The leadership is required to be familiar with winter protection knowledge, strengthen administrative management, and stress on the implementation of regulations. The administrative authority should understand four major aspects: first, understand the winter protection situation, and comment and summarize in time; second, understand the operators' dressing, and find and solve problems in time; third, understand the operators' physical strength, and avoid exhaustion; fourth, understand the weather forecast, and take measures against cold.

2.5 Protective Measures Against Low Temperature Environment

2.5.1 Improve Medical Support

Medical support should be improved in low temperature environment by formulating scientific medical measures in view of human pathogenetic characters in northeast cold region, to protect operators' physical and mental health to the utmost. First, establish health records documentation, to conduct periodic medical tests and understand operators' physical condition. Second, maintain operators mentally healthy, to compose and distribute educational materials, to conduct mental care education in wide range, and to organize psychiatrists to make rounds of visits regularly. Third, take medical measures to prevent cold disease and injury, to enhance protection against infectious diseases and to give targeted vaccines or traditional Chinese herb soup to operators. Forth, ensure adequate supply of medicine for cold region, to distribute first aid kits to all operators before work and clarify the occasion, frequency, and dosage of the medicine.

2.5.2 Scientific and Rational Diet

When human is working in cold environment, his process of metabolism will speed up and require more nutrients. In this case, inappropriate diet and water drinking will pose adverse health effects on operators and result in decline in work performance. For operators in northeast cold region, it is necessary to ensure hot food supple and hot ginger soup. First, high-sugar, high-protein and low-fat hot food should be the staple food for operators, and in regions without adequate vegetable supply various types of vitamins should be taken. Second, supply of calories should be increased by 25–50 % than usual (4400 calories one day on per head), calories supply from fat should be increased by 20–25 %, and supply of various types of vitamin should be increased by 30–50 % [6]. Third, operators need to drink mainly boiled water with a small amount of salt, to supplement physical consumption. Fourth, scientific work and rest schedule need to be formulated according to different types of work and their different requirements, to avoid exhaustion and minimize the time in which human extremities exposed to low temperature.

2.5.3 Complete Sets of Mutual Compatible Gears

Winter protection gears supply plans should be further perfected and specified, and winter protection supply list should be examined and verified thoroughly, to make every single piece of item to be classified into specific categories and their responsibilities to be assigned to specific individuals, and to ensure winter protection gears complete and mutual compatible to function well in low temperature combat environment [7]. First, proper use of cold-proof suit. Unscientific and improper use of cold-proof suit is one of the major causes of cold injury. Cold-proof suit for winter should be simple, practical and warm. Furthermore, operators need to take good care of their face, ears, and hands, and use frostbite-proof skin cream on exposed body parts to prevent local frostbite. Second, scientific use of gloves. Working in cold environment, it is not necessary to wear gloves with temperature above −10 °C; knitted gloves for a temperature from −10 to −25 °C; leather gloves for a temperature under −25 °C. It is forbidden to blow air into gloves because the moisture human breath out will reduce their warmth retention property.

2.5.4 Establish a Warning Mechanism

The administrators should establish a warning mechanism based on weather forecast from Central Meteorological Station, to arrange the rest time for operators. They can establish this mechanism according to wind-chill index. First, they can set a frostbite safety level according to daily extremum of wind-chill index: daily extremum of wind-chill index from 1101 to 1200: frostbite warning period; daily extremum of wind-chill index from 1201 to 1400: frostbite critical period; daily extremum of wind-chill index above 1400: frostbite serious period. Second, they can set the safety level for outdoor work according to the average wind-chill index value. Wind-chill index from 801 to 1000: safe to work outside; wind-chill index from 1001 to 1200: difficult to work outside in overcast weather; wind-chill index from 1201 to 1400: difficult to work outside.

3 Conclusion

With the applying of the basic theory and analytical method of Man–Machine–Environment System Engineering, the research on human factor solution to improve operating performance in northeast cold region focuses on how to improve human acclimatization and operating performance in cold environment. With work experience summary, multiple solutions on human factor are provided, such as cold weather acclimatization training, improving mental quality, enhancing professional skills, strengthening administrative management, and taking protective measures, to improve operating performance in northeast cold region, which will provide important guidance in directing and regulating operating in northeast cold region.

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Research on Limit Boundary of High Temperature for Military Vehicle Personnel

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Abstract High-temperature and humidity environment has a serious impact on the military vehicle personnel. The effects of high temperature and humidity on the physiological and psychological effects of personnel were analyzed in this paper. According to the physiological temperature limit, working environment and labor intensity of military vehicle, the temperature safety limit and the critical limit value were proposed. On the basis of the research, the temperature change of military vehicle was studied, and the limit temperature was analyzed, which provides the data and basis for the operation time and safety of military vehicles in hot and humid areas.

Keywords Military vehicle · High temperature and humidity · Limit boundary

1 Introduction

For military vehicles, since most of the bases are made of metal, they have small specific heat capacity and can conduct heat quickly. There is little space inside the vehicle so that the temperature inside the vehicle rises quickly when the vehicle is working in hot and humid areas. When the external environmental temperature is 35 °C, the temperature inside the cabin of a military vehicle can be above 50 °C. After working for a long time in the hostile environment of high temperature and high humidity, personnel in military vehicles may suffer from serious psychological and physiological effects. They may even make large mistakes and reduce working efficiency. Studying the critical tolerance of the operating personnel in the environment of high temperature and high humidity and the degree of influence of thermal environmental parameters on the working efficiency of the crew, evaluating the working capability of the operating personnel in the extreme environment of high temperature and high humidity and taking relevant measures are of important

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significance for improving the working capability of personnel operating in the environment of high temperature and high humidity.

2 Research on the Effect of High Temperature and High Humidity on Personnel in Military Vehicles

The environment with high temperature and high humidity will affect the circulatory system, increase the burden on the heart, result in change of blood pressure and make people dizzy. Moreover, with the action of high temperature and thermal radiation, the movement function of nervous system of regulating center of the cerebral cortex will be restrained seriously. Therefore, operational capability of muscle, accuracy and harmony of actions, reaction speed and attention will decrease. Moreover, high-temperature environment will also act on the physiological functions of the bodies, cause emotional changes, result in fidgety mood, etc. This kind of symptom is called "Psychological heat stroke." The emotional, cognitive and behavior disorders resulting from this will lead to low concentration, work efficiency reduction and other symptoms. These symptoms will be a threat to the safety production of workers in the environment of high temperature and high humidity [1, 2].

Since the working environment of high temperature may reduce people's interest and enthusiasm for work, people may have the mood of boredom and the cells of central nerve may be restrained, which leads to psychological fatigue. Moreover, it is difficult for the body to cool down and people's physiological fatigue may be increased because of working in high-temperature environment. Physiological and psychological fatigue may greatly reduce the crew's working efficiency in high-temperature environment, which mainly reflects in distractibility, poor action stability, declining endurance capacity of body, shortened working hours, etc.

3 Research on Critical Condition of High Temperature Limit of Military Vehicles

The evaluation for the physiological impact of the environment of high temperature and high humidity on human body is an effective way to reduce the threat of thermal environment to human health, prevent heat-induced diseases and injuries, ensure the normal working order and reduce accidents. At present, the physiological indexes of human body closely related to the thermal environment and labor intensity are mainly energy metabolism rate of body (M), oral temperature (OT), heart rate (HR), skin temperature (ST) and the heat storage rate (S) [3]. Its limiting value related to the labor intensity is as shown in Table 1.

Table 1 Physiological tolerance limit of the human body under high-temperature environment

Labor intensity	M (W/m^2)	HR (bpm)	ST (°C)	OT (°C)	S (W/m^2)
Light	170	120	38.1	37.8	23
Medium	270	150–160	38.3–38.8	38.0–38.4	60–80
Heavy	390	170–180	38.7–39.0	38.3–38.6	130

Table 2 Human tolerance schedule under different heat storage conditions

Thermal tolerance	Heat storage capacity (W/m^2)				
	58	117	175	233	292
	Tolerance time (min)				
Have no influence	50	25	15	10	8
Tolerance to maximum	70	35	20	15	10
Critical limits of tolerance	95	50	35	25	15

Among the above indexes, oral temperature (OT), heart rate (HR) and skin temperature (ST) are visual and can be easily measured in the test. For workers of medium labor intensity, if their heart rates reach 150–160 times/min and their oral and skin temperatures reach 38 °C, the their bodies may reach the tolerable critical temperature. At this time, the operators in the environment of high temperature and high humidity shall be warned and asked to stop working to rest in the areas of lower temperature or reduce labor intensity, so as to avoid thermal hazards. When the oral temperature is above 40 °C, the amount of sweat will reduce. Then, the body cannot regulate the body temperature through sweat evaporation and the body temperature begins to rise rapidly. At this time, the workers have lost their working capability generally [3, 4].

Since different kinds of operating personnel have different labor intensity and different situation of heat produced from metabolism, the high-temperature and high-humidity protective field must take thermal balance of the personnel into consideration. Due to the physiological barrier result from heat storage, the working efficiency may be reduced and the health of the personnel may be harmed, so the amount of heat storage can be used to evaluate the tolerable situation and tolerable time of people as shown in Table 2.

Since the heat storage amount of body is not a visual and measurable amount in actual operation, it may bring inconvenience to use. It shall be paid more attention to that actual limiting operating time of personnel of different labor intensity is different under different temperature and humidity. The labor intensity of personnel in military vehicles is generally medium or so. The temperature limits inside military vehicles for the personnel in military vehicles have been clearly specified from the perspectives of labor intensity and operating time, as shown in Table 3.

According to the above researches, the representative values of critical limit for the personnel in military vehicles in the environment of high temperature and high humidity can be obtained: environmental temperature, humidity, heart rate and oral

Table 3 Temperature limit in the thermal environment

Temperature requirement	Temperature limit	Relative humidity	Labor intensity	Operation time	Duty rate
Degradation efficiency	≤36	50–75	260	≤2	≤3
	≤38	≤50	260	≤2	≤3
Safety tolerance	38	>75	Unlimited	≤1	≤1
	41	50–75	Unlimited	≤1	≤1
Tolerance limit	44	>75	Unlimited	≤0.5	≤1
	47	50–75	Unlimited	≤0.5	≤0.5/2

Table 4 Temperature limit of the passenger in military vehicles

Limit condition	Ambient temperature	Ambient humidity	Heart rate	Oral cavity temperature	Working hours
Upper safety limit	38–40	>75	145	38.3	<1
Tolerance limit	>41	>50	174	40	<0.5

temperature of the personnel and the working time that can be adhered to under the upper limit of safety and critical limit. Its limits are shown in Table 4.

4 Research on Limiting Temperature Inside Military Vehicles

Changes in temperature and humidity inside military vehicles are paid attention to in most of the tests. However, there are few researches on long-time changes in temperature and humidity inside military vehicles. To study the temperature changing situation inside military vehicles in hot and humid areas within a day, thick-shell military vehicles and thin-shell military vehicles are selected for window-closing exposure test. During the test, the external temperature changes within the range of 33–38 °C. The temperature testing positions are the positions of the personnel in the vehicle. The temperature changing curve of different military vehicles exposed in sun is as shown in Figs. 1 and 2.

According to the exposure result of the military vehicles, the temperature of each point inside the military vehicles is above 35 °C and the crew reaches the degree of degradation in working efficiency after being exposed in sun with windows closed for more than 1 h. 3 h later, the temperatures of all the personnel points are above 38 °C and the personnel inside the military vehicles reach the temperature of upper safety limit. Four hours later, the temperature inside the military vehicles is above 40 °C and the crew inside the military vehicles reaches the tolerable limit. They will risk their lives if they go on working. After the military vehicles have been exposed

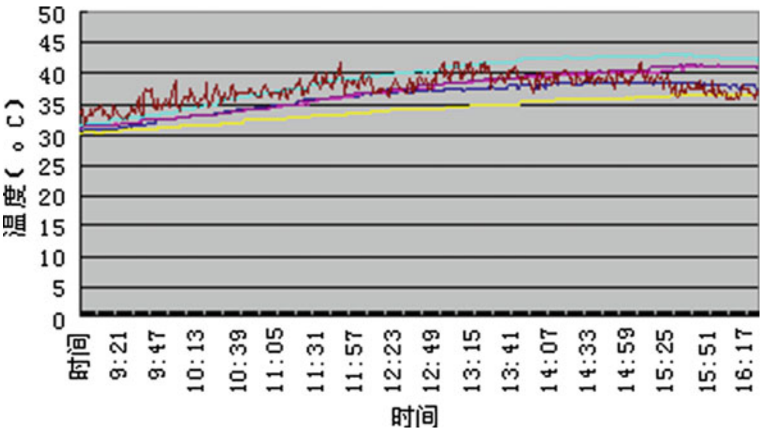

Fig. 1 Temperature variation of armored vehicle

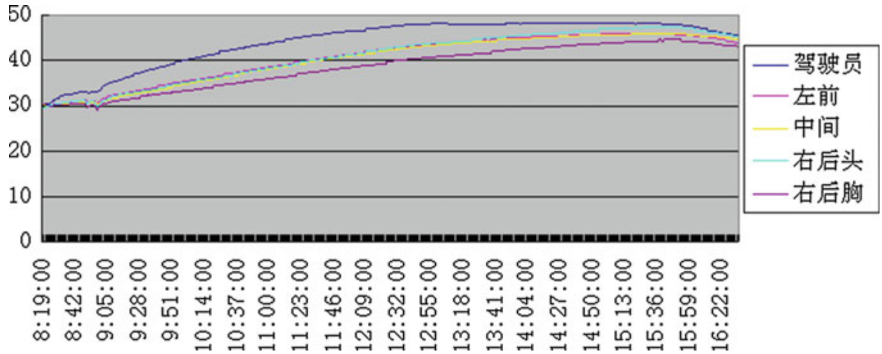

Fig. 2 Temperature variation of Shell of vehicle

in sun for 6 h, the highest temperature of each point of the personnel is about 42 °C with an average temperature inside the military vehicles of about 41 °C. For thin-shell military vehicles, the temperature of each measuring point is above 38 °C, the safety limit of the personnel, after the vehicles are exposed in sun for 1 h and 20 min. The temperature of each measuring point is above 40 °C, the tolerable limit of the personnel, about 2 h later. After the vehicles have been exposed in sun for 6 h, the temperature inside the vehicles reaches the peak of 48.1 °C and the average temperature of the personnel inside the vehicles is about 46 °C.

According to the above data analysis, it is known that the temperature of thick-shell military vehicles will reach the safety limit of the personnel after 3 h because of their thick armors if no cooling measures are taken, and the temperature of thin-shell military vehicles will reach the safety limit of after 1 h because of their thin armors if no cooling measures are taken. If no cooling measures are taken in the above-mentioned military vehicles, it is difficult for the personnel to achieve long-time operation.

5 Research on High-Temperature Protective Measures of Personnel in Military Vehicles

In general, main protective measure for the operating personnel in the environment of high temperature and high humidity is to wear personal protective equipment which mainly refers to protective clothing, working cap, gloves and other clothes with heat resistance, small heat conduction coefficient and good air permeability. The technical measures mainly refer to the thermal insulation, ventilation, cooling and other measures. Health care measures mainly refer to providing the personnel with enough salty drinks, prophylactics, etc.

In recent years, man–machine–environment problems of the military vehicles have attracted more and more attention. Most of the military vehicles have been equipped with air conditioners, fans and other cooling measures. In addition, some near-body cooling technologies for the crew have also been carried out, such as cooling seats and cooling garment. In general, after being equipped with air conditioners and other cooling devices, the temperature inside the vehicles will be kept below 35 °C after the cooling device works for a certain period of time. The personnel shall work safely for 2–4 h in the work efficiency degrading or work efficiency guaranteeing status. Figure 3 is the situation of temperature drop after the air conditioner of the military vehicle has been worked for a certain period of time.

From the figure, it can be seen that the temperature inside the vehicle may quickly drop to below 35 °C with the action of the air conditioner. Finally, the temperature inside the military vehicle will reach below 30 °C, so as to ensure the safety and efficiency of personnel.

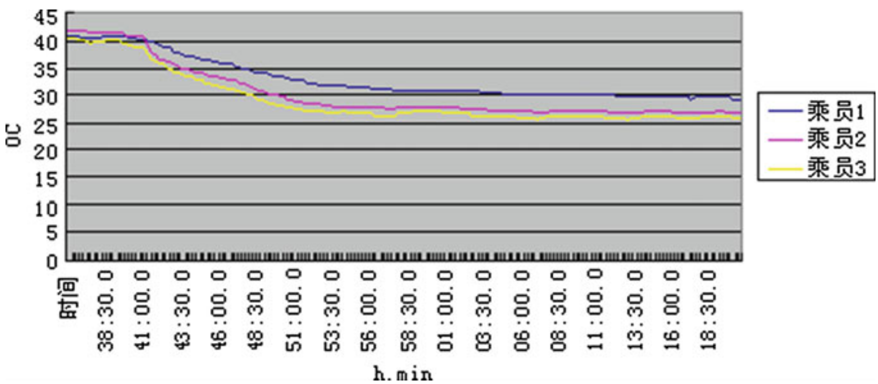

Fig. 3 Temperature drop curve of vehicle in a air condition

6 Conclusion

The paper has studied the limit of physiological safety and the tolerable limiting temperature of personnel under the environment of high temperature and high humidity. Taking the temperature and humidity environment inside the military vehicles and the labor intensity and efficiency requirements of the personnel into consideration, the safety limit and the tolerance limit under testable hot environment can be obtained. Based on this, long-time sun exposure researches have been carried out for some environments of high temperature and high humidity, so as to obtain the limiting temperature for safety and the curve of tolerable temperature of these military vehicles. Finally, the cooling measures of the military vehicles have been evaluated.

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Part VI
Research on the Machine-Environment Relationship

The Impacts on the Operational-Using of a Type of Information System in the Conditions of High-Frigid Mountainous Region

Zuohui Bao, Zuobin Yang, Shukai Liang, Ruijie Yin and Yangke Liu

Abstract Objective: To study the impacts on the operational-using of a type of information system in the conditions of the High-Frigid Mountainous Region. Methods: Analyse the impacts on the operational-using of the system under the environment of the southwest border High-Frigid Mountainous Region, through the field application and the consultative literature. Results: Through the study, it was found that the environment of the southwest border has great impacts on the system maneuver, position disposition, command communications, and safety protection of the system. Conclusion: The factors of High-Frigid Mountainous environment reduce the environmental adaptability of the system, affect the original performance, and provide a basis to further enhance the operational-using capability of the system in High-Frigid Mountainous Region.

Keywords High-Frigid Mountainous Region · A type of information system · Operational-using · Impact

1 Introduction

China's southwest border region has a vast territory, and a lot of countries bordering with thousands of kilometers of High-Frigid Mountainous boundary line, so the operational direction of the High-Frigid Mountainous Region border is an important strategic direction of our army military struggle preparation [1]. Joint operations are the main mode of responding to the southwestern border war in the future. However, a type of information system as the "nerve center" of the joint operation of air defense combat under IT-based conditions, the performance of the system has a critical influence on the process and results of air defense operations. The factors of the cold climate, high mountains and steep slope, deep groove, narrow valleys, bring a lot of difficulties in using of the system, and directly affect

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the performance of the system. Therefore, based on the existing equipment and the special geographical environment, we should strengthen the research on the operational-using of the system in the conditions of High-Frigid Mountainous Region, and it will play a positive role in promoting the effectiveness of the system in the particular operational environment.

2 The Characteristics of the Environment of High-Frigid Mountainous Region

High-Frigid Mountainous Region refers to the plateau region, which is affected by altitude and mountain range with an average altitude above 4000 m, and an average temperature above 0 °C. According to the possible operational requirements, it breaks down into four main parts: the subtropical rainforest mountains in southern Himalayan, the alpine gorge in southern Kailash, the wide valley lake basin in southern Tibet, and the mountains in western Tibet [1].

The environment of High-Frigid Mountainous Region consists of the lack of the resources, complex terrain, changeable climate, the fragile plant cover, terrain conditions, the lack of transportation, and fragmented landform. Compared with the inland and coastal areas, it brings many adverse factors to the warfighter's basic living, the troops maneuver, command and communications, information acquisition, material transportation, battlefield construction, and personnel and equipment security protection [2]. The specific characteristics are as follows.

2.1 Complex Terrain and High Altitude

In High-Frigid Mountainous Region, the mountainous area accounts for 75 % of the total area, and the average altitude is higher. The altitude mostly is above 4000 m in the possible implementation of combat area, with high mountains and steep slope, ravines aspect. The regional distribution of rivers, lakes, swamps, hills and grass area, etc., at the same time, there are more than 60 channels through outward pass, which inclusions in the steep, narrow mountains.

2.2 Bad and Changeable Weather

Climatic conditions in High-Frigid Mountainous Region border area were bad and changed constantly. Main performance: low temperature, large temperature difference between day and night, and the ice period is long; less precipitation, air drying, and snow cover period is long; high wind speed, a wide range, and long duration;

low pressure, hypoxia, and the air is thin; long sunshine hours, solar radiation intensity, and ultraviolet radiation is strong. The region's annual average temperature is below 0 °C, where might be used for the implementation of operations, the day and night temperature difference between 15 and 20 °C, and the maximum difference in temperature is up to 30 °C; the winter ice period lasts for up to six months, the winter average temperature is −12 °C, the minimum is −40 °C, and the annual frost free period is only 90 days; the annual precipitation is 37 mm, and more concentrated from June to September; annual average wind speed is 3.2 m/s, more than 17 m/s wind speed of wind has more than 40 days; the oxygen in the air reduced 30–60 % than the plain areas, the high pressure is just 61 % of the sea level, and the intensity of ultraviolet radiation is higher 40–50 % than the plain area.

2.3 Poor Road Conditions and Traffic Inconvenience

In this region, the number of the roads is too little, and the quality is poor, so that the transportation is inconvenient. Firstly, the number of the railway is less, and the capacity of transportation is limited, so we can not directly reach the area of operations, and still need to motorized and pedestrian relay maneuver; Secondly, the number of the road is scarce, and most of them are easy road, which is below standard level six. The slope steep turn is urgent, the turning radius is small, many hills and the mountains across the valley, visibility is poor, and it's vulnerable to Glacier, mudslides, floods, avalanches, landslides, sand, and other natural disasters, so the traffic capacity of this area is poor.

3 The Impacts on the Operational-Using of the System in the Condition of High-Frigid Mountainous Region

The recent regional wars show that air defense combat to a certain extent is the confrontation between command information system of two sides [3]. The southwest border areas as an important strategic direction of China's preparations for military struggle, however, under the environment of the southwest border High-Frigid Mountainous, the system also has been greatly affected, specifically in system maneuver, position disposition, command and communications, and security protection etc.

3.1 Impact on System Maneuver

The good maneuvering ability is the basic condition for the operation of the system. However, the impacts on the harsh natural environment of the High-Frigid Mountainous Region are inevitable.

1. Low temperature lead to the vehicle is difficult to start, affect the system maneuvering. The altitude of the system vehicle platform technical performance index requirement should be not more than 4000 m. If the altitude is above 4000 m, it will bring mainly problems, such as: Vehicle platform is very difficult to start, the capacity of battery is reduced easily, and the plate load is too large, even damage the battery. The cold temperature will also makes the lubricant viscosity of vehicle platform increases, reduce the mechanical strength of moving parts, and eventually led to pair wear [4]. At the same time, the low temperature conditions also affect the physical function of operational staff, leading to the increase in the preparation time before the system maneuver.
2. Low temperature and hypoxia led to the engine's power reduces, affect the normal ability to play. In the area with an altitude of more than 4000 m, the engine's power fells 30 % on average, and vehicles platform may be difficult to pass through a large slope, ridge, ditch, due to the lack of motivation. When the vehicle platform running in the snow and ice roads, the tires are easy to slip, the average fuel consumption increase by more 15–30 % than in the plain area, and the travel mileage will be significantly reduced, due to hypoxia [5].
3. Poor road conditions and limited motorized road affect the systems in motor speed and bring many security risks. The most serious impacts on the seasons are summer and winter. In summer, there will be more rain, and it will form many water zones; in winter, the snow will block the channels and the mountains. All of those will affect the vehicle platform pass through many sections.
4. Complex terrain and low temperature cause the failure rate of the system increases. The rough and bumpy roads will increase the impact of the mechanical parts of the system, and with the decreasing temperature, the mechanical properties of the rubber seal will show a downward trend, all of those will lead to the moving parts of the system vehicle platform damage.

3.2 Impact on Position Disposition

The position disposition of the system is closely related to air defense combat weapon unit. However, the complex High-Frigid Mountainous Region environment will bring serious influence to the position disposition.

1. The mountainous area, where the ground is little, the battlefield capacity is limited, can be used to set the position of the place is very scarce. Therefore, we cannot accord to the conventional forces into the system deployment disposition.
2. Due to high mountains and steep slopes, large cover degree, and many shooting dead, it's not conducive to effectively combat on the reverse slope target.
3. Rugged road and complex road conditions bring a lot of inconveniences on the occupation of the position, the withdrawal of the position and the choice of reserve positions for the troops. Those can easily lead to combat timing delays, and even make us be attacked by the enemy.

3.3 Impact on Command and Communications

The steep geographical area and the complex battlefield environment, extremely cause the communications "blind spots," and form a communications "dead." In addition, the enemy in the technological means is better than us, so it also brings a lot of command and communications problems [6].

1. The battlefield environment is specially, the application of communication means is limited. In the Mountainous sparsely vegetated alpine mountain environment, it is difficult to meet requirements of the opening playing field, and the convenience of maneuvering and setting up for the communication equipments; wire communication is affected by geographical conditions in High-Frigid Mountainous Region, the erection and maintenance of the route is difficult, and easily be destroyed in the combat; radio communication will suffer large interference by magnetic storms and civilian equipment interference, so that it is difficult to contribute the normal communications; and the simple signal communication is not easy to observe and receive.
2. The operational area is complex, and the performance of communication equipment is reduced. Strict high temperature cold beyond the temperature limits of the equipment normal work and lead to equipment cannot boot properly; the barriers of the mountains can shorten the communication equipment of the effective communication distance. The vagaries of climate and the complex topography, seriously affect the communication equipment of electromagnetic signal detecting disturbance, and the equipments are difficult to achieve the established technical performance.
3. The communication support is blocked, and the command and control of the system are limited. In the environment of High-Frigid Mountainous Region, the communication support of the system is blocked, so that it is difficult to realize the information and command sharing in real-time and the command coordination of the troops, relying on the system. At last, it may eventually lead to the opportunity of combat delay, and affect the results of the combat.

3.4 Impact on Security Protection

In air defense combat under the conditions of informatization, security protection of information system is an important measure to ensure the smooth operation, and improve the system's capability to survive. But the alpine mountain harsh environment caused a great threat for the security protection of the system.

1. Under the conditions of the single and revealing terrain background, the system is not easy to conceal and camouflage, the enemy can be easy to complete the stereo all-weather reconnaissance, and constitute an obvious information advantages.

2. The system may easily be affected by the electromagnetic detection and interference of the enemy. The system equipped with a large number of electronic equipments, so it has the features of strong radiation with itself, and electromagnetic spectrum covering a wide range. Because of those features, the enemy can easily implement listening, positioning, disturbing, and damaging through the technology advantages.
3. The complex terrain brings a lot of inconveniences to maneuver for the troops. When we should divert positions after the combat, we may be affected by the terrain and roads, so that the time of dismantling and evacuation become so long, and we will even become a target.

4 Conclusions

This paper analysis the impacts on system maneuver, position disposition, command and communications and security protection of a type of information system in Alpine harsh climatic conditions, and the complexity of the geographical environment, objectively pointed out problems, and the analysis results can offer some reference for the related department for arguing, developing, producing, and operational-using. Due to the limited knowledge of this aspect, there still exist deficiencies about the study. But through this study, we should clearly recognize that in order to cope with the possible military threat from Southwest China's border areas in the future, we should improve the equipment level and combat capabilities in the High-Frigid Mountainous Region, and study the impacts on operational performance of weapon equipment comprehensively, scientifically and systematically.

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Part VII
Research on the Overall Performance of Man-Machine-Environment System

Virtual Verification System of MME Design for Ship Control Cabins

Kun Yu, Ying Zhang and Shuqin Zhao

Abstract The man–machine–environment (MME) of control cabins has been the very complex system in large-scale ships; it plays a very important role on the efficiency, comfort, safety of ship monitoring and operation. The virtual verification method for MME design of ship control cabins was researched. The main factors of ship control cabins MME were analyzed, and the structure of MME virtual verification method was constructed. The integrated clustering method was constructed to synthetically combine the virtual verification results based on the dominance. The virtual verification system was constructed based on EON, and the development process of virtual verification system was interpreted. Finally, a ship wheelhouse virtual verification case based on EON and virtual hall environment with applying the proposed method was used to prove the effectiveness of this method. It was expected to optimize MME design to improve the operation safety and efficiency of ships.

Keywords Virtual verification system · MME · Ship control cabins · Clustering method

1 Introduction

In the large-scale ships, the control cabins include wheelhouse, centralized control cabin, communication cabin, etc. and the MME design plays a very important role in the efficiency, comfort and safety of ship monitoring and operation. For example, the wheelhouse is the central work area of the ships sailing, concentrating the steering, monitoring, security, lighting, alarms and other human–machine–media. It is prone to the human factors issues working area [1]. In 1992–2005 years, nearly 65 % ferry sea accidents in Greece was due to human factors; in 2000–2006 years, the 73.8 % ships' grounding accidents in Japan involved crews' manipulation,

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outlook, command and other human factors [2]. Therefore, it is necessary to research MME in order to reduce the possibility of human errors in ship control cabins. The USA used the digitized 3D human body model to check the work-space design in the air carriers [3]; the USA used the digital design techniques for ergonomic assessment of tenders; CATIA platform was used in the cabins habitability assessment [4] and control panel layout simulation assessment [5]; visual simulation technology was used in equipment layout assessment for wheelhouse [6]. It proves that the virtual verification technology research for ship MME design is valuable. In this research, virtual verification method for MME design of ship control cabins was researched, and virtual verification system was constructed based on EON.

2 The MME Virtual Verification Method

The MME virtual verification method was based on the visual simulation model, verification indicators and integrated clustering model, to get verification data, combined with the design criteria to analysis and optimization, in order to improve design quality of ship control cabins MME. Figure 1 shows the main factors and structure of MME virtual verification method for ship control cabins.

1. The visual simulation model not only focused on engineering and scientific, but also required visual esthetic. It achieved the cab geometry, color, texture, lighting, exterior ocean, waves, sky, islands and natural ambient lighting visual simulation; the alarm equipment, running noise and waves noise in the ship control cabins; and the steering wheel, telegraph handle, doors, chairs and other motion simulation.
2. According to the visual, auditory information, combining with participants' own judgment, to achieve the assessment of subjective suitability, matching expectations and emotional experience, for the equipment, sight, color, lighting and the overall environment in control cabins.

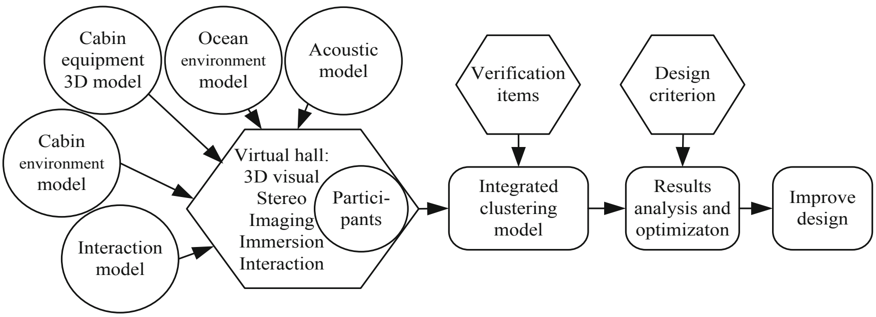

Fig. 1 The main factors and structure of MME virtual verification method for ship control cabins

3. In order to overcome the limitations of computer window screens, using three-dimensional stereoscopic display environment to improve true feelings of audiovisual information in control cabins.
4. A fuzzy clustering model based on dominance was proposed. The clustering model was constructed to exactly calculate the final result from verification data.

3 The MME Virtual Verification System

3.1 Development of Virtual Verification System Based on EON

The virtual verification system for MME design of ship control cabins was constructed based on the visual simulation platform EON. EON has advanced interactive design interface, including object modeling module, rendering module, interactive behavior module, immersive analog module and combined script, EON SDK to program complex interactive behavior model [7]. Figure 2 is the interaction virtual simulation model for ship control cabins.

The virtual verification information of ship control cabins MME mainly depends on participants' visual and auditory. The virtual verification system requires: ① It has realistic internal visual and auditory environment in ship control cabins; ② it has realistic external sea, sky and natural lighting environment; ③ it has interactive behaviors, such as simulation environment roaming and observation angle switching. Figure 3 is the development process of virtual verification system.

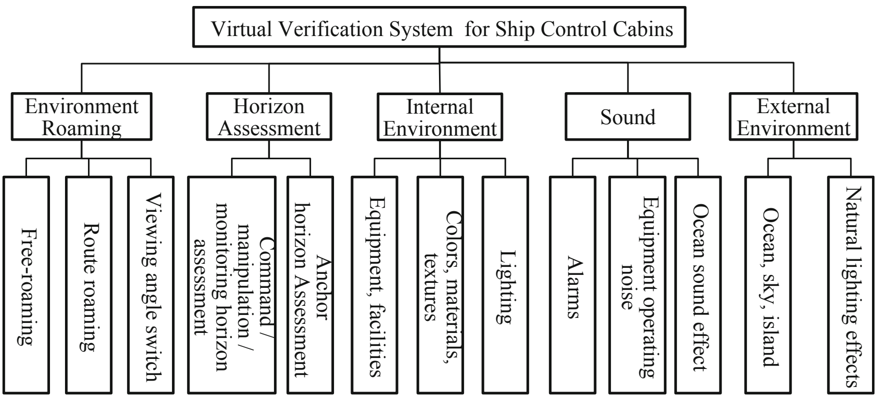

Fig. 2 Basic interaction virtual simulation model for ship control cabins

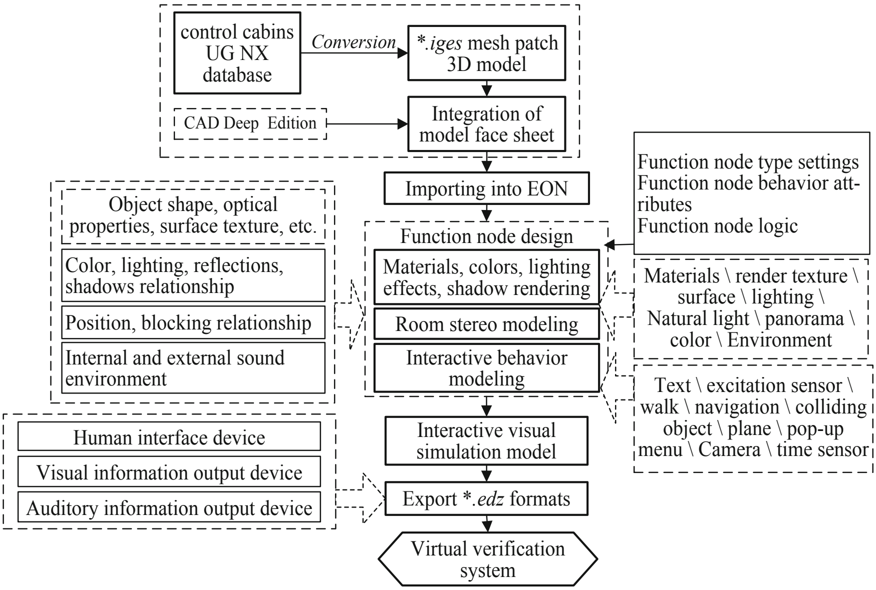

Fig. 3 The development process of virtual verification system based on EON

3.2 The 3D Model Construction

First, the 3D model database of ship control cabins was developed using UG NX. Then, the 3D model database was converted into *.iges mesh patch format. For UG NX, models contain lots of curves, surfaces and rounded face; the converted *.iges models have a huge number of points, lines, polygons sheet elements. Therefore, the CAD Deep Edition was used to optimize the *.iges models, in order to avoid *.iges models taking up too much system resources. The optimized control and display devices, control consoles, seats and other marine facet model were imported into EON to assembly object shape environment of ship control cabins.

3.3 The Visual Simulation Model Construction

First, prepare texture images for the geometric model of ship control cabins. The texture images were attached to model geometry surfaces, adjusting offset, tiling and rotation UVW angle to ensure precisely matching to face sheet, to describe the detail texture of ship control cabins' equipment. Then, rendering the material, color, lighting effects of model surface, and combine the geometric entity information, hierarchical structure information, location information and material, etc. To ensure the realistic feelings on vision of the participants.

3D auditory model of ship control cabins was primarily constructed based on internal alarm, voice command, equipment operation noise and external sound effects and other related natural sea noise environment. EON direct-sound note techniques were used to develop the room stereo model, establish the initial and the second sound source of ship control cabins and simulate room echo effect, resulting in true feelings of the auditory organ in sound distance, direction, orientation, propagation attenuation and reflection.

3.4 Simulation Model Driven

EON interactive behavior agent nodes use kinematics to transform basic moving translation, rotation, using dynamic simulation method to calculate the object physical interactions effects of inertia, torque, etc., to generate more complex and realistic movement. Interactive mode includes latch, keyboard, click-sensor nodes, to receive participants' input information, and output the feedback information; walkabout node operating simulates sports scene walking, running action according to the participants' visual; collision object node simulates collision effects between participants and geometric objects. Figure 4 is the interaction logic design case based on agent nodes for wheelhouse.

4 The Integrated Clustering Method

In the virtual verification, it is very important to develop a data processing method for integrating and understanding the virtual verification results. In this research, the fuzzy interval numbers were used to collect the initial virtual verification data; fuzzy clustering function was used to analyze the membership analysis of the initial

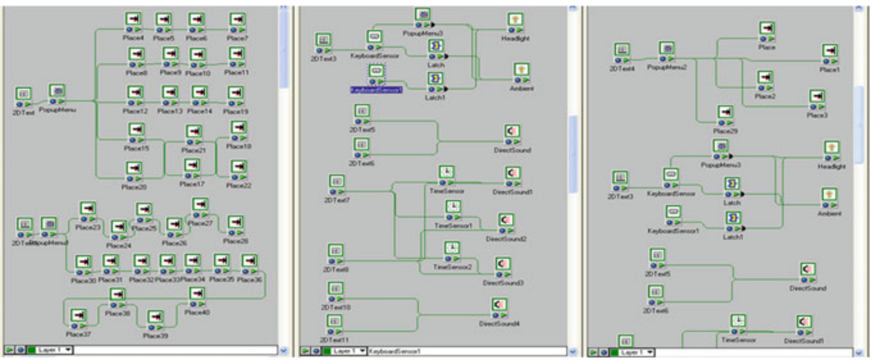

Fig. 4 Interaction logic design case based on agent nodes for ship control cabins

virtual verification data; the sorting method based on the dominance was used to sorting the interval membership [8]. First, construct the clustering result grades set for the initial virtual verification data. $G_{\text{set}} = [(g_1^1, g_1^2, g_1^3), (g_2^1, g_2^2, g_2^3), \ldots, (g_k^1, g_k^2, g_k^3)]$, in which, $g_i = (g_i^1, g_i^2, g_i^3)$ was triangular fuzzy numbers, $g_i^1 \le g_i^2 \le g_i^3$. The expected value was used to excavate the focus of triangular fuzzy numbers, and $g_i^{(\alpha)} = f(\alpha_1 g_i^1, \alpha_2 g_i^2, \alpha_3 g_i^3)$ was the expected value for g_i. The fuzzy clustering function was used to construct the integrated clustering by linking the $(g_i^\alpha, 1)$ of the ith result grade with $(g_{i-1}^\alpha, 0), (g_{i+1}^\alpha, 0)$. The constructed $f^i(i = 1, 2, \ldots, k)$ was shown as in (1.1).

$$f^i(x) = \begin{cases} 0, & x < g_{i-1}^\alpha \\ (x - g_{i-1}^\alpha)/(g_i^\alpha - g_{i-1}^\alpha), & g_{k-1}^\alpha \le x < g_k^\alpha \\ (x - g_{i+1}^\alpha)/(g_i^\alpha - g_{i+1}^\alpha), & g_i^\alpha \le x \le g_{i+1}^\alpha \\ 0, & x > g_{i+1}^\alpha \end{cases} \tag{1.1}$$

Construct the sorting model based on the dominance for interval membership of the initial virtual verification data. $C = [c_1, c_2, \ldots, c_n]$ was nth interval membership, set $c_{\max} = [c_m^1, c_m^2]$ was maximum interval membership dominance of c_i, and c_m^2, c_m^1 was shown as in (1.2). And the dominance D_{ij} of $c_i \succ c_j$ was shown as in (1.3).

$$c_{\max} = \left[c_{\max}^1, c_{\max}^2\right] = \left[\max_{i=1,\cdots,n}\left\{c_i^1\right\}, \max_{i=1,\cdots,n}\left\{c_i^1, c_i^2 \backslash c_{\max}^1\right\}\right] \tag{1.2}$$

$$D_{ij} = \frac{\sqrt{\left(c_{\max}^1 - c_j^1\right)^2 + \left(c_{\max}^2 - c_j^2\right)^2}}{\sqrt{\left(c_{\max}^1 - c_i^1\right)^2 + \left(c_{\max}^2 - c_i^2\right)^2} + \sqrt{\left(c_{\max}^1 - c_j^1\right)^2 + \left(c_{\max}^2 - c_j^2\right)^2}} \tag{1.3}$$

Calculate the dominance matrix of C_{set} to get $R = (r_1, r_2, \ldots, r_n)^{\mathrm{T}}$, in which $r_i = (\Sigma 1/D_{ij} - n)^{-1}$. According to the integrated clustering method and sorting model, we can get the final clustering result.

5 MME Virtual Verification Instance

As an instance of a 17,000 tons large vessels, the developed MME virtual verification system for wheelhouse as shown in Fig. 5. Based on the EON visual simulation verification model, the virtual hall environment with multi-channel cylindrical screen projection system, the liquid crystal shutter glasses and stereo sound were used to enhance the true feelings of participants' visual and auditory. Figure 5a–c is the developed MME virtual verification system for this wheelhouse based on EON and (d) is based on the virtual hall environment.

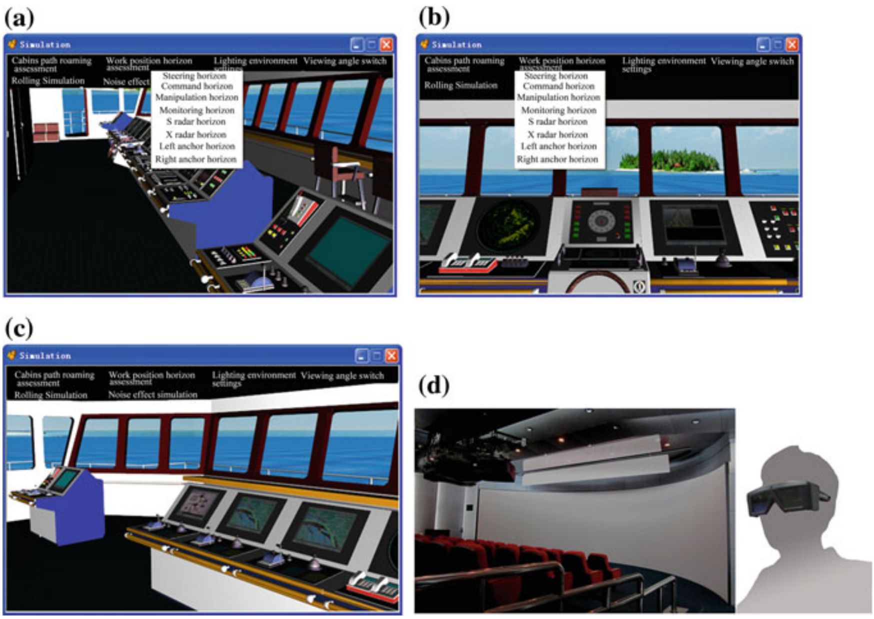

Fig. 5 The developed MME virtual verification system for this wheelhouse based on EON and virtual hall environment

In the cases, the clustering results set G was divided into five categories: $G = \{\text{failed}(1), \text{passed}(2), \text{medium}(3), \text{good}(4), \text{excellent}(5)\}$, with ten participants involved. For five issues, the corresponding triangular fuzzy numbers in the clustering model were $f^1([0,1,2])$, $f^2([2,3,4])$, $f_3([4,5,6])$, $f^4([6,7,8])$, $f^5([8,9,10])$. The fuzzy interval numbers comments set for 5 issues is shown in Table 1.

Table 1 The fuzzy interval numbers set of five issues by 1ten participants

1	2	3	4	5
[7.5,7.9]	[9.0,9.5]	[4.5,5.4]	[6.6,7.3]	[3.0,3.5]
[6.7,7.5]	[8.2,8.7]	[5.2,5.6]	[6.5,7.0]	[3.1,3.9]
[6.4,6.9]	[8.6,9.2]	[5.5,6.5]	[6.5,7.2]	[2.5,3.4]
[6.4,7.1]	[9.3,9.5]	[5.0,6.2]	[7.4,7.7]	[3.3,4.4]
[7.2,7.5]	[8.6,9.4]	[5.6,6.5]	[7.4,8.0]	[3.4,3.9]
[6.4,7.1]	[8.7,9.3]	[4.4,5.0]	[6.6,7.1]	[3.5,4.2]
[6.8,7.5]	[9.2,9.7]	[5.7,6.5]	[6.8,7.6]	[2.8,3.5]
[6.1,6.9]	[8.6,9.2]	[4.9,5.8]	[7.1,7.5]	[3.0,3.6]
[7.2,7.6]	[9.1,9.6]	[5.8,6.5]	[7.0,7.0]	[3.1,3.6]
[7.4,7.9]	[9.2,9.4]	[5.2,6.2]	[6.6,7.4]	[3.1,3.8]

The R of fuzzy interval numbers as follows:

$$R = \begin{bmatrix} 0.192 & 0.192 & 0.143 & 0.021 & 0.132 \\ 0.192 & 0.192 & 0.143 & 0.021 & 0.443 \\ 0.211 & 0.192 & 0.301 & 0.032 & 0.181 \\ 1.000 & 0.223 & 0.284 & 0.900 & 0.130 \\ 0.211 & 1.000 & 0.143 & 0.033 & 0.130 \end{bmatrix}$$

According to the principle of maximum, the final result was $[4, 5, 3, 4, 2]$: issue 1 was good, issue 2 was excellent, issue 3 was medium, issue 4 was good, issue 5 was passed.

6 Conclusions

The MME design of ship control cabins can obviously affect operators' efficiency and operation safety. The virtual verification system of MME for the ship control cabins was studied in this paper. The structure of MME virtual verification method for ship control cabins was analyzed, and the interaction virtual simulation model for virtual verification was constructed. The virtual verification system for MME design of ship control cabins was developed based on EON. The development process of virtual verification system was researched and introduced. An integrated clustering model based on dominance was proposed. The clustering model was constructed to exactly calculate the final clustering result among verification data. With applying virtual verification system in MME design, the MME design defects of ship control cabins can be discovered in time. It was expected to optimize MME design to reduce operation burden of operators and to improve the operation safety of large-scale ships.

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Analysis of Safety Investment and Safety Benefit in Coal Enterprise

Yan Li, Jingman Li and Jianping Jiang

Abstract In China, coal mine accidents occurred frequently in recent years. So this paper tried to find the equilibrium point between the study of safety investment and safety benefits in coal enterprises, by using a combination of t theoretical analysis and empirical analysis methods. We discussed and analysed the safety investment and benefits of coal enterprises with more serious problems. By using DEA data envelopment analysis method, we established the model for discussing the safety and the efficiency, and we analysed the production situation of 15 coal mines of Shaanxi Province in 2010 and drew results and suggestions in order to provide a reference for enterprises to obtain maximum security benefits.

Keywords Safety inputs · Safety benefits · Coal enterprises · Data envelopment analysis (DEA)

1 Introduction

In 2011, China's coal production exceeded 35 tons, becoming the world's largest coal producer, and in 2012 China's coal production increased by 4 % over the previous year, while China's coal output has maintained a leading place, but behind all the accomplishments, the coal mine accidents still occur frequently; one of the influencing factors of the accident is how big safety input is.

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We need to further understand and analyse the factors that influence the safety input, so as to improve the safety and efficiency of coal enterprises [1]. Qian Yongkun et al. proposed safety input cost model, and have used it to interpretate the effect of the government regulation of township coal mine number on production safety [2]. Xie Donghui et al. hold that security has been divided into two categories: the strategic security investment in the prevention of health care and the non strategic investment [3]. Li Hongxia, Tian Shuicheng study the relationship between the output of coal mine safety and economic benefits and coal mine safety input, and analysed the role of safety economic benefit analysis and the ways to improve [4]. K.S.Son, the best research on security investment of Korean Enterprises [5]. Scott Farrow and others, permeate a safe investment management philosophy into the mainstream, such as "safety first", "an ounce of prevention value, a pound of cure", which vividly reveals the prevention was a safe investment, and will be of great value and returns [6].

In order to study the safety investment and optimization more directly, this paper mainly selects two methods of empirical analysis and structural equation modelling analysis.

2 Construction of DEA Model

Suppose there are n DMU, and each DMU has an m input and an s output, in which the input vector is $\chi_j = (\chi_{1j}, \chi_{2j}, \ldots \chi_{mj})^{\mathrm{T}}$, and the output vector is expressed as $y_j = (y_{1j}, y_{2j}, \ldots y_{sj})^{\mathrm{T}}$, $j = 1, 2, \ldots n$.

$$h_j = \frac{u^{\mathrm{T}} y_i}{v^{\mathrm{T}} \chi_j} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{mn} v_i \chi_{ij}}, \quad j = 1, 2, \ldots n. \tag{1.1}$$

And we are trying to find the right weight, making $h_j \leq 1, j = 1, 2, \ldots n$ to determine whether the decision-making unit is effective, and through analyze the data, the greater h_j means the j_{th} decision making unit uses fewer inputs to get more output. So we can evaluate the decision-making unit, to determine whether it is effective, so as to carry out a detailed analysis [7].

The general application of the DEA approach is: to determine the purpose of assessment, select the decision-making unit (DMU), create an input/output index, select the DEA model, and carry out DEA analysis [8]. Data envelopment analysis (DEA) is based on DMU on both the input and output data, through the establishment of an effective model to evaluate. As the input of negative index should be as little as possible, and output indicators are positive signs, so the more value, the better. It derived the relative efficiency of each evaluation object of quantitative indicators through C^2R model, in order to determine whether the DEA is effective.

2.1 DEA Model Construction of Safety and Benefit in Coal Enterprises

In order to make further research from the concrete theory and real economy, we need to introduce the corresponding theoretical basis, which belongs to the range of linear programming of these need slack variable S^+ and surplus variable S^-, and make the inequality into: min θ

$$s.t.\begin{cases} \sum_{j=1}^{n} \lambda_j \chi_j + s^+ = \theta_{\chi 0} \\ \sum_{j=1}^{n} \lambda_j \chi_j - s^- = y_0 \\ \lambda j \geq 0, j = 1,2,\ldots m. \\ s^+ \geq 0, s_- \geq 0, \theta\text{无约束} \end{cases} \tag{1.2}$$

Here θ is relative efficiency; n is the number of decision units; λ is the coefficient of each decision-making unit; χ_j is the input of the jth decision unit; y_j is the output of the jth decision unit, then:

1. If $\theta = 1$, and $S^+ = 0, S^- = 0$, then the decision-making unit DEA is effective, and this kind of production condition is the best.
2. If at least one input or output slack variable is greater than 0, the decision-making unit is weak DEA effective.
3. If $\theta < 1$, the decision-making unit is not effective for DEA.
4. λ_j can be used to represent the proportion of income. If $\Sigma\lambda_j = 1$ is established, the scale of the decision unit returns the same; $\Sigma\lambda_j < 1$, it indicates that the size of the decision-making unit is increasing, and $\Sigma\lambda_j > 1$ indicates that the scale of diminishing returns.

In short, DEA is a relatively effective method of evaluation between the input and output of a department. By this method, you can help make decision of safety data project investment in terms of the safety input and output mode of coal mine, and such analysis can provide effective economic method for the enterprises to conduct a comprehensive study. In the choice of the DEA model, we study the safety investment value, and in the choice of the C^2R model, we used slack variables based on the output calculated. By this method and based on actual situation, we can find that, for the coal enterprises in the future, rational utilization and management of each resource, can we maximize the function and achieve the maximization of benefit.

2.1.1 Analysis Process by DEA

We have selected 15 coal enterprises in Shaanxi Province, the input and the output values of each decision making unit in 2013 as shown in Table 1. The data were obtained through China's Coal Resources Network (Table 1).

By using Integer Programming Linear, we can get the results shown in Table 2 in the quantitative analysis system software (winQSB, Quantitative Systems for Business). Among them, $S_1, S_2, S_3, S_4, S_5, S_6, S_7$, are the slack variable, the value of θ is the relative efficiency, λ is the coefficient of the decision-making unit. From fourth DEA analysis, we will get all enterprises being DEA effective.

After getting all the companies being DEA effective, we can adjust the data of these enterprises as shown in Table 3.

3 DEA Evaluation Result Analysis

1. Based on the above analysis, only the 6 businesses being effective in the first DEA analysis stay at the ideal state, and none of the others reach the relative efficiency of 1, while among the ones that did not reach the effective enterprise, Shaanxi Fanjiahe Coal Mine, Shaanxi Dongfeng Coal Mine, Shaanxi Hongshiyan Coal Mine, Shannxi Nanjiazui Coal Mine, Shannxi Shenmu County Mini-Coal Mine have witnessed decreasing profits; though they are in the best production status, they did not reach DEA and effective. There are several other enterprises that did not reach DEA effectively and are still in the stage of decreasing returns to scale, which are neither best in production stage, nor effective.
2. Through the 15 coal enterprises, we can clearly understand that the majority of enterprises did not accomplish the DEA effectively and safety investment is not up to the standard. It is also the coal enterprises' widespread phenomenon this year in Shaanxi Province, and we should pay attention to this phenomenon and make proper adjustment to change:

   First of all, we can consider further reform, on the one hand, to expand the scale of enterprises and, on the other hand, to implement human resource management, reduce staff honour and improve work efficiency;
   Secondly, we measure security investment standards correctly. Based on the fact that different environments of enterprises in Shaanxi Province carry out the appropriate investment strategy to capture the balance between input and output,

Table 1 Input and the output values of each decision-making unit in 2013

Decision-making unit	Index of input				Index of output		
	Total assets/thousand RMB	Number of employees/person	Safety investment/ thousand RMB	R&D/Thousand RMB	Coal production/ thousand tons	Million tons/death rate	Net income/thousand RMB
Fanjiahe Coal Mine	52,901	510	3835	7432	445	0.043	2660
Beimafang Coal Mine	64,798	809	490	0	520	0.03	4325
Dongfeng New Coal Mine	55,392	662	6379	5116	511	0.042	4109
Zhenba Coal Mine	72,577	1201	4968	2308	788	0.006	7443
Hanzhong Coal Mine	83,302	791	4480	6745	523	0.014	4503
Dajin Coal Mine	61,021	1103	3021	3392	633	0.4	2501
Hongshiyan Coal Mine	27,945	370	2991	2003	450	0.087	2392
Huanglingdiantou Coal Mine	55,930	1020	4099	3122	599	0.034	6112
Huangling Mining Co. LTD	41,706	918	3725	665	5387	0.019	4024
Nanling Mining Co. LTD	81,849	925	2553	90	3097	0.035	2408
Nanjiazui Coal Mine	29,999	434	1089	1928	2837	0.37	3470
Wuyi Coal Mine	55,143	893	4032	2711	2246	0.048	3375
Shenmu County Mini-Coal Mine	86,031	941	8002	4757	2006	0.071	3254
Binchang Coal Investment Co. LTD	77,433	782	6033	4661	4098	0.035	4776
Binxian Coal Mine	63,221	660	4432	900	6022	0.5	5901

Table 2 DEA fourth analysis results

Decision variable	θ	$\sum_{j=1}^{15} \lambda_j$	Slack variable							Returns to scale
			Index of input				Index of output			
			S_1	S_2	S_3	S_4	S_5	S_6	S_7	
Fanjiahe Coal Mine	1	1	0	0	0	0	0	0	0	Invariant
Beimafang Coal Mine	1	1	0	0	0	0	0	0	0	Invariant
Dongfeng New Coal Mine	1	1	0	0	0	0	0	0	0	Invariant
Zhenba Coal Mine	1	1	0	0	0	0	0	0	0	Invariant
Hanzhong Coal Mine	1	1	0	0	0	0	0	0	0	Invariant
Dajin Coal Mine	1	1	0	0	0	0	0	0	0	Invariant
Hongshiyan Coal Mine	1	1	0	0	0	0	0	0	0	Invariant
Huanglingdiantou Coal Mine	1	1	0	0	0	0	0	0	0	Invariant
Huangling Mining Co. LTD	1	1	0	0	0	0	0	0	0	Invariant
Nanling Mining Co. LTD	1	1	0	0	0	0	0	0	0	Invariant
Nanjiazui Coal Mine	1	1	0	0	0	0	0	0	0	Invariant
Wuyi Coal Mine	1	1	0	0	0	0	0	0	0	Invariant
Shenmu County Mini-Coal Mine	1	1	0	0	0	0	0	0	0	Invariant
Binchang Coal Investment Co. LTD	1	1	0	0	0	0	0	0	0	Invariant
Binxian Coal Mine	1	1	0	0	0	0	0	0	0	Invariant

we can improve the efficiency of asset utilization and reduce the cost of enterprise;

Thirdly, for DEA ineffective enterprises, the management should account safe investment and accident loss clearly and accurately, in order to realize more effective and accurate cost control and inspection of safety and security benefits;

Finally, the 9 coal companies that did not achieve the effective in the first time DEA in Shaanxi Province, they both ignored the development of science and technology.

According to the analysis, we can see that in Shaanxi Province, the coal enterprises need to improve the overall efficiency of production safety and rational allocation of resources, and to reduce the redundant staff, and they should also increase investment in research and development, reduce the rate of accidents, master the use of advanced science and technology, improve the efficiency of coal enterprises, and enable input to achieve the ideal state of the safety of coal enterprises in Shaanxi Province.

Table 3 Values of each decision-making unit after DEA4

Decision-making unit	Index of input				Index of output		
	Total assets/ thousand RMB	Number of employees/person	Safety investment/ thousand RMB	R&D/Thousand RMB	Coal production/ thousand tons	Million tons/death rate	Net income/ thousand RMB
Fanjiahe Coal Mine	34,613.12	333.69	1190.35	1764.70	445	0.068	3750
Beimafang Coal Mine	47,568.21	593.88	40.709	0	520	0.03	4303
Dongfeng New Coal Mine	29,125.11	159.17	3354.07	1114.04	511	0.042	4109
Zhenba Coal Mine	72,577	1201	4968	2308	788	0.006	7443
Hanzhong Coal Mine	83,302	791	4480	6745	523	0.014	4503
Dajin Coal Mine	21,223.10	149.75	1050.70	1133.92	633	0.4	4590
Hongshiyan Coal Mine	21,542.80	285.22	904.201	939.020	450	0.087	3421.8
Huanglingdiantou Coal Mine	55,930	1020	4099	3122	599	0.034	6112
Huangling Mining Co. LTD	41,706	918	3725	665	5387	0.019	4024
Nanling Mining Co. LTD	54,863.38	260.98	1711.27	29.5378	3097	0.035	4517.2
Nanjiazui Coal Mine	15,830.47	70.311	574.665	908.905	2837	0.37	3470
Wuyi Coal Mine	19,250.42	311.74	1173.66	450.000	3413	0.048	3375
Shenmu County Mini-Coal Mine	66,665.42	397.06	6200.74	1636.51	4055.6	0.071	4842.7
Binchang Coal Investment Co. LTD	77,433	782	6033	4661	4098	0.035	4776
Binxian Coal Mine	63,221	660	4432	900	6022	0.5	5901

4 Conclusion

The purpose of this paper is to establish a safe investment and to find the key areas for the efficiency and security of the enterprises. According to the data envelopment analysis method, we come to the following conclusions:

1. Through theoretical analysis and considering the actual situation, by using security input system, we found that, the relationship between input and output was increase security investment, means improve security benefits.
2. Under data envelopment analysis method, we took 15 coal enterprises as decision-making units, with the help of the different data analysis obtained in Shaanxi Province 15 coal enterprises safety investment benefit level in 2010, we got the direction to pursue safety benefit maximum. Research results are that the coal mining enterprises are becoming clear of their safety investment direction and content.

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Subway Crowded and Stampede Neural Networks Safety Assessment Basing on SHEL Model

Qiquan Wang

Abstract Abnormal crowded subway is extremely easy to cause the stampede accidents. This paper made typical stampede accident analysis and statistics in recent years to conclude the subway crowded stampede influencing factors. Then introducing the SHEL model, centered on human factors it is researched to study the relationship between personnel, hardware, software and environment causing the subway crowded stampede. In view of the characteristics of fuzzy, incomplete and uncertain of analysis object data, it introduces the BP artificial neural network. And an instance subway station is chosen as an analysis example to quantitative study training as well as fitting of crowded stampede process. The analysis results show that there is risk in Liveware–Liveware(L–L) and Liveware–software(L–S), which has been verified in the actual operation of the instance subway station. The crowded shoving, collision, quarrels in the instance subway often occur. But the management measures of the subway station traffic grooming are limited and the grooming effectiveness is little. Therefore, using BP neural network evaluation method to construct the comprehensive assessment system, based on the SHEL model, can quantitatively assess the crowded subway stampede accident risk, so as to promote the safety of metro operation to provide basis for decision making.

Keywords Subway · Crowded and stampede · Neural networks · SHEL · Safety assessment

1 Introductions

Subway traffic has the advantage of convenient, fast, stable, large volume as a modern of transport. Around the world in the modern city, the subway traffic has get more and more widely used, which even become an iconic facility of modern urban civilization. The subway, as a modern urban rail transport, bears the more and

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more important passenger transport task. The lower cost of subway attracted more and more people to come in, making the subway become unprecedented crowded [1]. Because of the subway traffic and narrow space, which equipped all the necessary conditions of the stampede occurred (people, more crowded, closed, changeable), if there are extend causes to people's psychological panic, it will be very prone to stampede and the situation will be difficult to control in the case of extremely crowded [2].

Subway crowded stampede causes serious consequence which is often become a subway mine accident. Its political influence and economic damage are extremely shocking and alarming [3]. Especially after the "3.29" Moscow subway bombings accident shocked the world, the subway security has sounded in our country. In our country, especially in commuter traffic during peak hours, the subway is in a state of overload operation basically, bringing challenge to the stability of the facilities. How to effectively prevent and control the subway crowded stampede has aroused the government's high attention.

Because foreign metro traffic density is relatively small, the subway crowded stampede is relatively rare. So research focused more on the subway fire risk analysis and emergency evacuation [4], including the research of cluster panic behavior [5] and the ability of evacuation action research [6]. British SERT center puts forward the concept of ORSET model, and developed a lot of personnel evacuation models: the NIST researchers taking the research on safety evacuation, discussing personnel's psychological reaction; Japan pays attention to combining the fire statistics personnel behavior and evacuation safety assessment methods, the fire risk assessment and performance-based design [6]. At home, environment college of Nankai University and urban public security research center proceed key technology research of urban typical public situation and facilities risk assessment and analyze the crowded stampede in public places in the urban [7]. And characterize the highly crowd gathered parameter with "cluster index." And do the system analysis on the factors affecting the public crowded stampede, and then put forward the counter measures to prevent. The topics ("system and evaluation method research," "public gathering places the export ability of emergency evacuation," "subway network operating personnel evacuation system research") carry out the basic relevant research, aiming at subway passenger flow safety early warning mechanism [8]. These studies focus on the basis of mathematical statistics theory with statistical analysis data from the past crowded stampede to conclude the influence of artificial factors on the crowded stampede although this method is effective. It cannot adapt to the dynamic changes in the environment [9].

This paper according to the result of 18 typical stampede accident statistics in recent years concludes the subway crowded stampede influencing factors. It uses the system safety engineering ideas with the perspective of risk management, introducing the SHEL model [10], centered on human factors to study the relationship between personnel, hardware, software and environment causing the subway crowded stampede. In view of the characteristics of fuzzy, incomplete and uncertain of analysis object data, it introduces the artificial neural network. Through quantitative study training as well as fitting of crowded stampede process, it broadens the subway crowded stampede risk assessment method and solves difficult technical problems due to incomplete information in the process of risk assessment and evacuation. And it is applied to the analysis of the security situation in the actual subway station. Through the training and testing, the predicted results comply with basic security situation in subway station, which means the evaluation method worth widely used in the subway crowded stampede risk assessment.

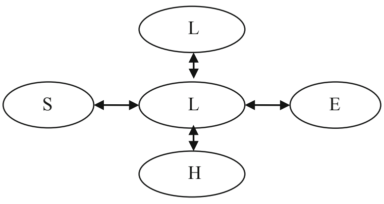
2 Neural Network Assessment Method Based on the SHEL Model

2.1 Subway Crowded Stampede SHEL Model Building

Professor Edward proposed the SHEL model of safety work for the first time in 1972 and points out the principle of people's specific system interface. These interface component elements include: Liveware, software, hardware and environment. Person is core of this model. The four interface of this model are Liveware–Liveware (L–L), Liveware–software(L–S), Liveware–hardware (L–H) and Liveware–environment (L–E) [10]. Liveware–Liveware (L–L): Refer to the relationship of personnel in the workplace, such as operation people, equipment maintenance personnel and passengers. Liveware–hardware (L–H): Refer to the interaction between such as personnel and equipment, implement, places. Liveware–software (L–S): Refer to the relationship between personnel and the support system on its activities, such as safety rules, emergency instructions and hidden dangers rectification list. Liveware–environment (L–E): Refer to the relationship between personnel and the internal as well as external environment. The internal environment includes temperature, surrounding environment, noise and vibration, and the external environment includes political and economic restriction.

The interface must work together; otherwise, the system cannot function. As shown in Fig. 1, the human factor in the center position, in order to reduce the

Fig. 1 SHEL model



impact pressure of staff performance, must understand the interaction between people in center and other factors in the box.

Based on the SHEL model, the author do the statistical analysis and research about the subway typical crowded stampede occurred since 2006. It is concluded that there are a total of 13 direct cause crowded stampedes. Subway crowded stampede occurred mainly in commuting time, relatively concentrated period of time on holiday. And it happened in places that mainly includes the escalator, transferring to up and down the stairs and the import and export. Based on the idea of safety system engineering, the SHEL model can be obtained as follows:

Liveware–Liveware (L-L): Mainly relates to crowded, stampede, retrograde flow, falling collision and quarrel;
Liveware–hardware (L-H): Mainly relates to the elevator breakdown, road slippery and short circuit, power off;
Liveware–software (L-S): Mainly involved in emergency managements imperfection, information to deliver wrong, bring/put items, etc.
Liveware–environment (L-E): Mainly involves lighting defects and bad weather;

After the analysis of the above four factors of subway stampede, safety assessment SHEL model of subway stampede is built, as is shown in Fig. 2.

In Fig. 2, the prevention system of subway stampede is shown by function $F(S, E)$, and $S = (s1, s2, s3, s4)$ indicates the control measure of Liveware, hardware, software, environment, $E = (e1, e2)$ indicates the static and dynamic assessing index, $(f1, f2, \ldots ft)$ indicates the subsystem of the prevention system of subway stampede, and $f(tk)$ indicates the dynamic feedback function.

2.2 The Subway Crowded Stampede Safety Assessment of Neural Network Modeling

The author introduced neural network evaluation method based on the SHEL modeling to do the metro crowded stampede safety assessment. When data has the characteristics of fuzzy, incomplete and uncertain or a lack of a clear mathematical

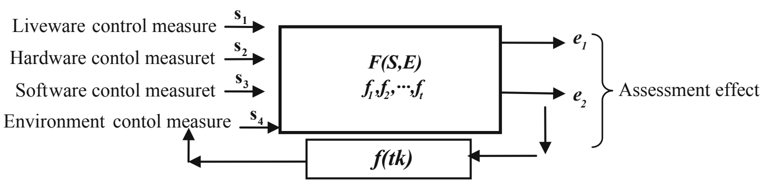


Fig. 2 Safety assessment model of subway stampede

algorithm, we can use neural network evaluation method, through training, to analyze and make a quantitative, objective analysis and conclusions.

2.2.1 The Steps of Setting up the Subway Crowded Stampede Neural Network Evaluation Model

1. Determine subway crowded stampede security evaluation index are four factors—Liveware–Liveware, Liveware–hardware, Liveware–software, Liveware–environment.
2. Determine the destination vector. An objective analysis of the risk of subway crowded stampede is made on output layer neurons with different levels of number as the goal. In their evaluations, the output of target volume weighted average, to get the quantitative evaluation;
3. Make the normalization processing to the input and output vector and the input values transfer into a range. Determine the network structure which is of three layers;
4. Select samples, determine the sample data of neural network assessment;
5. Initialization, to give the three layers the weight vectors.
6. Input the training samples, do the neural network training and inspection, until meet the requirements of error;
7. Obtain subway crowded stampede safety assessment index waiting for evaluation, enter the trained neural network to work out the evaluation results.

The process of building safety assessment is shown in Fig. 3.

2.2.2 The Determination of Neural Network Structure

BP network has the satisfactory approximation ability of continuous map, which can meet the requirements of the assessment. And BP network is also the most popular study with most clear cognitive network [11]. The network structure is:

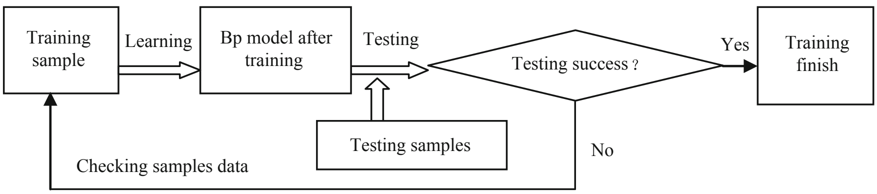


Fig. 3 Training and testing of neural network

Table 1 Input parameter table based on the SHEL model

The indicator system	The input parameters
L-L (A)	Crowded A_1, stampede A_2, retrograde flow A_3, fall down, the collision A_4, quarrel A_5
L-H (B)	The elevator breakdown B_1, a short circuit, power outages B_2, the stairs slippery road B_3
L-S (C)	Wrong information C_1, excess/placed to carry items C_2, education and training C_3, emergency management defects C_4
L-E (D)	Lighting defects D_1, bad weather D_2
All	L-L (A), L-H (B), L-S (C), L-E (D)

1. The determination of input layer
   On the subway crowded stampede, combined with the neural network model needs to be established. Build the input parameters which are shown in Table 1.
2. The determination of output layer
   The evaluation result is the degree security of each system, so the output response of each system should reflect the result. Generally speaking, we can use a continuous variation real number within a certain scope on behalf of the security degree of quantitative, so the output layer for each system can be replaced by a neuron.
3. Determination of hidden layer
   Hidden layer neurons only equip calculate significance, which the number have no strict rules. A recognized guiding principle is that the simplest (smallest) network can conform (same) with a given sample is the best choice when there is no other empirical knowledge, which is same as the deviation of sample points under the permit scope to approximate unknown nonlinear mapping with the smooth function. In practical applications, it can utilize the test and error method to determine the best number [11]. Through the test, the hidden layer number is shown in Table 2.

2.2.3 Assessment of BP Neural Network Model Training Sample

Using the principle of the orthogonal design method to select the network training samples [12]. According to the principle of the orthogonal design method in the application of neural network, the risk level of evaluation factors can be divided into four levels described by "better (perfectly safe)," "good (safer)," "general (general security situation)" and "bad (dangerous)." In this paper, all the real output of the training sample adopt the method of expert appraisal by experts according to the actual situation and combined with orthogonal table which represents level of 16 kinds of combination, giving the specific quantitative numerical network training samples as the actual output (Table 3). The output data are described by any real numbers between 1 and 4, all of which are quantitative security level data. The

Table 2 Hidden layer neuron numbers of subsystems

Subsystems	A	B	C	D	All
Hidden layer neurons	5	3	4	2	4

Table 3 Orthogonal training table

Training number	1	2	3	4	5
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	2	1	2	3	4
6	2	2	1	4	3
7	2	3	4	1	2
8	2	4	3	2	1
9	3	1	3	4	2
10	3	2	4	3	1
11	3	3	1	2	4
12	3	4	2	1	3
13	4	1	4	2	3
14	4	2	3	1	4
15	4	3	2	4	1
16	4	4	1	3	2

output data—1 (100), 2 (75), 3 (50), 4 (25)—can be converted into qualitative indicators, respectively, described by "better (perfectly safe)," "good (safer)," "general (general security situation)" and "bad (dangerous)."

3 A Subway Station Instance Analysis Based on the SHEL Model BP Neural Network Security Assessment

3.1 Assessment Instance Profile

The author chooses the transfer station of Beijing subway as the research object. The site is located in the junction between urban and rural areas, which is the only transfer station between exurban county subway lines and the city subway. The station has two exports, two entrances, six escalators, four transfers to the stairs. In 2015, the station is on the list of the top 10 in and out of the station of Beijing metro traffic station and 10 interchange station. The site has the obvious characteristics of tidal flow. In and out of traffic and interchange flow is very big in morning and evening rush and the station is more crowded. During the morning rush, passenger go to work from exurban county metro line transfer to the city subway constitute a morning rush "mainstay." Due to the science and technology, enterprise around the site is relatively intensive and in and out of the station traffic also considerable [13].

3.2 BP Neural Network Safety Assessment Basing on SHEL Model

The analysis steps of subway stampede BP neural network safety assessment basing on SHEL model is shown in Fig. 4.

1. BP model of L-L subsystem

- Network structure (Fig. 5)
- Input and output of training samples

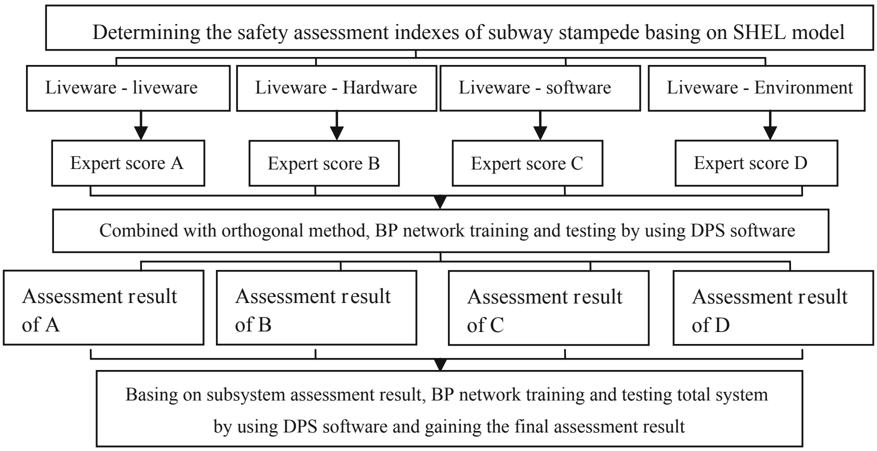
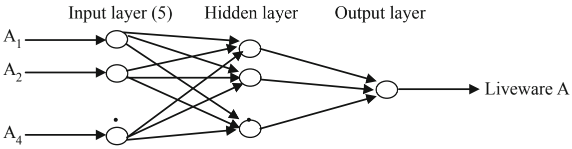


Fig. 4 Safety assessment operation steps of the subway instance

Fig. 5 BP model of L-L subsystem



Analyzing L-L subsystem, combined with $\mathbf{L_{16}}(4^5)$ orthogonal table, the experts give the input sample data, as is shown in Table 4. And the fitting residual error curve of L-L subsystem is shown in Fig. 6.

- The weight matrix, output matrix and the fitting curve after training and testing [14]

$$B_1 = \begin{matrix} [4.2148 & 0.7690 & -6.9732 & 2.3882 & -1.4487 \\ -3.0814 & -1.6879 & 3.0544 & -0.6876 & -3.7402 \\ -2.2299 & -0.2673 & 3.0420 & -0.2784 & 5.0680 \\ -0.7757 & 0.6705 & -1.5401 & -1.1832 & -2.7571 \\ 0.0255 & 1.8203 & -3.6058 & 0.6987 & -2.6205] \end{matrix}$$

$$W_1 = \begin{matrix} [-4.186 \\ 1.0658 \\ -5.7974 \\ 1.9542 \\ 7.1769] \end{matrix}$$

$$y_1 = 3.1915$$

In the same way, using BP model and matching the error permitting, the training and testing results of L-H, L-S, L-E subsystem can be reached, as is shown in Table 5.

According to the output of the subsystem, the further training and testing of the total system are made. The training and testing data are shown in Table 6.

The weight matrix, output matrix and the fitting curve after training and testing of total system are shown below. The fitting residual error curve of total system is in Fig. 7.

$$B_5 = \begin{matrix} [0.6652 & 1.0537 & -0.9750 & -0.4229 \\ -0.0166 & 0.1917 & -0.5441 & -3.8078 \\ 2.8092 & 0.0089 & -0.4872 & 2.8310 \\ -2.6870 & 0.5679 & 0.8505 & -2.8815] \end{matrix}$$

$$W_5 = \begin{matrix} [3.9631 \\ 1.4982 \\ -2.9652 \\ -8.4230] \end{matrix}$$

$$y_5 = 2.8463$$

As you can see by the test sample error, the theory the output value of test sample has some deviation compared with actual value, but still in the reasonable scope.

According to y_5 = 2.8463 in the “general (security)” to “good” (safe) and close to the general, the level of the security situation in the subway station is middle.

Table 4 L-L BP training and testing data table

Training samples								Testing samples							
Input					Actual output	Theory output	Error	Input					Actual output	Theory output	Error
1	1	1	1	1	0.9845	1.0667	0.0822	1	1.5	2.5	3	1	2.7869	2.7821	−0.0048
1	2	2	2	2	3.6342	3.489	−0.1452	2	2.5	4	2.5	1	3.6547	3.6663	0.0116
1	3	3	3	3	3.2134	3.5178	0.3044	1.5	2	3	2	1	3.3214	3.3125	−0.0089
1	4	4	4	4	3.5071	3.3843	−0.1228	3	2	3.5	3	2.5	3.0147	3.0209	0.0062
2	1	2	3	4	3.0121	3.0231	0.011	2	3	4	3.5	3.5	3.3847	3.3692	−0.0155
2	2	1	4	3	2.3764	2.3784	0.002	1	1.5	2.5	2.5	3.5	3.2058	3.2024	−0.0034
2	3	4	1	2	2.8036	2.8127	0.0091	1.5	3	4	3.5	3	2.3698	2.4346	0.0648
2	4	3	2	1	3.0327	3.019	−0.0137	1	2	3	4	4	3.4587	3.4729	0.0142
3	1	3	4	2	3.8964	3.7993	−0.0971	1.5	3	3	4	2.5	2.8976	2.8943	−0.0033
3	2	4	3	1	2.9367	2.9438	0.0071	2	2	4	3.5	3	3.7896	3.7599	−0.0297
3	3	1	2	4	3.5049	3.4715	−0.0334								
3	4	2	1	3	2.8796	2.8936	0.014								
4	1	4	2	3	3.5879	3.5955	0.0076								
4	2	3	1	4	3.8897	3.7924	−0.0973								
4	3	2	4	1	3.7531	3.7471	−0.006								
4	4	1	3	2	2.9876	3.0027	0.0151								

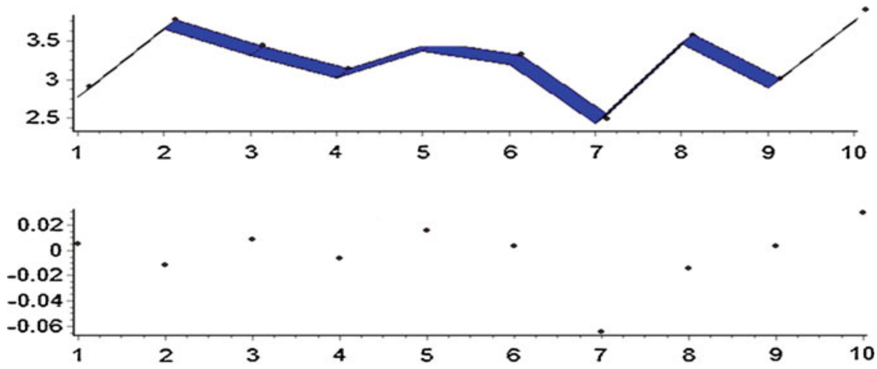


Fig. 6 L-L BP model fitting residual error and residual error scatter chart

Table 5 L-H, L-S, L-E theory output table

Serial number	L-H	L-S	L-E
1	2.7099	3.1983	1.2340
2	3.0267	3.0075	2.4359
3	2.9388	3.5677	1.9237
4	3.2054	3.0012	2.4508
5	3.3055	3.2579	2.4836
6	2.9388	3.3179	1.2340
7	2.9177	2.6583	2.4631
8	2.7233	3.0054	1.4916
9	2.9353	3.5660	2.4631
10	3.0346	3.5660	2.2411
Weighted prediction	2.9736	3.2146	2.0421

There is the possibility of crowded stampede accident, so we should strengthen supervision and control ability, on the basis of current safety situation, effectively prevent and control the accidents.

According to the predict value of subsystem of the instance subway, the L-L and L-S evaluation of the instance subway station is relatively low, respectively, 3.1915, 3.2146, equivalent to a percentile were 45.21 points, 44.64 min, which are risk prevention and control weak links [15] of the instance subway stampede accident. The actual operation condition of the instance subway station verifies the evaluation scores accuracy. With the passengers tidal flow feature, the instance subway station has large amount passenger flow and very crowded on morning and evening peak. The crowded shoving, collision, quarrels in the instance subway often occur. The management measures of the subway station traffic grooming are limited, which is basing on the traditional personnel onsite grooming and the effectiveness is little.

Table 6 Total system BP training and testing data table

Training samples							Testing samples						
Input				Actual output	Theory output	Error	Input				Actual output	Theory output	Error
1	1	1	1	1.0023	1.1121	−0.0351	2.8	2.71	3.2	1.23	2.5	2.479	0.0094
1	2	2	2	1.7605	1.6493	0.0773	3.7	3.03	3	2.44	3	3.0124	0.0017
1	3	3	3	2.4936	2.6364	0.0462	3.3	2.94	3.6	1.92	2.9	2.9433	−0.0001
1	4	4	4	3.2416	3.0887	0.0186	3	3.21	3	2.45	2.9	2.9252	−0.0007
2	1	2	3	1.9926	1.9808	0.0688	3.4	3.31	3.3	2.48	3.1	3.0739	0.0011
2	2	1	4	2.2529	2.2496	0.0328	3.2	2.94	3.3	1.23	2.6	2.6474	−0.0006
2	3	4	1	2.5052	2.4976	−0.0075	2.4	2.92	2.7	2.46	2.7	2.6559	−0.0007
2	4	3	2	2.7541	2.7654	0.0463	3.5	2.72	3	1.49	2.6	2.6214	0.0007
3	1	3	4	2.7454	2.7673	0.0812	2.9	2.94	3.6	2.46	3	2.9788	0.0009
3	2	4	3	2.9977	2.9788	0.0375	3.8	3.03	3.6	2.24	3.1	3.1255	−0.0242
3	3	1	2	2.2535	2.3124	−0.1152							
3	4	2	1	2.5029	2.4682	−0.0114							
4	1	4	2	2.7468	2.7526	−0.0118							
4	2	3	1	2.4969	2.5117	−0.0459							
4	3	2	4	3.2469	3.1126	−0.0432							
4	4	1	3	2.9969	2.969	−0.1432							

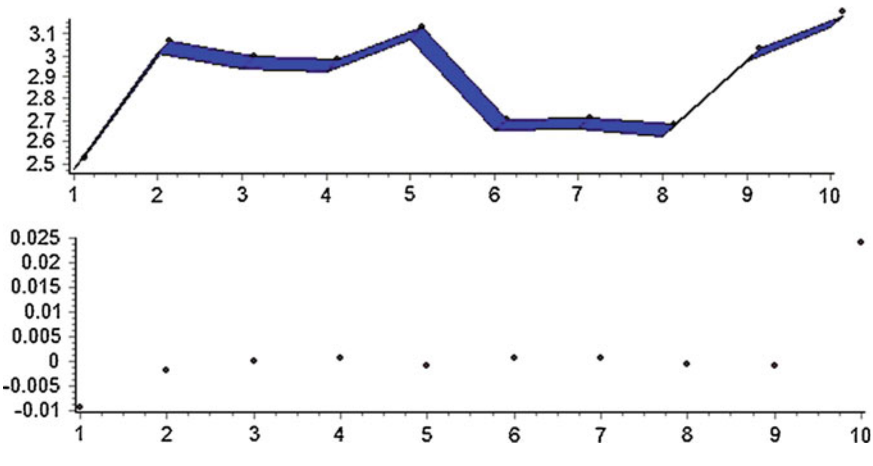


Fig. 7 BP model fitting residual error and residual error scatter chart of total system. *Remarks* the maximum number of iterations of training me = 1000, the expected squared error eg = 0.03

4 Conclusions

1. This paper analyzes and evaluates the security situation based on using artificial neural network evaluation method on the SHEL model and the subway station

as an example. The analysis results show that the security situation for the subway station is middle level close to the better; evaluation results basically tally with the actual safety situation. Therefore, using artificial neural network evaluation method to evaluate risk is feasible.

2. In general, the most suitable problem for using neural network analysis should have the following characteristics: knowledge (data) about these problems which have the characteristic such as fuzzy, incomplete and uncertain. Or mathematical algorithm of these questions analysis is lack of clear resolution; it must have enough data to generate sufficient training set and test mode, in order to effectively train and evaluate the performance of neural network [11].
3. Artificial neural network evaluation method combines the quantitative and qualitative analysis, which can reduce the disadvantages of individual subjective. Each subsystem of subway safety assessment system can set up evaluation model after broken down and concluded that the specific assessment quantitative values of one kind of the risk by carrying on the analysis.
4. This paper uses the BP neural network evaluation method to analyze the stampede accidents, the assessment result consistent with the actual situation of the instance subway station. The results show that there is risk in L-L and L-S, which has been verified in the actual operation of the subway station. Therefore, using BP neural network evaluation method to construct the comprehensive assessment system, based on the SHEL model, can quantitatively assess the crowded subway stampede accident risk, so as to promote the safety of metro operation to provide basis for decision making.

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A Human Factors Integrated Methods for Weapon System Effectiveness Evaluation

Shilei Liu and Hao Li

Abstract System effectiveness evaluation is important for development and application of weapons, but traditional methods seldom take human factors into account, which is critical for applying modern equipment of weapons. Different results will come from same weapons but operated by different persons, so perfect results could only be achieved with highly harmony of weapons and persons who operate the weapons. An improved system effectiveness evaluation method is developed by integrated human factors into the traditional ADC method which has been widely used. Firstly, the concepts about system effectiveness are introduced with the ADC. And then, after detailed discussion about human effectiveness metrics, components from human factors are redefined and integrated into the ADC model with two strategies. At last, how the method is implemented is demonstrated with a typical application example for system effectiveness evaluation of a main tank, and the result shows that the new method to be feasible and reasonable.

Keywords Human factor · Effectiveness · Evaluation · Weapon

1 Introduction

The weapon is a typical kind of human–machine integrated system, which will complete special operational task in special environment. So it is important to evaluate weapons not only during development process but also before supply for the army. Traditional system effectiveness evaluation methods have taken many factors into account, such as performance, cost, operating time, and efficiency. With wide application of the system theory, more attention has been drawn to evaluation

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of the weapon system as a whole. There are two important parts in the warfare: The one is the weapon and the other is the person who handles the weapon. Historical information has shown that different results will come from same weapons but operated by different persons, so human factors are even more important than the weapon. Unfortunately, designers and developers of weapons have seldom taken care of human factors, and the gap between the weapon and its user can only be identified too late after development process. Human factors must be integrated into evaluation of the weapon.

On the other hand, human factors and/or ergonomics professionals worldwide contribute to the design and evaluation of tasks, jobs, products, environments, and systems in order to make them compatible with needs, abilities, and limitations of people [1]. Many human-centered approaches have been developed and promoted, which considers the broad set of physical, cognitive, social, organizational, environmental, and other relevant human factors, which form the base of our research.

In rest of the paper, definitions of system effectiveness are presented with some traditional evaluation methods. And the widely used ADC method is discussed in details. Then an improved ADC method integrated human factors is introduced after discussion of some important components in human factors. The core of the improved method is the human factors integrated ADC model, which integrates some necessary components of human factors in the traditional ADC model. At last, evaluation of a main tank with the new method is presented as a demonstration.

2 Definitions of System Effectiveness and Evaluation Methods

System effectiveness is the essence of system analysis, which is the key definition in the fields of the operation research and the system theory [2]. And traditional system effectiveness evaluation methods are all systematic methods.

2.1 Definitions of System Effectiveness

In the system theory, a system is something which must be treated as a whole because each part is interrelated to every other part included in it. When talking about human factors, a system is an organized collection of men, machines, and methods required to accomplish a specific objective.

The definition of system effectiveness can be put forward on the base of concepts of the system. Effectiveness is a desired result, outcome, consequence, or operation, which means doing the right things right, to achieve the objective. System effectiveness is a measure of the ability of system to accomplish its objective. It is a measure of the extent to which a system can be expected to achieve a set of specific

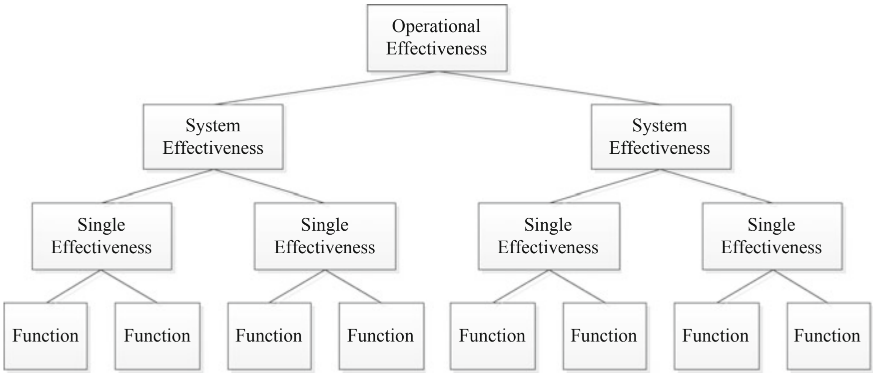


Fig. 1 Hierarchy of system effectiveness

goals. It can also be thought of as the probability that the system will achieve its objective. There are three main branches about definitions of system effectiveness.

The first is based on the reductionism. The hierarchy of systems can be partitioned into levels, and the partitioning levels are based on the objectives and goals of the system, such as the hierarchy showed in Fig. 1, in which effectiveness has been divided into three levels [3], and functions of each part in the system organized the base of effectiveness.

The second is based on the states of the system, which deal with three effectiveness factors: availability, dependability, and capability. The states are described with these factors, as shown in Fig. 2.

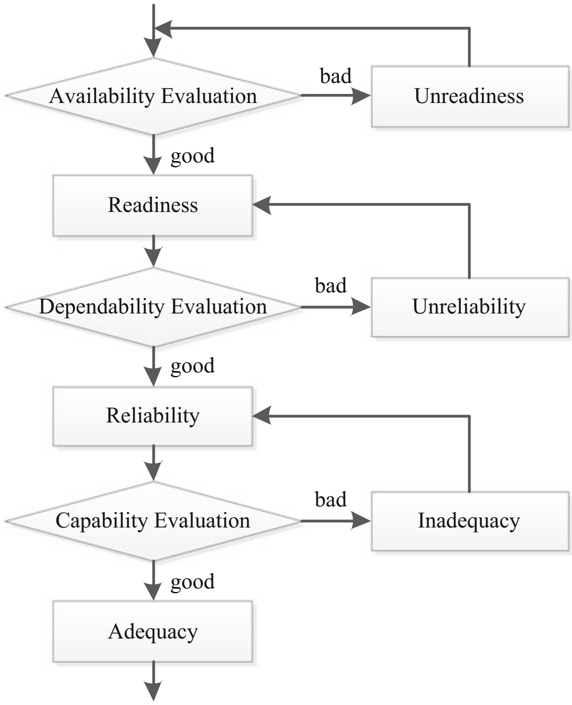
The third is based on the process that the system completes, and system effectiveness is defined as result by comparing between the system capabilities and the mission requirement in the common attribute space.

2.2 *Traditional Methods for System Effectiveness Evaluation*

Traditional methods for system effectiveness evaluation can be divided into three types, which are corresponding to the branches about the definitions relatively.

The first type is static synthesis method, such as the analytic hierarchy process (AHP). According to the hierarchy in Fig. 1, measures of different parts on the same level are weighted summed as measure of the part on the upper level. Then measure of effectiveness (MoE) can be gotten from measures of performances (MoPs) on the bottom level.

Fig. 2 Different states of system effectiveness



The second type is mathematical method, such as the availability–dependability–capability (ADC). Each factor is modeled, and MoE of the whole system is calculated with the synthesis function.

The third type is simulation-supported method, such as the system effectiveness analysis (SEA). The system and the mission are modeled, respectively, and simulation outputs defined on the common attributes from the two models are compared for MoE.

The first type of methods is not suit for complex weapon systems, and the third type of methods is difficult to implement for getting necessary information about the system and the mission requirement, so the second type is chosen.

2.2.1 The ADC Method

The ADC method was proposed by the Weapon System Effectiveness Industry Advisory Committee (WSEIAC) [4]. The main idea of the ADC is that the quantification of system effectiveness must account for system limitations due to degradation in system readiness, physical failures, and design limitation [2]. It follows that system effectiveness E is a measure of the extent to which a system may be expected to achieve a set of specific mission requirement and is a function of availability A, dependability D, and capability C, as follows,

$$E = A \cdot D \cdot C \tag{1.1}$$

Availability A is a measure of the system condition at the start of a mission and is a function of the relationships among hardware, personnel, and procedures, which is described with a vector. For example, a simple vector A consists of two elements,

$$A = \begin{bmatrix} a_1 & a_2 \end{bmatrix} \tag{1.2}$$

where a_1 is the probability that the system is operable at a random point in time, and a_2 is the probability that the system is in repair at a random point in time,

$$a_1 = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \quad a_2 = \frac{\text{MTTR}}{\text{MTBF} + \text{MTTR}} = 1 - a_1 \tag{1.3}$$

where MTBF is the mean time between failure, and MTTR is the mean time to repair, both of them are estimated from the reliability assessment.

Dependability D is a measure of the system condition at one or more points during the mission, which is described with a $n \times n$ matrix,

$$D = \begin{bmatrix} d_{11} & \dots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{1n} & \dots & d_{nn} \end{bmatrix} \tag{1.4}$$

where d_{ij} is the probability that the system will enter and/or occupy any one of its significant states (indexed with j) from the ith state during a specific mission and will perform the functions associated with those states, then $\sum_j d_{ij} = 1$.

Capability C is a measure of the ability of a system to achieve the mission objectives, which is described with a vector,

$$C = \begin{bmatrix} c_1 & \dots & c_n \end{bmatrix}^{\mathrm{T}} \tag{1.5}$$

where c_1 accounts for the performance spectrum of the system with given the system condition and the mission requirement.

The ADC model is based on an enumeration of the significant system states over the entire mission. System states are discernable condition of the system which result from events occurring prior to and during the mission.

3 An Improved ADC Method Integrating Human Factors

3.1 Foundation of the Human Effectiveness

Human factors have played an important role in research and development of weapons. A wide range of human factors research, development, and testing is conducted in diverse topic areas, such as complex weapon systems and advanced technical equipment. Human effectiveness usually instead by human performance is often measured as an essential component of complex human–machine interaction in military research field [5]. Aircraft, ships, and tanks are all examples of large systems in which human operators play an integral role. Therefore, effectiveness of such systems depends not only on the properties of machines, but also on the characteristics of human operators.

Based on studies about human factors or ergonomics in military, human effectiveness can be measured by metrics showed in Fig. 3.

3.2 Improvements of the ADC Model

In order to integrate human factors into the ADC model, there are two alternative strategies. The former is to integrate human effectiveness into each component of the ADC model, and the latter is to add new component in the model. Both of them are realized in the paper.

The availability vector in (1.2) is determined not only by the state of the weapon but also the preparation of the personnel at the start of the mission. In order to embody affect from human factors on availability, a new variable MTHO is defined as the mean time of human operation. Because the mean time that the machine is ready is usually longer than the human's, we let MTHO $\subseteq$ MTTR, as shown in Fig. 4. Then the new availability vector

$$\widetilde{A} = [\,\tilde{a}_1 \quad \tilde{a}_2\,] = \left[\frac{\mathrm{MTHO}}{\mathrm{MTBF}+\mathrm{MTTR}} \; \frac{(\mathrm{MTBF}-\mathrm{MTHO})+\mathrm{MTTR}}{\mathrm{MTBF}+\mathrm{MTTR}}\right] \tag{1.6}$$

The dependability matrix in (1.3) is divided in two aspects, $\widetilde{D}_W$ and $\widetilde{D}_H$ to describe reliability of the weapon and the person, respectively. $\widetilde{D}_W$ and $\widetilde{D}_H$ are both $n \times n$ matrixes. $\widetilde{D}_W = D$, and

$$\widetilde{D}_H = \begin{bmatrix} \tilde{d}_{11} & \cdots & \tilde{d}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{d}_{n1} & \cdots & \tilde{d}_{nn} \end{bmatrix} \tag{1.7}$$

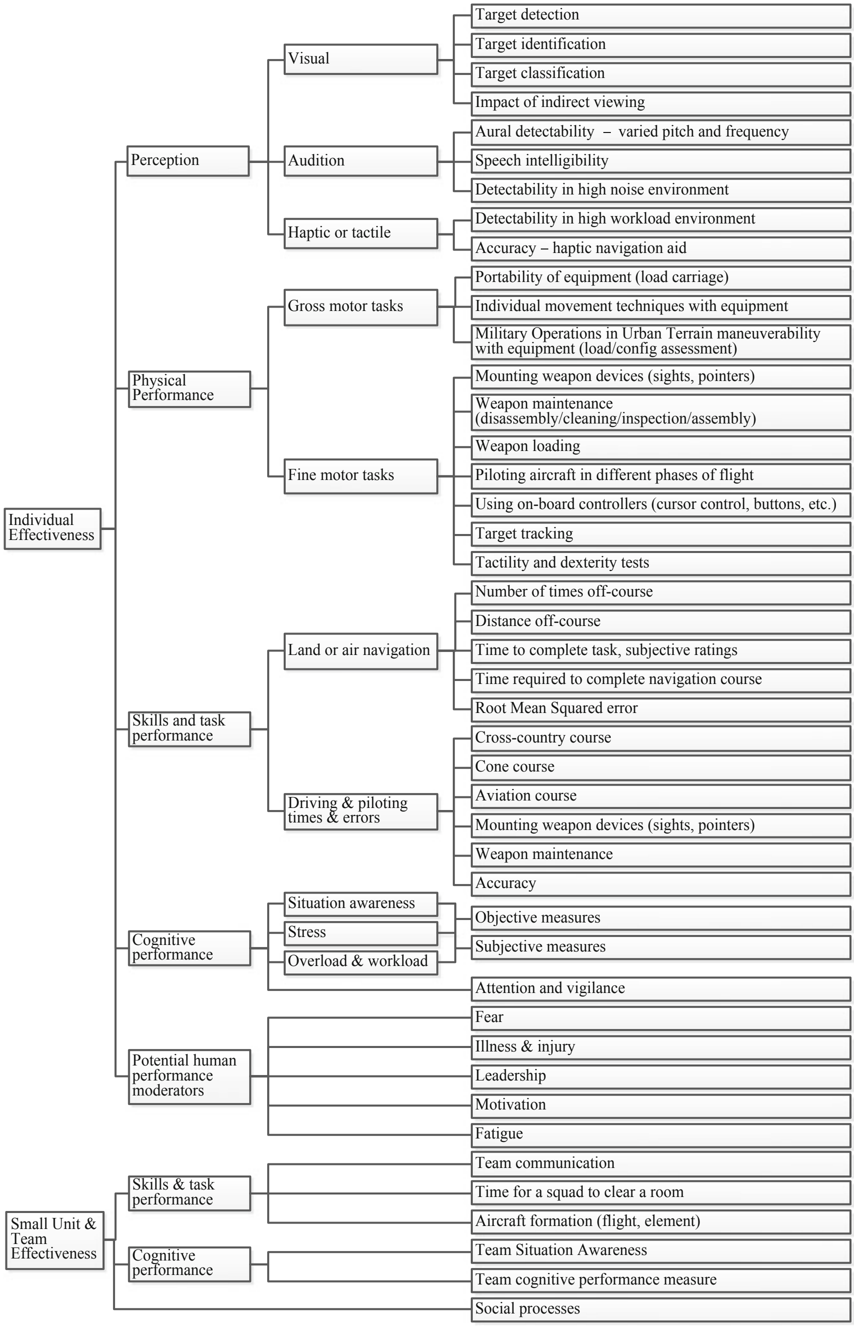


Fig. 3 Human effectiveness metrics

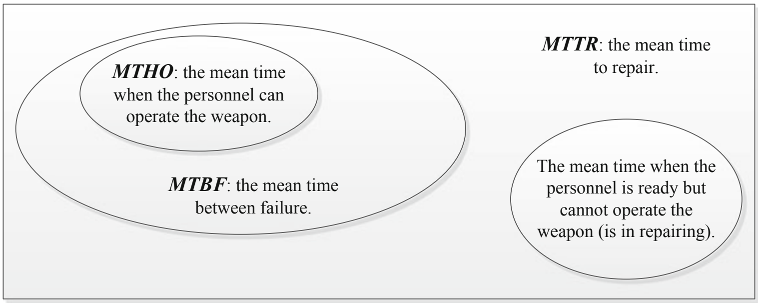


Fig. 4 Definition of MTHO

where $\tilde{d}_{kl}$ is the probability that the personnel will enter any one of its significant states (such as normal, fatigue, wounded, or illness, indexed with k) from the lth state during a specific mission and will perform the functions associated with those states with the relative state of the weapon, then $\sum_k \tilde{d}_{kl} = 1$. $\widetilde{D}_H$ can be set up with ergonomical method, such as the usability test [6].

The capability vector in (1.4) is determined not only by the design adequacy of the weapon but also ability of the personnel and relationship between the weapon and the personnel. So a new matrix $\widetilde{C}_H$ is defined for describing human factors affecting on the performance spectrum of the system with given the system condition and the mission requirement,

$$\widetilde{C}_H = \begin{bmatrix} \tilde{c}_{11} & \cdots & \tilde{c}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{c}_{n1} & \cdots & \tilde{c}_{nn} \end{bmatrix} \quad (1.8)$$

where $\tilde{c}_{st}$ accounts for the performance spectrum of the personnel (indexed by t) with a variety of the weapon state and mission requirement (indexed by s), then $\sum_s \tilde{c}_{st} = 1$. Values of elements in $\widetilde{C}_H$ can be determined by research in the fields of ergonomics design and ergonomics evaluation about the metrics showed in Fig. 3 [7]. $\widetilde{C}_W = C$ is still the measure of the ability of the weapon to achieve the mission objectives when the personnel are operable.

3.3 Summary

Integrated with human factors, system effectiveness $\widetilde{E}$ is

$$\widetilde{E} = \widetilde{A} \cdot (\widetilde{D}_W \cdot \widetilde{D}_H) \cdot (\widetilde{C}_H \cdot \widetilde{C}_W{}^{\mathrm{T}}) \tag{1.9}$$

The improved model is synthesis of human–machine–environment relationship essentially:

- The availability vector $\widetilde{A}$ describes relationship between the initial condition (environment) of the weapon system (composed of men and machines).
- The dependability matrix $\widetilde{D}_W$ and $\widetilde{D}_H$ describe reliability of the weapon (machine) and the personnel (men), respectively.
- The weapon capability vector $\widetilde{C}_W$ describes design adequacy of the weapon (machine).
- And the personnel capability matrix $\widetilde{C}_H$ describes features of the personnel (men) and relationship between the personnel (men) and the weapon (machine).

4 An Example: Application for a Main Tank

System effectiveness evaluation of a main tank is selected as a typical example for demonstration of the improved ADC method. In order to compare the improved method with the traditional one, three cases are taken into account:

- In case 1, the main tank is the only objective evaluated by using the traditional ADC method without caring about human factors, i.e., it is a normal case of traditional system effectiveness evaluation study.
- In case 2, the system composed of the main tank and personnel is the objective evaluated by using the improved ADC method and personnel are skillful and in perfect physiological and psychological state.
- In case 3, the system composed of the main tank and personnel is the objective evaluated by using the improved ADC method, but personnel are tenderfeet who need more training.

The main tank that is operable is usually composed of several subsystem, such as fire subsystem, mobile subsystem, armor subsystem, communication subsystem, and electrical subsystem. The main tank most often has three crew members:

- Commander—The commander is responsible for commanding the tank, most often in conjunction with other tanks and supporting infantry. The commander is provided with all-round vision devices rather than the limited ones of the driver and gunner.
- Driver—The driver drives the tank and often also serves as the tank's day-to-day mechanic.
- Gunner—The gunner is responsible for laying the gun.

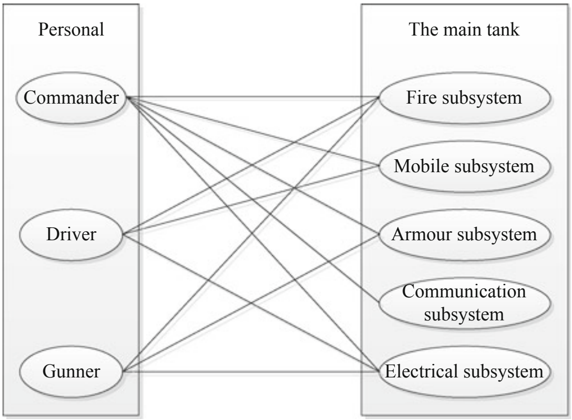


Fig. 5 Relationship between personnel and subsystems of the main tank

Relationship between personnel and subsystems is shown in Fig. 5. These subsystems are selected as objects to be evaluated, and characters and functions of each person are integrated into the connected subsystem for simplification.

Then the improved ADC model of the main tank is built up following the methodology present in the paper. The data of the model are gotten from sources as follows:

- Design parameter of subsystems of the main tank
- Historical data from all kinds of reference
- Data from experiment and war games
- Empirical data from experts and personnel
- Advices given by physiologists and psychologist

Part of results from the study is listed in Table 1. Measures of the whole system effectiveness are listed in the table too, which are calculated by weighted summing with data of subsystems. And all data are normalized for comparison.

Table 1 Results from system effectiveness evaluation of a main tank

	Fire subsystem	Mobile subsystem	Armor subsystem	Communication subsystem	Electrical subsystem	Tank system
Case 1	0.4791	0.6782	0.7372	0.6392	0.5082	0.5690
Case 2	0.6279	0.8911	0.7170	0.7112	0.4936	0.7071
Case 3	0.1205	0.2223	0.5125	0.1126	0.4415	0.2483

5 Conclusion

By comparing the results in Table 1, some conclusions can be drawn, as follows:

- Human factors play an important role in system effectiveness evaluation of the weapon, especially in some subsystems which have many operations by personnel.
- Even for the same weapon, different in results of system effectiveness evaluation from different personnel is obvious.
- Higher human effectiveness can lead to higher system effectiveness that means personnel can enhance the weapon with effect as "1 + 1 > 2."

All of these conclusions above are coincident with observations from real experiments and war games, which also shows that the new method to be feasible and reasonable. On the contrary, the method presented in the paper is still simple and not suits for complex system effectiveness evaluation, so more details need to be add into the model for higher precision. And then, other additional methods, such as modeling and simulation, need to be integrated to get more information about system effectiveness.

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Study of Risk Factors, Organization Method, and Risk Assessment in Troops' Live Hand Grenade Training

Zhenguo Mei, Chang Mei, Ye Tao and Leiming Yao

Abstract Live hand grenade throwing is a common training subject in troops. Its high security risk has long made it one of the most frightening training subjects for junior military officials. Live hand grenade training bears complicated potential risk factors, including actions of officers and soldiers, dangerous materials, training ground environment, and organization and management. Among all these factors, the action of trainees, the condition of safety officer, and training organization method are the most important ones. To ensure the safety precaution work of the training is well-done, hidden troubles must be eliminated completely, training organization method must be optimized, risk assessment must be launched scientifically, and good prevention and control measures must be applied. In this way training risks can be efficiently lowered, and the safety of the training is guaranteed. This thesis takes a deep research on risk factors, organization method, and risk assessment in troops' live hand grenade training.

Keywords MMESE · Live hand grenade training · Risk factors · Organization mode · Risk assessment

Live hand grenade throwing is a common and essential training subject in troops [1]. Since its risk is quite high, once the training organization fails, accidents may happen. In recent years, many accidents and dangerous situations have happened during live hand grenade training, making it one of the most frightening training subjects for junior military officials. Therefore, in order to ensure the safety of troops' training, it is of great importance to strengthen the research on security risk problems in training, investigate potential risk factors, scientifically launch risk assessment, and efficiently control training risk.

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1 Potential Risk Factors in Troops' Live Hand Grenade Training

Many potential risk factors lie in troops' live hand grenade training. To summarize, there are mainly four factors: actions of officers and soldiers, dangerous materials, training ground environment, and organization and management [2].

1.1 Actions of Officers and Soldiers

This factor includes the action of trainees and safety officers. For trainees, they may bear too much pressure in mind and fail to hold the grenade and cannot complete standardized actions, and the throwing angle or force is too small so grenade hits the protecting wall and rebounds. For safety officers, they may fail to protect trainees properly and have chosen wrong standing position or facing direction or focusing point, and thus, they fail to notice danger at once and waste a lot of time and fail to deal with dangerous situation properly and efficiently, thus caused injuries and deaths. Generally, there is 2.8–4 s' time before a hand grenade explodes after being thrown [3]. This period is long enough for dealing with dangerous situations like dropping the grenade accidentally. If such situations are not noticed at the first moment, or treating measures are not efficient enough, accidents may happen.

1.2 Dangerous Materials

Hand grenade belongs to dangerous materials, and it is the main dangerous source in a live training. Hand grenades first leave the warehouse, next being transported to training grounds, and then being distributed to trainees and being thrown, and finally, the duds are disposed. During the whole process, risks exist in every step. In transportation, traffic accidents may happen, and grenades may explode after being collided. In distribution, trainees may casually fiddle with the grenade, causing the drop of safety pin or grenade itself. In training, grenade may be dropped accidentally, or it hits the protecting wall and rebounds. In the disposal of duds, danger exists if the disposal measures are improper.

1.3 Training Ground Environment

This factor includes training ground condition, surrounding environment, and bad weather. For training ground condition, risks may exist because the ground is too small, and thus, grenades may be thrown out of caution zone; the protecting wall is higher than 1.2 m [1], blocking the flight path of grenades; and arrangement of shelter is not suitable, or its shape is not standardized. For surrounding environment, risks may exist because irrelevant people break into the caution zone by accident; weeds grow thickly, and thus, fire may be caused by the explosion of grenade. For bad weather, risks may exist because rain, fog, chill, and strong wind will affect trainees, making them slip or miss the target while throwing.

1.4 Organization and Management

This factor is more complicated. Improper organization method will increase training risk. Safety rules may be too complex or too simple, making it not convenient for officers and soldiers to carry out under emergency. Safety officers may lack emergency training and thus are not familiar with treating methods and process. Trainees fail to accept good safety education and psychology guidance, and some may become too nervous or behave irregularly during the training. Safety guarding organization is poor, and irrelevant people break into caution zone by accident.

Among the above-mentioned four factors, hand grenade, being a dangerous material, which has its own risk, is hard to control, though troops can try to reduce it by strengthening transportation management and distribution organization. People's actions are influenced by their minds, psychological condition, physical features, knowledge, and skills. Their actions are complicated and can be divided into conscious actions and unconscious actions, so they are partly controllable. The organization of training, ground, weather, and environment can be decided by men. Therefore, in conclusion, risks in live hand grenade training do exist, and the risk factors are partly controllable.

2 Organization Method in Troops' Live Hand Grenade Training

Among the four risk factors in troops' live hand grenade training, risk in actions of officers and soldiers is controlled through strengthening peacetime training and organization and management. Meanwhile, the most critical factor in organization and management is the organization method of training. Live hand grenade training organization method means the way to set the number of training grounds or throwing fields and the number of trainees and safety officers in each ground/field. The difference between organization methods marks the main difference between various training plans.

Common live hand grenade training organization methods are as follows:

Method A: setting one training ground, one trainee, and one safety officer, abbreviated as "1-1-1."
Method B: setting two training grounds, one trainee, and one safety officer in each ground, abbreviated as "2 × (1-1-1)."
Method C: setting one training ground, one trainee, and two safety officers, abbreviated as "1-1-2."
Method D: setting one training ground, two trainees, and two safety officers, abbreviated as "1-2-2."
Method E: setting one training ground, several trainees, and several safety officers, abbreviated as "1-*n*-*n*," $n > 2$.

In the five methods, A and B have fewer people in the ground than C, D, and E; A, C, D, and E all set one ground, and thus, only one guarantee force is needed, including a command group, a security group, a grenade group, an EOD group (Explosive Ordnance Disposal (EOD)), and a rescue group. Method B sets two grounds; then, if the two grounds are far apart, two guarantee forces are needed, including two command groups, two security groups, two grenade groups, two EOD groups, and two rescue groups. B requires more guidance and forces in training.

3 Risk Assessment in Troops' Live Hand Grenade Training

Live hand grenade training includes four steps: grenade transportation, distribution, throwing, and dud treatment. Risk assessment means assessing the risk of each step separately and taking their highest risk level. Grenade transportation, distribution, and dud treatment are usually done by professionals. Therefore, the main training risk lies in throwing step. Here, MES method is applied to assess the risk in grenade throwing. MES method is a risk assessment approach proposed in 2002 by Chinese security expert SONG Dacheng [4]. In his view, risk is the combination of possibility and consequence of a specific risk event, while the possibility of a specific risk event depends on control measure, written as M, and dangerous situation frequency, written as E. The scale of control measures M, danger frequency E, and consequence S is reflected by points. The higher the point is, the larger the scale will be. Finally, the three points are multiplied to show the size of risk degree R, namely $R = MES$.

Following is a case study of live hand grenade training in Troop A. Basic information: 1120 officers and soldiers participate in the training, including 256 recruits served as trainees. Trainees have been in the army for two months, and training period is 2 days.

See the process of risk assessment in live hand grenade training below:

Step 1: Determining the point of *M*. See Table 1 for the criterion:

M in throwing step depends on organization method, danger disposal plan, condition of safety officer and trainees' ability to protect themselves, etc. If organization is unreasonable, danger disposal plan is imperfect, safety officer lacks experiences, and then, *M* takes 5 points; if organization is reasonable, danger disposal plans are good, safety officer is experienced, and then, *M* takes 1. For *M* points of different organization methods of Troop A, see Table 5. *M* in Method A and B takes 3 or 1, depending on the quality of safety officer. If safety officer is of high quality and is experienced in danger disposal, *M* takes 1; conversely, *M* takes 3. *M* in Method D follows the same standard.

Step 2: Determining the point of *E*. See Table 2 for the criterion:

For live hand grenade training, the value of *E* depends on the frequency of human exposure *E*1 and the frequency of dangerous situation *E*2. For this troop, if people are exposed to hazardous environment within daily working hours, *E*1 takes 6. Meanwhile, if dangerous situation occurs weekly, *E*2 takes 3. Thus, *E* takes the median of the two, which is 4 or 5. Whether *E* takes 4 or 5, the quality of officers and soldiers needs to be considered. Since many recruits take part in the training and their psychological quality is relatively weak, their training level will be relatively low and *E* can take the bigger point 5.

Table 1 Condition of control measure *M*

Point	Condition of control measure
5	No protective measures or failure of protective measures. For example, placing flammable, explosive materials under direct sunlight, alarm monitoring system has broken down
3	Having some protective measures but not good enough. For example, having non-perfect alarm monitoring system
1	Having targeted and effective protection measures. For example, having both alarm monitoring system and conscientious staff on duty

Table 2 The frequency of human exposure or dangerous situation E

Point	*E*1: The frequency of human exposure	*E*2: The frequency of dangerous situation
10	Continuously	Continuously
6	During daily working hours	During daily working hour
3	Weekly	Weekly
2	Monthly	Monthly
1	Several times per year	Several times per year
0.5	Hardly	Hardly

Step 3: Determining the point of S. See Table 3 [5] for the criterion:

For live hand grenade training, the number of people in the training ground and their safety quality are the key to determine the value of S. The more people involve in, the more serious the possible consequences are; thus, the greater S will be. If people have high safety quality and strong self-protection ability, the consequences of accidents will be comparatively less serious; if not, consequences will be serious. When determining the value of S, control measures are generally not considered. For S points of different organization methods, see Table 5. S of Method E takes 6 or 8 or 10, and the main consideration is the number of people involving in. In general, if there are 5–8 people in the training ground, S takes 6; 9–12 people, S takes 8; more than 12 people, S takes the maximum value 10.

Step 4: Calculating and determining risk level. Multiply M, E, and S, and we can get the value of R (risk degree). Using Table 4 as reference, risk level L can be finally determined. For detail, see Table 5.

Table 3 Possible consequences of accidents S

Points	Possible consequences of accidents	
	Personal injury	Property damage (Yuan)
10	More than 15 people dead or more than 40 people seriously injured	≥200 million
8	6–14 people dead or 20–39 people seriously injured	10 million (inclusive)–200 million
6	2–5 people dead or 11–19 people seriously injured	One million (inclusive)–10 million
4	One person dead or 2–10 people seriously injured	200,000 (inclusive)–one million
2	One person seriously injured or slightly injured requiring hospital treatment	10,000 (inclusive)–200,000
1	Slight injuries, only requiring first aid	<10,000

Table 4 Risk degrees

Risk degree R	≥180	90–150	50–80	20–48	≤18
Risk level L	Level 1	Level 2	Level 3	Level 4	Level 5
Alert	Red alert	Orange alert	Yellow alert	Blue alert	None

Table 5 Risk table of live hand grenade training in Troop A

Organization method		*M*	*E*	*S*	*R*	*L*
A	"1-1-1"	3 or 1	5	4	60 or 20	3 or 4
B	"2 × (1-1-1)"	3 or 1	5	4	60 or 20	3 or 4
C	"1-1-2"	3	5	6	90	2
D	"1-2-2"	3 or 5	5	6	90 or 150	2
E	"1-n-n" ($n > 2$)	5	5	6 or 8 or 10	150 or 200 or 250	2 or 1

According to Table 5, organization method has a great influence on risk degree and risk level of the training. Different methods are sorted in ascending order as follows: A and B < C < D < E.

4 Conclusion

Troop live hand grenade training bears high risks and its potential risk factors including actions of officers and soldiers, dangerous materials, training ground environment, and organization and management. Among these factors, action of trainee, condition of safety officer, and training organization method are the most important ones. For trainees' actions, if officers and soldiers have high training level, the frequency of dangerous situation can be reduced. For safety officers, if he or she is of high quality and experienced, he or she can help defuse dangerous situations and avoid accidents. For organization method, it affects risk degree and risk level through control measures and possible accident consequences. According to the result of risk assessment, Method A and Method B bear the minimum risk; thus, "one training ground, one trainee, and one safety officer" is the most secure organization method.

From the above research, five suggestions can be concluded to help lower the risk in live hand grenade training, abbreviated as "five needs." Firstly, daily training needs to be strengthened to improve hand grenade throwing skills and psychological qualities of officers and soldiers. Secondly, organization needs to be optimized, and people in the training ground should be as few as possible. Thirdly, training grounds need to be set scientifically, and the grounds must meet safety requirements. Fourthly, safety officers need to be carefully selected, only allowing experienced and high-qualified officers to shoulder the responsibility. Fifthly, security plans need to be improved, and troops should carry out emergency drill well and be familiar with the treatment of possible dangerous situations.

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Research on the Root Causes of Car Accidents in Air Defense Forces

Zhenguo Mei, Shichang Wang, Chang Mei, Ye Tao and Peng Gong

Abstract Car accidents are often seen in air defense forces. Researching their root causes has a great significance on improving the prevention work scientifically and promoting the security development of air defense forces. With the use of Cognitive Reliability and Error Analysis Method, this thesis analyzes 182 car accidents in air defense forces and establishes the cause category table of car accidents, the possible cause table of human error patterns, and the "cause–effect" tracing table of human errors in car accidents in air defense forces. The thesis also constructs the method of tracing and analyzing their root causes. Applying this method, root causes of car accidents are found, which provides effective method and scientific basis for researching and preventing car accidents in air defense forces.

Keywords CREAM · Air defense forces · Car accidents · Root causes · Tracing and analyzing

Car accident is the first major accident in troops, accounted for 70 % approximately [1]. Car accident belongs to human accidents and is caused mainly by human errors. Therefore, researching the pattern of human errors in troop car accidents and exploring their root causes have a great significance on improving the prevention work scientifically and promoting the security development of air defense forces. On the basis of Cognitive Reliability and Error Analysis Method (CREAM) [2], this thesis analyzes 182 car accidents in air defense forces and constructs the method of tracing and analyzing their root causes. Applying this method, root causes of car accidents are found, which provides effective method and scientific basis for researching and preventing car accidents in air defense forces.

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1 Classification of Human Error Patterns in Car Accidents in Air Defense Forces and Construction of Cause Category Table

1.1 Classification of Human Error Patterns in Car Accidents in Air Defense Forces

American scholar James Reason divided human errors into two categories. The first category is error made in setting up the plan/intention, called "mistake" and "violation"; the second category is error made in implementing the plan/intention, called "slips" and "lapses" [3]. On the basis of this framework and specific circumstances, this thesis classifies errors in car accidents in air defense forces as slip, lapse, mistake, and violation. See Fig. 1.

1.2 Construction of Cause Category Table of Car Accidents in Air Defense Forces

Based on the analysis of 182 car accidents in air defense forces, causes of human errors are classified into 5 categories: "person" (P), "car" (C), "road" (R), "environment" (E), and "management" (M). Each category is further divided into several specific causes, represented by adding a number after category letters. The names and codes of different causes are shown in Table 1.

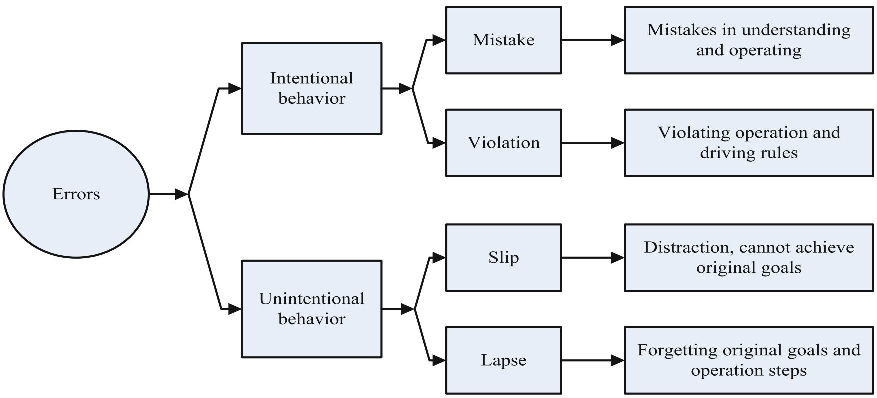

Fig. 1 Human error patterns in car accidents in Air Defense Forces

Table 1 Cause category table of human errors in car accidents in Air Defense Army

Code	Name	Interpretation
P1	Cognitive bias	Incorrect cognitive tendency
P2	Misjudgment	Misjudgment of speed, distance between cars and road conditions, etc.
P3	Fluke or adventure	Being too confident or attempting to succeed or avoid disaster through accidental factors
P4	Tension	Spirit in a state of high tension; nervous in mind
P5	Weary driving	Poor sleep; fatigue caused by longtime driving
P6	Distraction	Mental distraction caused by personal or environmental problems
P7	Slow response	Slow response caused by mental, physical, or technical problems
P8	Illegal driving	Violation of traffic safety law, e.g., speeding, overloading, overrun, drunk driving, running red lights, and running forbidden lines
P9	Poor driving skills	Learner driver with little knowledge; weak in controlling car; unskilled driving
P10	Bad driving habits	Smoking/phoning while driving, driving too fast, etc.
P11	Character flaw	Deficiencies in character, such as being impulsive, adventurous, and irritable.
C1	Poor car condition	Performance degradation or damage of electronic/mechanical components, thus the car cannot achieve normal performance
C2	Unqualified car components	Car components fail to reach quality standards; security risks exist
R1	Complex/dangerous road	Complex road condition; road being a traffic accidents hot spot
R2	Poor road quality	Damaged or rough road
R3	Unreasonable setting of traffic lights and signs	No traffic signs; distance between two traffic lights/signs is too close; information being displayed is inaccurate or blurry
R4	Bad road design	Problems in design of road alignment and grade
E1	Bad weather	Windy, rainy, snowy, foggy, etc.
E2	Complex traffic environment	Traffic jam, too many pedestrians
M1	Poor driving plan and organization	Unreasonable or impractical plan, driving disorganized
M2	Poor safety education	Inadequate or ineffective safety education, leading to poor safety consciousness
M3	Inadequate skill training	Inadequate or ineffective skill training, leading to poor driving skills
M4	Rules not well implemented	Fail to follow the rules strictly, deviations exist
M5	Unsuitable staff selection	Fail to consider mental/physical condition and adaptability in staff selection
M6	Irresponsible cadre in the car	Cadre in the car fail to help observe road condition; fail to remind driver of safe driving; change routes without permission
M7	Irresponsible administrator	Irresponsible administrator, sloppy work
M8	Loopholes in management	Implementation not complete; defects in supervision and management; imperfect system

2 Construction of Cause Table and Tracing Table of Human Error Patterns in Car Accidents in Air Defense Forces

2.1 Possible Cause Table of Human Error Patterns in Car Accidents in Air Defense Forces

According to the classification of human error patterns, combining with the causes categorized in Table 1, possible causes of these four patterns can be analyzed. See Table 2.

2.2 Construction of "Cause–Effect" Tracing Table of Human Errors in Car Accidents in Air Defense Forces

First, regard each cause in Table 2 as an effect. Next analyze its common and special causes. Then take its special cause as root cause, while common cause as another effect. Repeat the process several times and finally we can get "cause–effect" table. See Table 3 [4].

Table 2 Possible cause table of human error patterns in car accidents in Air Defense Army

Human error pattern	Possible causes
Slip	P4, P6, P8, C1, R3, E1, E2, M1, M5, M6
Lapse	P1, P2, P3, P6, P7, E1, E2, M3
Mistake	P2, P7, P9, C2, R1, M1, M3, M7, M8
Violation	P3, P5, P8, P10, P11, C1, R1, R2, R4, M1, M2, M4, M7, M8

Table 3 "Cause–effect" tracing table of human errors in car accidents in Air Defense Forces

Code	Effect	Common cause	Special cause
P2	Misjudgment	P1, P4, P9, R3, E1, E2, M3	Because of cognitive bias, psychological stress, driving skill, weather or environment, driver makes mistake on judging speed, distance between cars and road conditions
P3	Fluke or adventure	P1, P2, P11, M2	Lacking safety consciousness, expecting fluke or adventure
P4	Tension	P8, P9, C1, R1, R2, E1, E2, M3	Facing unexpected circumstances, too much psychological pressure or fear

(continued)

Table 3 (continued)

Code	Effect	Common cause	Special cause
P5	Weary driving	M1, M4, M5, M8	Workload beyond driver's capability, thus leading to mental and physical problems
P6	Distraction	P4, P5, P10, E2	Energy dispersion due to personal problems or environment inside/outside the car
P7	Slow response	P4, P5, P6	Slow response due to anxiety, lack of concentration, fatigue and poor car condition
P8	Illegal driving	P1, P3, P10, P11, M1, M2, M4, M5, M6, M8	Driver lacks safety consciousness
P9	Poor driving skills	P4, P5, P8, C1, M3	Wrong control on power, direction, and braking
P10	Bad driving habits	P1, M2, M4, M6	Driver lacks safety consciousness
C1	Poor car condition	M4, M8	Poor car maintenance
M1	Poor driving plan and organization	M4, M7, M8	Organizer lacks capability or responsibility
M2	Poor safety education	M4, M7, M8	Poor educational organization, educated people fail to pay enough attention
M3	Inadequate skill training	M4, M7, M8	Insufficient or ineffective training
M4	Rules not well implemented	M7, M8	Organizer lacks capability, responsibility or safety consciousness
M5	Unsuitable staff selection	M7, M8	Failing to consider mental/physical condition and adaptability when selecting staff
M6	Irresponsible cadre in the car	M2, M8	Lacking responsibility and safety consciousness

3 Analysis of Root Causes of Human Errors in 182 Car Accidents in Air Defense Forces

3.1 Process of Analyzing Root Causes of Human Errors in 182 Car Accidents in Air Defense Forces

The whole process can be divided into 5 steps: (1) Determine human error pattern according to the characteristics of human errors in car accidents; (2) Identify the possible cause in the cause category table. Make this cause as the logical starting point for root cause analysis; (3) Regard the possible cause in step (2) as "result."

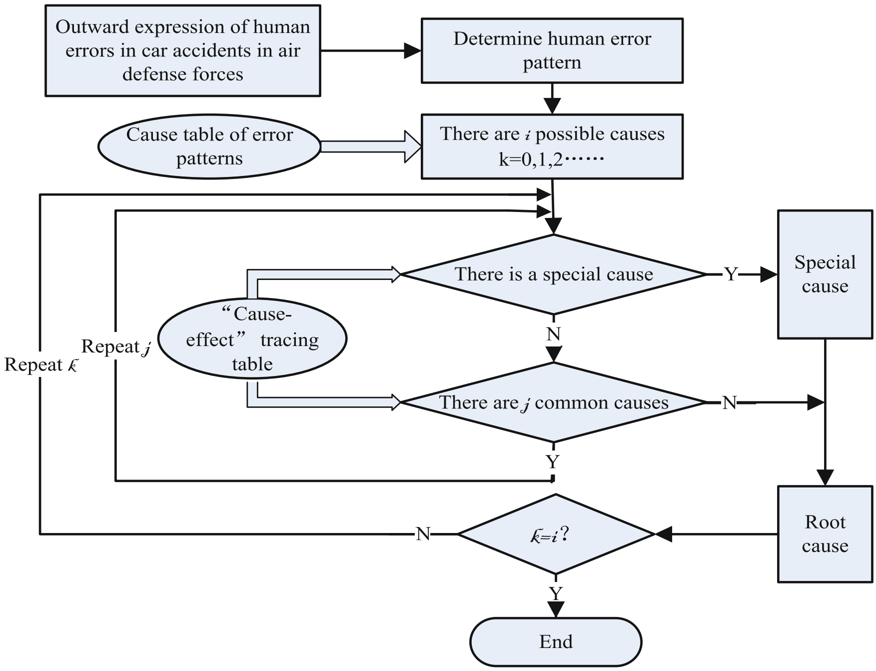

Fig. 2 Flowchart of the process of analyzing root causes of human errors

Then find its common and special causes from "cause-result" tracing table. If it has a special cause, take the special cause as root cause and complete analysis; if it only has a common cause, repeat the former process and turn back to "cause–effect" tracing table until special cause is found; (4) During the process, if the accident has more than one cause, analyze them, respectively; if there is no "proper" cause, finish the analyzing line; (5) Follow step (3) to run each analyzing line till all analyses are completed.

The process is shown in Fig. 2 [5].

3.2 Result of Analyzing Root Causes of Human Errors in 182 Car Accidents in Air Defense Forces

After analyzing root causes, results are sorted out. See Table 4.

According to Table 4, root causes related to driver are "fluke or adventure" and "tension"; root causes related to cadres are "irresponsible administrator" and "irresponsible cadre in the car"; root causes related to organization are "poor safety education" and "inadequate skill training."

Table 4 Result of the analysis of root causes of 182 car accidents in Air Defense Forces

Root cause	Accident number	Proportion (%)
Fluke or adventure	82	45.1
Tension	39	21.4
Poor safety education	170	93.4
Inadequate skill training	77	42.3
Irresponsible administrator	99	54.4
Irresponsible cadre in the car	74	40.7

4 Conclusion

This thesis applies Cognitive Reliability and Error Analysis Method (CREAM) to analyze 182 car accidents in air defense forces. During the analyzing process, cause category table, possible cause table of human error patterns and "cause–effect" tracing table are established, and analysis method of root causes of human errors in car accidents in air defense forces is created. Through the analysis of 182 car accidents, 6 root causes are finally found: fluke or adventure, tension, irresponsible administrator, irresponsible cadre in the car, poor safety education, and inadequate skill training. This provides effective method and scientific basis for researching and preventing car accidents in air defense forces.

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Creative Research on Recruit Training Based on Myocardial Enzymogram Perspective

Ye Tao, Wenying Xing and Zhenguo Mei

Abstract Recruits add fresh blood to army. The quality of recruit training will influence their own growth, army development, and combat effectiveness. In general, recruits' physical fitness needs to be improved by training. Therefore, the impacts of high-intensity training on recruits' body function are highly concerned by military administrators. This thesis analyzes recruits' myocardial health through detecting samples of their myocardial enzymogram. Causes of their myocardial health problems are traced, and strategies on strengthening and innovating recruit training are discussed. Training organizers should adhere to scientific training principles, innovate training methods, and strengthen management and control throughout whole process. This provides an important basis and useful reference for recruit training under current situation.

Keywords Recruits · Myocardial enzymogram · Recruit training · Training innovation

Recruits add fresh blood to army. The quality of recruit training will influence their own growth, army development, and combat effectiveness. When recruits face high-intensity physical training, many factors may adversely affect their health, such as weak fitness foundation, improper training methods, and changing of training environment. To solve possible problems, the army should take a deep study on recruits' physical characteristics, grasp health laws, and organize the training scientifically. This thesis analyzes recruits' myocardial health through detecting samples of their myocardial enzymogram. Reasons which can lead to their

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myocardial health problems are traced, and strategies on strengthening and innovating recruit training are discussed. This provides an important basis and useful reference for recruit training under current situation.

1 Detection of Myocardial Enzymogram and Results

1.1 Detecting Object and Method

The detection is carried out in Army A. 182 soldiers who have just enlisted for a month in 2014 (recruits) and 60 who have enlisted for more than one year (veterans) are taken randomly as the detecting object. They are all male soldiers of 18–22 years old.

Extract 4 ml recruits' and veterans' fasting venous blood and recruits' blood after training, respectively. Then, use biochemical analyzer to detect the myocardial enzymogram. The values of five proteases were detected: AST (aspartate aminotransferase), LDH (lactate dehydrogenase), CK (creatine kinase), CK-MB (creatine kinase-MB), and α-HBDH (α-hydroxybutyrate dehydrogenase). Measurement unit of the value is (μ/L). The detection is carried by medical staff and professional inspectors. Operating instructions are strictly followed.

1.2 Statistical Analysis

Statistical analysis of the detection data is performed with SPSS Ver. 15.0. Statistical results are presented as mean value ± standard deviation ($\bar{x} \pm s$). Carry out *t* test for all the items in myocardial enzymogram. If $P < 0.05$, the difference is considered significant.

1.3 Results

See Table 1 for the results of recruits' and veterans' myocardial enzymogram.

According to Table 1, veterans' values are all within the range of normal adults' standard. But recruits' LDH, CK, and α-HBDH values are out of the range, with CK being several times of normal value.

1. Compare recruits' value with veterans'. All the values of recruits are higher. Recruits' CK value is 7 times of veterans; their LDH and α-HBDH values are nearly twice of veterans.
2. Compare recruits' value before and after training. After training, values do not show a high rise, but according to clinical requirement, the changes in the

Table 1 Result of myocardial enzymogram detection ($\bar{x} \pm s$)

Protease	AST	LDH	CK	CK-MB	α-HBDH
Reference value of normal adults' [1] (μ/L)	8–40	109–245	24–194	0–25	72–182
Recruits (μ/L)	29.6 ± 9.3*	286.0 ± 30.2*	485.2 ± 38.1*	15.7 ± 4.2*	203.5 ± 24.1*
Veterans (μ/L)	26.5 ± 7.2	138.9 ± 22.1	74.9 ± 22.6	13.4 ± 5.6	123.5 ± 14.3
Recruits after training (μ/L)	32.4 ± 8.7	301.5 ± 31.3	537.2 ± 42.0**	20.1 ± 8.7**	230.1 ± 27.4**

Notes *$P < 0.05$ versus veterans; **$P < 0.05$ versus recruits proportion of proteases also need to be observed. For example, if CK > 190 μ/L, and CK-MB accounts for 4–25 % of CK value, people may suffer from acute myocardial infarction. If the rise of α-HBDH is higher than the rise of LDH, then cardio-cerebral health is greatly harmed [2]. According to Table 1, before training recruits' CK-MB/CK ratio is (15.7/485.2)3.2 %, while after training the ratio turns into (20.1/537.2)3.7 %, which is nearly 4 %. This means some recruits may face the danger of acute myocardial infarction.

2 Cause Analysis

According to the result of myocardial enzymogram, after one month's training in army, some recruits' myocardial health condition shows a downward trend comparing with normal people, while remaining a big gap comparing with veterans, and potential threats toward cardiac health have increased. The causes of this phenomenon can be categorized into the following three aspects.

2.1 Weak Fitness Foundation

Nowadays, most recruits' fitness foundation is relatively weak. In 2014, Wu Zhengxian, deputy of the National People's Congress, noted that many factors, such as good living conditions, parents' too much love for their only child, and lack of physical exercise on campus, had led to 25 years' continuous decline of China's youth physical condition, including young people's strength, speed, and endurance [3]. This decline directly causes weak fitness foundation for recruits.

2.2 Improper Training Methods

According to statistics, during recruits' basic training period, their training injury rate is quite high. In Chinese army, the rate is 7.9–37.7 %, while in foreign armies, the rate is 4.8–8.5 %. Among all training injuries, more than 73 % are caused by improper training methods [4]. Problems mainly lie in two aspects. First, many recruits lack knowledge about exercise physiology, health, military training injuries, and circuit training. Second, some training organizers show a trend of formalism. They only pay attention to subjects that will be examined by superiors, while ignoring other subjects. Also, sometimes, there are missing subjects in training. For example, organizers only organize strength and endurance training while neglect flexibility and sensitivity training.

2.3 Changing of Training Environment

The impact of training environment is on two aspects. First is the impact of summer training. From 2013, China began to implement a summer conscription policy. Compared with winter training, recruits' physiological condition is weaker in summer. According to a research, if temperature reaches 33 °C or above, people's metabolism will speed up, which can affect blood circulation. This will further affect heart and may cause heart diseases. Second, training intensity has increased. Since 2014, military forces actively carried out recruit training. Many new subjects are added, including counter-terrorism and riot, military sports, assassination, climbing net wall, rolling tyres, combat, hand grenade throwing, battlefield protection, first aid practice, firefighting, and light weapon firing. In addition, many forces shortened recruits' basic training time to two months. In the last month, comprehensive exercises for actual war are organized in all forces, and all examination subjects are set in tactical background.

3 Strategies on Strengthening and Innovating Recruit Training

Through measurement and cause analysis of recruits' myocardial enzymogram, many problems can be seen in current recruit training. Organizers should adhere to scientific training principles, innovate training ideas and patterns, and increase quality and efficiency of recruit training. This will ensure recruits to grow healthily in army.

3.1 Adhere to Scientific Training Principles

To achieve scientific training, three aspects need to be noticed.

First, adhere to the principle of gradual improvement. This is the basic principle of recruit training. Training should be organized based on each recruit's actual situation. Training content, organization, trainee arrangement, intensity, schedule, and difficulty should all be managed separately, fitting each recruit's need. Recruits should adapt to high-intensity training gradually. This can prevent irreversible damage to recruits' tissues or organs such as heart muscle and skeletal muscle.

Second, follow the laws of military training. Military training has two basic laws: develop in waves and improve in spirals. Recruits need to first adapt to basic training, then try high-intensity training, and gradually make progress [5]. Recruits' first half month in army is their adaptation period. During this time, training should focus on subjects that have lower strength requirement and easier to understand, such as queue exercising and equipment training. Half to two months is the mid-season of training. During this period, recruits have been familiar with army life, and training atmosphere is usually strong. Therefore, subjects of higher strength requirement and tactical subjects can be organized, such as crossing obstacles, cross-country, shooting, and basic tactics. After two months, recruit training comes to its later period. Tactic exercising within classes and platoons can be organized. Recruits should take part in comprehensive training in actual war background and improve themselves through examinations. Supplementary and recurrent training may be organized to redeem remaining defects.

Third, regulate training load scientifically. Training load is the most active factor in recruit training and also the basic engine of exercise state transfer. Organizers need to scientifically determine the measure of training load and adjust it at any time.

3.2 Innovate Training Methods

To increase the quality of recruit training, armies need to consider the new situation and problems brought by social environment change, adjustment of recruit training time, and complex component of recruits. Three aspects should be paid special attention.

First, train strictly and follow military rules. After the adjustment of new conscription time, training time has expanded. Armies need to follow military rules, carefully study the characteristics of new situation, analyze new features, and solve new problems.

Second, train happily and flexibly. Recruits bear heavy training tasks and pressure. Since many recruits are the only child at home, they may get homesick and feel hard to blend into groups. Organizers should adjust training methods flexibly. They can organize singing activities or talent shows during break, which will be happily accepted by young recruits and liven up training atmosphere. Meanwhile, since most recruits are competitive, organizers can hold military skills competition to mobilize their enthusiasm of training and improve training effect.

Third, guide recruits psychologically through training. Most recruits have a strong sense of honor. They never give up, love competitions, and eagerly want to win. This makes the launch of physical training easier and also mobilizes recruits' enthusiasm of physical training. In this way, physical training should fit recruits' psychological characteristics. Armies need to improve the whole set of rating and assessing system. Competitions can serve as a motivation for recruits. Their performances in training should be remarked every day, evaluated every week, and compared every month. Armies need to post their training results regularly, so that every recruit can see their own progress and further can create an atmosphere of competing, learning, chasing, helping, and exceeding. In training, on the basis of general subjects, organizers can also arrange some contests, confrontation, and competitive games. This can make physical training more interesting and motivate recruits' enthusiasm and persistence.

3.3 Strengthen Management and Control

To ensure that recruit training is done well, armies need to strengthen training management and control. Special attention must be paid on plan making, training organization, and training assessment [6].

First, training plans need to be made scientifically. The plan should neither be too strict nor too loose. The impact of weather and training conditions should be considered in advance. Weak points and defects in training should be overcome in time. Organizers need to achieve "full control, hierarchical management, and good links between different levels." The system is built based on three levels: department, battalion, and company; it also has three categories: stage, month, and week. On management, a stage plan should identify training goal and a month plan should identify training and supporting methods, while a week plan should identify training timetable, trainees, ground, and subjects. On setting elements, a plan should include trainees, training content, standards, assessment, ground, trainers, and training methods. On coordination, the lower rank should obey higher rank's plan. Each training element need to be linked well and avoid missing.

Second, train strictly. But apart from being strict, training should also be reasonable, scientific, and proper. Organizers need to seek a balance between training strictly and following training principles. On training content, it can never be arbitrary. Organizers cannot avoid those difficult and dangerous subjects and should never train partially, ignore, or miss some subjects. On training methods, trainers need to follow relevant regulations when guiding recruits. They should avoid being crude and eliminate bad behaviors such as corporal punishment, beating and scolding, and insulting.

Finally, assess training strictly. Assessment order of recruit training should be standardized. Examiners should not only focus on enhancing the authority of assessment, but pay more attention to identifying and solving problems in training. Training content and standards need to be refined to enhance the effectiveness of assessment.

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Research on Risk Identification of Actual Combat Training of Troops

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Abstract Actual combat training is the main path by which the fighting capacity of troops is improved. In recent years, with gradual improvement of actual combat training the complexity is on the rise and safety risk is increasingly becoming apparent, so risk management has necessarily been the main task. Risk identification is the basic step of risk management and is the basic condition of risk evaluation and is also the basis of risk control. It has important significance to strengthen research on risk identification for developing risk evaluation and risk management and control. The article mainly researches the working procedure and detailed methods of risk identification based on risk management theory in combination with characteristics and regularity of actual combat training from the basic risk factors; thereby, the article provides the basic methods and paths for risk identification.

Keywords MMESE · Troops training · Actual combat · Risk factors · Risk identification

With the continuous improvement of a strong military practice, the intensity and difficulty of actual combat training of troops are gradually on the rise, unsafe factors is increasingly expanding, safety risk is gradually apparent, and developing risk management during the training is under schedule. Risk identification is the basic step of risk management and is the basic condition and the basis of risk control. Therefore, it is of great realistic significance to strengthen research on risk identification during actual combat training, to check risk factors scientifically and,

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respectively, to provide basis for risk evaluation and risk control, and to promote finishing actual combat training tasks smoothly and safely.

1 The Basic Risk Factors

Different training activities have different risk causes, but have common points. To sum up, there are the following 5 risk causes of actual combat training.

1.1 Risk Factors of the Training Tasks

Risk factors of the training tasks mainly include three aspects: One is about the complexity of risks. Actual combat training complexity differs in certain degree, so does the degree of risks; the more complicated the training tasks are, the higher the training requirements are, the higher the risk degree is. Two is about the scale of the risk. The bigger the training scale is, the higher the joint degree is, the higher the risk degree is. Three is about the risk in training danger, training difficulty, and training intensity. The higher the training danger is, the bigger the training difficulty and the training intensity are, the higher the risk is.

1.2 Risk Factors of the Trainees

Risk factors of the trainees mainly include 3 aspects: One is about physiological and psychological risks. These risks refer to overrun load, physiological fatigue, abnormal psychology, and abnormal healthy condition for officers and men; two is about the risks in quality and ability. These risks refer to weak risk consciousness, poor preventive ability, and imperfect technical level for the working staff, commanders, and managers during the training time. Three is about behavioral risks. These risks refer to human error factors such as operational error and mistakes in command for officers and men including violation in organization, command, support, operation, and other unsafe habits [1].

1.3 Risk Factors of Equipment and Materials

Risk factors of equipment and materials mainly include two aspects: One is about physical risk. These risks mainly refer to the following defects in weapons and equipment, facilities, technical prevention, safety protection, signal mark, and so on. Two is about chemical risk. These risk factors mainly refer to dangerous ones of ill-formed technical criterion in storing, transporting, keeping, using, protecting inflammables, and explosives and toxic substances.

1.4 Risk Factors of the Training Environments

Risk factors of training environments mainly include three aspects: One is about bad weather conditions. These risks mainly refer to ones the terrible meteorology and hydrology cause; two is about poor geological terrain. These risks mainly refer to ones uneven roads, complicated area, and geological disasters cause; three is about other environmental risks. These risks mainly refer to ones complicated social conditions, public feelings, and the epidemic bring in the neighboring area when troops training [2].

1.5 Risk Factors of Organizational Management and System

Risk factors of organizational management and system mainly include two aspects. One is about training system and standard risks. These risks refer to ones imperfect rules and regulations and ambiguous technical criterion bring; two is about organizational management risks. These risks refer to ones unscientific training schemes, unreasonable training plans, imperfect safety organization, lack of implementation for safety responsibilities, and ineffective management function bring.

2 The Basic Process of Risk Identification

Risk identification of actual combat troops training is a process that a series of activities constitute, and the whole process generally includes the following 6 steps.

2.1 Making Clear Identification Object

Making clear risk-identification object is the first link of risk identification. Firstly, carrying out risk identification is to make clear the object of risk identification, to confirm the range of risk identification, and also to confirm the important point through analysis of the working units, staffs, equipment, and risk factors distribution that risk identification involves; then, according to training arrangements, time limit of the completion and requirements is confirmed.

2.2 Making Known the Basic Situation

After making clear identification objects, the working staff still make known the related situation. One is about training safety in the past, including developing risk management in the past, what had happened in training accidents and the important points of safety management. Two is about training environments, including hydrology, climate condition, road and traffic situations, geological terrain, social conditions, and public opinions in the training area. Three is about the current training situation, including the current nature of the task, scheme and subject design, the composition and number of the working staff, equipment, organization, and leadership.

2.3 Confirming Identification Methods

Selecting suitable risk identification methods is an important step. Confirming identification methods should combine actual combat troops training characteristics, follow the principles with simple practicality and easy operation; emphasize integrated application of all kinds of identification methods. For example, we may firstly tease out the training process making using of flowchart method; we may also check and identify inherent static risk making using of simple risk checklist method and spot investigation method. We may still analyze and identify the unknown dynamic risk during the process of troops' mobility, assembly, and training implementation making use of flowchart interpretation method.

2.4 Preparing for Tools and References

After selecting identification methods, the necessary survey instruments need be prepared such as risk issues lists, questionnaires, and the basic chart. Whether tools and references are properly prepared or not has an important influence on effective implementation of investigation. One is that tools and references should fully be prepared, the necessary tools are listed in the form of list according to risk identification need, and all are prepared one by one. Two is that the professional staff should be designated to be responsible for the tools with strong specialty, and advice is extensively asked for to make sure the tools and references application scientifically and reasonably.

2.5 Deepening Investigation and Research

Deepening investigation and research is the key link of risk identification. Risk identification staff should go to each working unit and place, find the dead angles to the problems, fully check risk lists carefully, and simply analyze and sum up risk problems so as to provide an effective data support for confirming identification result. All officers and men need be called on to actively participate and provide real data and references in order to make investigative result scientific and precise.

2.6 Analyzing Affirmative Result

Analyzing affirmative result is the last link of risk identification. Risk investigation and risk situation are fully analyzed comprehensively; thus, risk projects are confirmed, and risk identification results are reached. Risk results are analyzed and confirmed through questionable assumptions, simulation experiments, and brainstorming or by way of the experience, common knowledge, and judgment of the working staff.

3 Risk Identification Enforcement

Risk identification enforcement is to identify and analyze the possible existing risk factors during the training process according to the basic process of risk identification through selecting suitable risk identification methods. Risk identification methods mainly include flowchart method, risk checklist method, spot investigation method, and expert evaluation methods [3]. Now the risk is identified toward training preparatory phase, training enforcement phase, and other key parts in combination with an actual combat training situation for a certain troops unit.

3.1 Risk Identification of Training Preparatory Phase

During the training preparatory phase risks are relatively steady; these risks are inherent ones involving staff, equipment, environments, organization, and management. These risks belong to static ones and may be identified through adopting risk checklist method. By way of applying risk checklist method, risks are identified, firstly risk checklist needs be worked out, then we check the possible risk parts and links, and finally we analyze and conclude risk identification. Risk identification results during an actual combat training preparatory phase for a certain troops unit are as follows. See Table 1.

Table 1 Risk identification results during an actual combat training preparatory phase for a certain troops unit

Sources	Causes	Influence on safety
Training tasks	1. Strong work intensity; long-distance troops march; complex training subject design; continuous work with long time 2. Complex and difficult military confrontation; complicated training environments; almost real confrontation contents with higher requirements 3. An unprecedented joint degree; training involves arms and more elements	Much more serious safety situation, much higher risk degree during the training process
Training staff	4. Some of the wounded soldiers lose confidence because of slow recovery; there exist some negative thoughts such as panic and fidget 5. Strong military training for long time causes body fatigue, breeds war-weary thoughts, emotion of fearing hardships appears, and consciousness of enduring hardship fades out 6. Much higher requirements cause some soldiers to have bigger psychological stress; lack of effective and communicative channel	Ideological and psychological problems in action may lead to distracting attention and trigger safety problems, or cause other emergency events
Equipment and materials	7. Some equipment and accessories are excessively used and overrun; they are timely declared worthless or returned to the factory repair without complying with regulations 8. Some equipment maintenances do not conform to regulations according to maintenance record and this cause techniques and tactics performance to decline seriously 9. Lack of proficiency for operators leads to incomplete troubleshooting, poor maintenance standard, and cheating on labor and materials, thus potential safety problems are hidden 10. Equipment operating is not well organized; some working staff are eager to seek preparation speed of equipments 11. Some equipment and vehicles are not equipped with safety precaution equipment such as extinguisher and warning signs	Potential safety problems are hidden for the follow-up units action and firing practice; equipment operating is not well organized and poorly managed, all these easily trigger crushing, bruising, scuffing, and the loss and damage to the equipment

(continued)

Table 1 (continued)

Sources	Causes	Influence on safety
Training environments	12. Road conditions are complex; in some sectors of an area terrain height is greatly different; roads are very narrow; civilian vehicles speed is much higher 13. Soil texture of some area in shooting range is very soft; marching in the rainy days and battlefield mobility are much more difficult; in some area mountains and hills are surrounded with poor communication conditions 14. Altitude in the area is very different; it takes some officers and men with physical weakness a certain time to adapt new environments 15. Enemy agents are very active and maintaining confidentiality is very difficult 16. Training area is relatively sparsely populated; habitation is far away with each other; materials support is much difficult 17. The hotter weather and stronger ultraviolet rays have much bigger influence on continuously high-intensity training	In training environments unsafe factors have much bigger influence on troops' action, hence there are much higher requirements for troops action
Organization, management and system	18. Training mobilization and conveying tasks are not comprehensive; some working staff are very vague for the present situation and tasks 19. Some new platoon commanders are lack of experiences of leading troops; loose managements are easily caused owing to improper methods 20. Some mainstays have much higher management requirements; these greatly decrease subordinates' enthusiasm 21. Some recruits do not have perfect and thorough understanding concerning the important tasks; grasping and finishing tasks easily causes deviation 22. Preparatory training work is very miscellaneous; there are many staff in the hospital or receiving further study and special training; the staff is dispersed, and it is very difficult to manage them	Much more difficult organization and management are easily out of control and trigger interior tension

During training preparatory phase risk identification is also to check training preparation, educate officers and men, and rectify and reform some risk problems. From Table 1 we may see we can not finish identifying many risk factors only depending on risk identification staff, extensive participation of officers and men is needed. Therefore to make sure risk identification accurately and objectively, we need to educate and instruct officers and men, check risk parts strictly and carefully, and avoid influence from individualistic subjective factors.

3.2 Risk Identification of Training Implementation Phase

During training enforcement risk is dynamic and changeable, and belongs to dynamic one; it is difficult to judge their types and degrees; the risk is normally identified through adopting flowchart method. By way of applying flowchart method risk is identified, firstly training enforcement flowchart need be worked out, and flowchart interpretation table need be drawn, then we analyze and check the possible risk in each part or link, and finally we conclude risk identification. During remote projection, we need to work out the interpretation table and then analyze the possible accidents, consequence, the final influence, and the real cause in each link of the phase, and finally we have trouble shooting and conclude risk identification. See Table 2.

3.3 Risk Identification in Other Key Parts

Except risk identification of the two phases over training preparation and training enforcement, we should still focus on checking the key parts in the whole training process specially. In these key parts risk factors are complicated; we need identify risk by way of applying checklist method, flowchart method, experts' meeting, survey, and investigation. The risk of the key parts mainly includes the following items.

Firstly, risk of fuel management. Whether transportation, storage, and management of fuel are well organized or not will have an important influence on safety. If there are fires or explosion the loss will be unpredictable.

Secondly, risk of ammunitions management. The main potential risk ammunition management faces is also fires. Whether the transportation, storage, and management of ammunitions comply with safety requirement or not should be drawn attention.

Thirdly, risk of safety and confidentiality. We should effectively evaluate the risk factors such as whether confidentiality system is implemented or not, whether confidentiality education is deepened or not, whether confidentiality facilities are perfected or not, and whether media management concerning confidentiality is strict or not [4].

Table 2 Risk identification results during a remote projection phase for a certain troops unit

Links	Motorized march	Railway transportations
Potential risk accidents	Rear-end collision and rollover crash of interior equipment and vehicles; scratching and crashing with civilian vehicles; attack from terrorism and so on	Falling down or rollover crash of the staffs and equipment in the trailers; weapons and ammunitions catch fire or explode; in the electric railway high-voltage arc is harmful to human health
causes	Confused organization and command; inadequate responsibility of officers in charge of vehicles safety; poor driving skills of drivers; concentration is distracted; excessively shorter distance between moving vehicles; violation of driving regulation; lack of guards and signs in the junctions; equipment do not abide by the regulation to connect air brake system and so on	Dragging the vehicles to the trailer without complying with regulations; equipment is not well fastened; officers and men move around in the trailer without complying with regulations; working on the top of equipments and so on
Possible consequence and loss	Possible casualties include drivers, officers in charge of vehicles safety, other officers and men in the vehicles, civilians; vehicles and equipment are declared worthless or damaged	Some casualties including falling down of staffs, electricity hitting; weapons and equipment are declared worthless or damaged

Fourthly, risk of camp sites selecting. Whether camp sites selecting comply with safety standard will be important; if natural disaster happens whether it will influence lives and property safety of officers and men and whether it is feasible to transfer officers and men safely or not will also be the key risk problems [5].

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Research on Operators' Selection Testing System Based on VTS

Runfeng Hou, Zhibing Pang, Cheng Jin, Zaochen Liu, Hongyan Ou and Haitao Zhao

Abstract Purpose: Through analysis and research VTS testing system will be applied to operators' selection and training and make selectiong and testing more scientific, standardized, and accurate. Method: The testing method of typical module in the VTS testing system is analyzed, and thus is applied to operators' selection and training. Result: VTS testing system may quantitatively describe the operators' physiological and psychological index accurately and make selection course scientific and standardized. Conclusion: It is of great significance to apply VTS testing system to operators' selecting, and it can dramatically promote selection operability, and thus improve capability about the combination of man and machine.

Keywords Operators selecting · VTS · Testing system

1 Introduction

Under the informationized condition, weapons and armaments are renewing rapidly, selecting the qualified position operators is not only one of the most important work, but also the basic path to improve troops fighting abilities; however, how to select operators scientifically and reasonably is the most important [1]. VTS (Vienna Test System) testing system adopts advanced foreign technology; mass modules are integrated in computers; in the meantime, it also adopts high-level hardware equipments, evaluates human intelligence, physical agility, skill and psychological personality scientifically and completely; quantitatively describes human physiological and psychological index. VTS testing system is applied into operators' selection and training and makes each index embodied in the

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form of accurate data and discriminates the difference among operators using the data; operators are trained scientifically and complemented one another perfectly, thus arrived at the state on the man–machine combination, and finally promote training effect.

2 Significance on Operators Selecting

Operators selection here means selection expectedly competent operators for specific equipments from serviceman community. The purpose is to combine man and the characteristics of the equipments organically and constitutes man–machine system with high efficiency to improve systematic reliability [2]. The essence is to find out the best combination between equipments and man. Aiming at training competent position operators, starting from equipments specialty and based on human's operation specialty, operators' selection and evaluation are discussed. As long as operators are scientifically selected, they will be in the best working state and reach the best combination between man and machine, and thus systematic working efficiency can be improved; the best systematic performance can be developed. There are three important significances on operators selecting.

Firstly, with the process of informationization, military equipments are rapidly renewing, military positions have been divided gradually in more detail, and great change has taken place for operators' demand. In combination with the current situation in the army there exist some questions such as much more qualitative analysis, much more subjective casualness, much less quantitative analysis, inadequate scientificity on operators selection method. To a certain degree, shortage of these 'soft power' has been the limit for military development and should also be the important link of development.

Secondly, from the production of combat effectiveness, it will shorten the production cycle and improve production speed of combat effectiveness to select more suitable working staff with the related position demand to a certain degree [3]. Meanwhile, the staffs with scientific selection have the corresponding condition and can meet the basic quality and demand of the position. Thus operators may effectively reduce human errors during the training process and guarantee the perfection of equipments and can effectively prevent safety accidents and decrease noncombat loss.

Thirdly, from the economic perspective, if we can rationally design positions and select more suitable working staff with the related position demand, thus we can effectively allocate human resources, shorten training time, decrease investment cost, and further promote the whole economic benefit of the military training.

According to different operation demand of the equipment, operators are selected to rely on specialized measuring equipment and apply scientific theoretical result, measure and judge the candidates' physiology and psychology, in combination with the objective of demand to select operators with the adaptable position demand [4].

3 Analysis on VTS Testing System

VTS testing system has 138 scales and more than 80 testing programs involving multi-domain psychological testing module such as intelligence test, nonverbal language ability test, general aptitude test, special aptitude test, personality structure test, attitude and interest test, aviation psychological test, traffic psychological test, leadership test, and clinic diagnostic test. It was widely applied to testing and selection of physiological and psychological indexes on talents. For each scale and test, VTS system has attached the detailed introduction including its theoretical background, the course and result of the formation, and development now we have an analysis on operators' selection and testing based on VTS system from the following 3 aspects.

3.1 Testing System on Special Intelligence

Testing system on special intelligence has 17 modules and is mainly applied to equipments operators' selection and training with complicated human–computer interface. Through the system, intelligence index on operators' memory and reaction is improved and man–machine combination ability is promoted. Now we analyze the module of the system from the typical cases.

3.1.1 VISGED (Visual Memory Test)

We analyze the module from the following aspects:

One is about application. The test evaluates the subjects' visual memory through testing their accepting and reviewing visual information (memorizing the icon and location in a city map). Two is about theoretical basis: The theoretical basis of the test is Visual Performance Theory from Kosslyn, processing model of consolidated information from Hanggi, and the related knowledge of "memory dots" among visual memory. Three is about testing form. There are 3 testing forms according to different degree of precision. Four is about scoring: the subjects score according to the following index: correct number, position offset, and reaction time. Five is about testing time: The testing time lasts from 10 min to 15 min according to different testing form.

3.1.2 RT (Reaction Time Test)

We analyze the module from the following aspects:

One is about application: The test precisely records reaction time to millisecond, meanwhile involving alert field, the ability to press the wrong reaction (a noticeable related field with diagnosis), and covering the distinction between alert and mode in the special form. Two is about theoretical basis: Dorsch defines the reaction time from signal occurrence to the reaction time of the subjects in milliseconds. Because, there exists reaction test; the measure of the reaction time involving single choice and multiple choices has become possible. Three is about testing form: The subjects receive instructions and press the reaction button when the interrelated stimuli appear on the screen. Four is about scoring: the subjects score according to the following index: correct reaction number, wrong reaction number, and reaction time. Five is about testing time: The testing time approximately lasts from 5 to 10 min.

3.2 Testing System on Special Aptitude

Testing system on special aptitude includes 34 modules and is mainly applied to selection and training of position operators with stronger skills and a large amount of operation. Through the system, operators' ability of sensory coordination and body coordination is improved and operators' physical function is relatively comprehensively progressed; thus, the whole task performance is advanced. Now we analyze the module of the system from the typical cases.

3.2.1 2HAND (Two-Hand Coordination Test)

We analyze the module from the following aspects:

One is about application: The system evaluates eye–hand coordination and hand–hand coordination and analyzes the tracking system and trains the subjects' coordination. Two is about testing form: The subjects employ the control knob or operating lever to control a luminous dot to move within the preset orbit and will move the luminous dot from right side to left side. Three is about scoring: The subjects score according to the following index: overall average duration, overall average time error, and overall time error percentage and speed, and thus, the reliability and validity of the subjects are worked out. Four is about testing time: The testing time approximately lasts from 10 to 15 min.

3.2.2 PP (Peripheral Perception Test)

We analyze the module from the following aspects:

One is about application: The system evaluates the subjects' perception from peripheral visual information. Two is about testing form: Through two knobs, the subjects control the cursor on the screen to track down the small balls with random movement; meanwhile, through a glance, the light stimulus is perceived from the two sides of the panel, when the key stimulus appears reaction is given through pedaling. Three is about scoring: The subjects score according to the following index: visual field, the right side and left side of the visual angle, tracking deviation, right click and left click, wrong reaction, missing reaction, and reaction time. Four is about testing time: The testing time lasts about 15 min.

3.3 Testing System on Personality Formation

Testing system on personality formation includes 3 modules and is mainly applied to evaluate operators' personality, character, and psychological index. Through the system, objective quantitative index is applied to make psychological test have strong operability and make abstract psychological phenomenon shown in the form of objective data with accuracy, objectivity, and economy [5] and also to make commanders master operators' psychological status comprehensively, thus guarantee training safety and high efficiency.

3.3.1 EPP6 (Eysenck Personality Profiler)

We analyze the module from the following aspects:

One is about application: The system is applied to evaluate 3 personality factors: extroversion, emotionality, and adventure. Two is about theoretical basis: EPP6 is an organizational multidimensional questionnaire based on EPP. Because of huge bandwidth of the models, the extroversion, emotionality, and adventure from EPP have better fitting with the overlapped hierarchical structure from Five-factor Model. The 3 universal factors are very typical. Three is about testing form: After instruction testing projects are presented one by one, the subjects input answers with three keys 'yes', 'no', and 'uncertain'. After answering, next project immediately appears, the previous project may be modified. 440 projects may be tested in accordance with the testing method, each projects also include 21 subscales. Four is about scoring: Original score includes subscale score, open scale score, and 'unanswerable' number. Original scores form the three factors are given from each scale. Five is about testing time: The testing time lasts about 55 min.

3.3.2 TCI (Temperament and Character Inventory)

We analyze the module from the following aspects:

One is about application: Based on lots of genetics research, the testing system is affirmed and is applied to evaluate human personality and temperament and to evaluate four-dimensional temperament, three-dimensional personality, and 24 sub-dimensions. Two is about theoretical basis: Temperament is a kind of experience produced by automatic emotional response. These human qualities belong to genetic factors and are kept in relatively stable status. On the contrary, 'Disposition' here refers to self-concept, whether personal goals are consistent with value, that will influence free decision, intention, and the importance of experience. Three is about testing form: The subjects must answer 240 questions with ‘yes’ or ‘no’. The subjects must give their answers otherwise they will be reminded in the end. Four is about scoring: The four temperament characteristics and three personality characteristics are evaluated, and the four temperament characteristics are uniqueness, self-protection, dependence, and will. The three personality characteristics are self-control, cooperation, and self-transcendence. Five is about testing time: The testing time lasts about 30 min.

4 Concluding Remarks

With the rapid development of information technology and continuous updating of weapons and equipments, the differences of talent demand with different equipments and positions are on the rise, special requirements for operators are increasingly higher, all these will force us to further reinforce selection of operators and research on human adaptability so as to arrive at the best combination between man and machine. Through analyzing the typical testing module of VTS system the article quantifies operators’ intelligence, physical agility, and skills and personality index; strengthens operability of operators’ selection and training with the help of scientific testing; and evaluating means of VTS system; thus, they will be satisfied with the demand of future war.

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Research on Evaluation Index and Method of CRM Training

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Abstract The Advisory Circular AC-121-FS-2011-41 was analyzed systematically to determine indices and methods for crew resource management (CRM) training and examination, and totally 65 items were collected from six parts of CRM training. Firstly, 25 specialists in aviation psychology and flight were selected for Delphi method survey and analytic hierarchy process (AHP). There were 65 indices in two levels specified by the three rounds in Delphi iteration, and the weights were rated as 0.112, 0.193, 0.138, 0.218, 0.242, and 0.097 for the top indices such as essential recognition, error management, decision making, communication, leadership and cooperation, and management of workload after AHP. Secondly, 8 pilots were voluntary to take part in an examination after CRM training on transport simulator flight to validate the indices and methods for CRM training and examination mentioned above. A group of 3 examinants rated points while watched training videos. The results were found that the indices and methods can distinguish 8 of the pilots and 5 of their compounding in three different CRM levels, and coincidence indicator was 0.92 among the examinants. It suggested that the examination methods can be applied in CRM training of flight.

Keywords CRM · Aviation · Pilot · AHP · Evaluation indicator · Validity · Reliability

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1 Introduction

Among all causes of civil aviation flight accidents or accident proneness, human error accounts for 60–80 %. Particularly in “two-crew” or “multi-crew” cockpits, many problems that occur in the aircrew are not necessarily associated with technical operations, but are closely related to crew resource management (CRM), including poor communication, improper group decision making, incompetent leadership, declined or lack of situational awareness, uneven distribution of workloads, and improper resource management [1]. The fundamental reasons include two aspects. One is that conventional wisdom emphasizes pilots’ individual performances and considers that the proficiency and technological levels of individuals represent those of the whole aircrew, not paying enough attention to psychological control of the aircrew, group decision making, and teamwork efficiency; the other reason is that as aviation technology gets increasingly advanced, automation becomes more and more important for flight control. As a result, “monitoring–decision making–control” is taking place of conventional “operation”-focused mode and different roles are emphasized under complicated working environment, raising requirements for CRM of the aircrew [2]. Therefore, the leadership of the pilot in command, cooperation of the crew, and teamwork efficiency of the crew are the key focal points of aircrew configuration. As the aircrew is lacking CRM, many airlines have introduced the CRM training for crew, consisting of two stages. Stage 1 is the concept stage, which lets the crew understand and get familiar with CRM. Stage 2 is the practice and consolidation stage, which incorporates CRM into various practical flight training and airline operation and obtains information feedbacks for improvement in awareness and skills of CRM. However, there is no unified assessment method for the effect of CRM training. A specific and feasible dynamic assessment system of indicators and methods is badly needed in civil aviation regarding the effect of CRM training so as to improve the crew resource management ability for multi-crew cockpits for better safety.

2 Indicator System Analysis for CRM

2.1 Objective

AC-121-FS-2011-41 content was analyzed with expert—evaluating method to find influencing factors on CRM and to define indicator system for dynamic assessment of CRM. On this basis, find the weight of each influencing factor.

2.2 Subjects

A total of 25 psychologists and flight experts (flight rating: level 1 or above) who have rich flight knowledge. Age: 43 ± 2.92 years.

2.3 Research Material

AC-121-FS-2011-41 is issued on November 30, 2011 by CAAC (Civil Aviation Administration of China), including 65 items of 6 categories.

2.4 Research Method

Delphi method to establish CRM indicator system: Ask the experts to analyze the 65 items in AC-121-FS-2011-41, collect experts' opinions, and eventually conclude a CRM indicator system after 2–3 rounds of surveys (Table 1). To ensure the results' reliability, require each expert to rate his proficiency in each filed himself on a scale of 1–10. Ratings above 8 (including 8) will be adopted [3, 4].

Analytic hierarchy process (AHP) [5, 6]: Experts conduct pairwise comparisons for all factors using analytic hierarchy process so as to determine the relative importance of each factor within the same hierarchy. Then, the weight of each indicator of the CRM indicator system is determined. The experts surveyed are from the same expert group.

1. Data statistics and processing
   Sum up the expert survey results with ordering relation method; process the weight survey results using AHP.
2. Establish judgment matrix U
   Element U_{ij} means the relevant importance ratio of indicator i; see Table 1 and the below matrix for the weight of each factor:

$$\mu_{ij} = \frac{1}{\mu_{ji}}, \quad \mu_{ij} = 1, \quad i, j, = 1, 2, \ldots, n \tag{1.1}$$

$$U = \begin{matrix} \mu_{11} & \cdots & \mu_{1m} \\ \vdots & \vdots & \vdots \\ \mu_{n1} & \cdots & \mu_{nm} \end{matrix}$$

Table 1 CRM indicator system and weights

Levels	Primary indicators	Weights of primary indicators	Secondary indicators	Weights of secondary indicators
CRM indicator system	U_1 general cognitive activities	0.112	U_{11} system awareness	0.278
			U_{12} environmental awareness	0.256
	U_2 error management	0.193	U_{21} error prevention	0.375
			U_{22} error identification	0.375
	U_3 decision making	0.138	U_{31} risk identification	0.265
			U_{32} risk assessment	0.235
	U_4 communication	0.218	U_{41} communication method	0.375
			U_{42} communication effect	0.248
	U_5 leadership and cooperation	0.242	U_{51} prestige and confidence	0.148
			U_{52} rule support and maintenance	0.324
	U_6 workloads management	0.097	U_{61} work planning and arrangement	0.575
			U_{62} emotion control	0.425

3. Calculate the weight of each indicator:
   Calculate row by row

$$v_i = n\sqrt{\prod_j \mu_{ij}} \tag{1.2}$$

$$\omega_{\mathrm{i}} = \frac{v_{\mathrm{i}}}{\sum v_{\mathrm{i}}}, \quad i = 1, \ldots, n \tag{1.3}$$

4. Consistency check
   According to the formula

$$\mathrm{C.I} = \frac{\lambda_{\max} - n}{n - 1} = 0.028 < 0.1, \tag{1.4}$$

   the matrix is considered to be consistent.
5. Calculate the weight of each factor of the expert group.
   A total of 25 experts participate in the assessment for weight value ω_{ij} of the i indicator and j expert.

2.5 Results

Crew resource management refers to the thorough, efficient, and proper utilization of all available resources to ensure safe, efficient flight [7, 8]. Through man–machine harmony, man–man harmony, and self-harmony, the crew resource management is integrated into a unity of man, machine, and environment. The man–machine harmony concept comes from the modern CRM's description of flight process, i.e., the whole fight process is a continuous error correction process. Therefore, we divide the "errors" into three levels: "minor" (general cognitive activities), "intermediate" (error management), and "major" (decision making). The man–man harmony can be achieved by improving the communication skills and teamwork spirit of the aircrew. Self-harmony refers to proper task distribution and emotion control shown in Fig. 1.

After 3 rounds of surveys, 127 opinions from experts are summed up and the weights thereof are calculated using AHP method. CRM is divided into two levels. The indicator system and weights are listed in Table 1.

The expert team has analyzed and classified the 65 items of 6 categories in AC-121-FS-2011-41. Through the verification of small samples from flight experts, taking clustering analysis results as a basis for classification, the assessment indicators for CRM and corresponding behaviors of indicators of each level are acquired so that the assessment experts can scientifically capture the behaviors of pilots in the cockpits during simulated training. Consistent judgment and assessment are made. Part of CRM assessment indicators and behaviors are listed in Table 2.

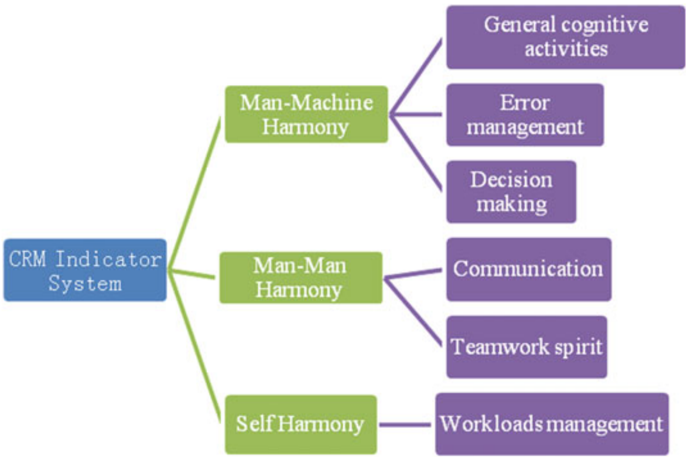

Fig. 1 CRM indicator system framework

Table 2 CRM assessment indicators and behaviors

Primary indicators	Secondary indicators	Behaviors	
		Good	Poor
General cognitive activities	System awareness	Know and understand the flight system and changes	Lack knowledge of flight system
	Time awareness	Good flight time awareness; know flight time and future situations	Lack time awareness
Error management	Error prevention	Promptly correct errors before the flight goes into unexpected situations	Cannot identify potential environmental or operational risks
	Error identification	Promptly identify errors before the safety is influenced or the flight goes into unexpected situations	Cannot identify errors occurred leading to more severe safety risks
Decision making	Planning	Select schemes	Fail to collect information and make schemes
	Risk identification	Conduct risk identification of schemes	Limited discussion among aircrew before determining schemes
Communication	Communication mode	Pay attention to disagreement	Lack consideration of others
	Communication effect	Consider feedbacks	Lack feedbacks
Leadership and cooperation	Prestige and confidence	Understand one's own position; make commands when necessary	Negative, lack self-motivation, and fail to understand one's own position
	Rule support and maintenance	Supervise and ensure rules being followed	Fail to follow and make others follow the rules
Workloads management	Work planning and arrangement	Clearly communicate and determine distribution of tasks and task priority	Improper task distribution
	Emotion control	Keep calm and behave as good models under emergency	Fail to control emotion properly

3 Dynamic Assessment of CRM

3.1 Objective

Based on the pilots' airline operation training on simulators, the assessment indicators and methods of CRM are validated. Discrimination validity and scorer reliability are calculated to verify the effectiveness and reliability of indicators and methods.

3.2 Subjects

A total of 20 male cargo pilots from an airline were selected. Age: 34.93 ± 9.24 years. Flight time: 2565 ± 1856.1 h.

3.3 Assessment Method

The team consists of 2 technical/flight instructors with long-term experience in simulated cockpit training and 1 psychologist. The judge team makes an on-site inspection of the simulated flight training and rates on a scale of 1–9 (9 is the best) according to the CRM indicator system and behaviors [9].

3.4 Results

Results of different items: The assessment results of the 8 pilots assessed by 3 experts have no significant difference. Based on normalization, assessment scores are obtained for 6 categories. Standard scores are calculated according to the formula $S = 15Z + 100$. One-way ANOVA analysis shows that there are significant differences among groups ($F = 15.15$, $P < 0.001$). The rankings of different categories are listed in Table 3 (Fig. 2).

It can be speculated from the assessment results that A and B have the most contribution to the good performance of the aircrew, especially in communication, and are more competent regarding the improvement of crew resource management ability. Mann–Whitney U-test and one-way ANOVA analysis show that there are significance differences between A's CRM assessment results and other 7 pilots' as well as between B and H's and other 5 pilots'. Therefore, the assessment method has preferable discrimination validity.

CRM assessment results of different aircrews: In simulated flight training, 8 pilots can make 9 combinations. The assessment results of the 9 aircrews have no

Table 3 CRM assessment results of 8 pilots

Name	General cognitive activities	Error management	Decision making	Communication	Teamwork spirit	Workloads management	Standard scores	Rankings
A	0.43	0.69	0.67	0.85	0.57	0.37	109.0	1
B	0.17	0.49	0.41	0.58	0.36	0.01	105.1	2
C	−0.42	−0.02	−0.28	0.01	0.02	−0.36	97.4	3
D	−0.30	−0.02	−0.08	0.02	0.01	−0.39	98.1	3
E	−0.27	0.02	−0.30	0.04	−0.03	−0.34	97.8	3
F	−0.32	−0.18	−0.27	−0.08	−0.42	−0.53	95.5	3
G	−0.33	−0.03	−0.16	0.04	0.23	−0.37	98.5	3
H	0.03	0.28	0.08	0.40	0.32	−0.13	101.5	2

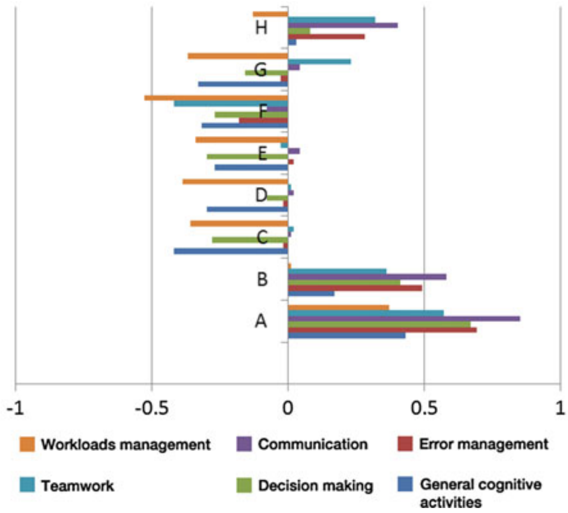

Fig. 2 CRM assessment results of 8 pilots

statistically significant difference. The assessment results of the 9 combinations assessed by experts have no significant difference. Based on normalization, assessment scores are obtained for 6 categories. Standard scores are calculated according to the formula $S = 15Z + 100$. One-way ANOVA analysis shows that there are significant differences among groups ($F = 25.26$, $P < 0.001$). The rankings of different categories are listed in Table 4.

The results show that the CRM performance of aircrew combinations 1, 3, 6, and 7 is excellent; combinations 2 and 8 are relatively weak in six aspects and are significantly lower than other combinations ($P < 0.01$).

Scorer reliability results: Conduct correlation test for assessment results from 3 expert groups, according to the formula below:

$$w = 12\left[\sum R_i^2 - \left(\sum R_i^2\right)^2/N\right] \Big/ \left[K^2(N^3 - N) - K\sum\sum(n^3 - n)/12\right] \tag{1.5}$$

The result is $w = 0.92$, which proves that the assessment method has preferable reliability.

Table 4 CRM assessment results of different aircrews

Group	Member names		General cognitive activities	Error management	Decision making	Communication	Teamwork spirit	Workloads management	Total points	Rankings
1	A	B	1.0	0.7	1.3	1.2	0.6	0.5	113	1
2	C	G	−1.4	−1.5	−1.2	−1.7	−1.5	−2.0	77	3
3	E	D	1.0	0.7	0.5	0.5	0.6	1.2	111	1
4	A	C	−0.6	0.7	−1.2	−0.9	1.3	−0.1	98	2
5	C	F	−0.6	−0.8	−0.4	−0.9	−0.8	−0.4	90	2
6	B	D	1.0	0.7	1.3	0.5	0.6	0.5	111	1
7	A	D	1.0	0.7	0.5	1.2	0.6	1.2	113	1
8	E	F	−1.4	−1.5	−1.2	−0.2	−1.5	−0.7	84	3
9	H	G	0.2	0.3	0.5	0.5	−0.1	−0.1	103	2

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Mechanism Analysis of Astronaut Manual Rendezvous and Docking Human Error Based on Reason Model

Jiayi Cai, Weifen Huang and Jie Li

Abstract To ensure that the astronaut manual rendezvous and docking mission can be done smoothly, the mechanism of the human errors was analyzed based on Reason model after analyzing the existing human error models. The astronaut manual rendezvous and docking human errors were divided into three types of three different cognitive levels. Mechanism of human errors was analyzed by combining each process operation. Horizontal and attitude handle operations may lead to KB level errors, field switching errors arise RB level errors, and image perception belongs to SB errors. And it provides a reference for the next astronaut training.

Keywords Rendezvous and docking · Human error · Reason model · SRK model

1 Purpose of Research

In the 1940s, a variety of complex and high-performance military equipment was used in the Second World War. Complex man–machine systems caused high-frequency occurrence of human errors and serious consequences; thus, people began to pay more attention to the reliability of man–machine system and began the research on human errors. Human errors refer to the damage or operation failure of the machines, equipment, and system since the working personnel fails to accomplish the specified operation according to the specified accuracy, time, and sequence. According to the research, it was found that 70 % of the accidents were caused by human errors in the fields of nuclear industry, chemical industry, and transportation [1]. In the civil aircraft crashes, 73–80 % of the accidents were caused by human errors. In the manned space flight, the accidents caused by the

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astronauts' errors in operation are also common. Astronauts' manual rendezvous and docking refers to that the astronauts manually control the translation and attitude manual controllers and adjust the spacecraft's state of motion in six degrees of freedom, so as to make the two spacecraft rendezvous at the same time and the same speed in the same position of the orbit and be connected to a whole. Manual rendezvous and docking missions mainly begin in the final approaching phase of the whole rendezvous and docking process. The process of a manual rendezvous and docking operation contains dozens of or even hundreds of alternate cognitive and operational activities. Each activity may affect the success of the entire mission because of the astronauts' errors. The astronauts' psychological state changes indifferent phases of the missions, the cognitive processing of external information, mode of thinking of operation, and decision-making under certain circumstances, levels of situation awareness under different levels of skill proficiency, and other aspects will affect the successful accomplishment of the missions. Therefore, mechanism analysis on astronauts' human errors in manual rendezvous and docking shall be carried out from the perspective of cognitive psychology, so as to provide theoretical guidance and reference to avoid the occurrence of human errors in astronauts' on-orbit dynamic operation.

2 Research Method of Human Error

The main purpose of the research on human error mechanism is to find out the root causes of human errors and provide the basis for the establishment of preventive measures. The main analysis method is to classify the human errors and carry out mechanism research on them. With the further research of human error categories, the categories gradually develop from the categories of simple executive behavior to the categories of cognitive process analysis. The human error theoretical models for the exploration of human cognitive behaviors are mainly Norman model, S–O–R model, Rasmussen model, Reason model, etc.

Norman approximately divided human cognitive process into three parts: information collection, intention formation, and intention execution. The mechanisms of errors occurred in different phases are different. Stimulation–organism–response (S–O–R) model divides the human cognitive process into three parts: perception, receiving stimulation signals, interpretation, and decision-making and output actions.

Rasmussen taxonomy is mainly used to describe the process of human cognitive behaviors. Jens. Rasmussen from Denmark's Risoe National Laboratory classifies human cognitive activities according to the theories of cognitive psychology and represents human cognitive activities as skill-based, rule-based, and knowledge-based activities by different signals, signs, and symbols [2]. Skill-based cognitive behavior pattern means the behavior pattern that the operators can respond almost without thinking. This pattern is similar to a human instinctive reaction. Rule-based cognitive behavior pattern means the operators need to choose certain rules and execute missions according to the requirements of the rules. Knowledge-based cognitive behavior pattern means the behavior pattern that the operators need to rely on their own knowledge and experience to analyze, make decisions, and execute. Human errors are affected by the operators' skills, experience, and degree of familiarity with the operating environment. The human errors occurred at each level of cognitive behavior are different. Rasmussen discussed human errors in depth and formed error taxonomic method based on SRK models.

Reason started from the human intentional behaviors and explored the characteristics of human cognition from the intentional behaviors and non-intentional behaviors. Intention is the plan that human makes before he executes the actions. J. Reason divided human cognition of missions into three stages, namely planning, storage, and execution. Planning means having clear objectives, and a series of action sequences have been selected to achieve the goal; storage means the selected plan is stored in memory and will be executed at appropriate time; execution means the plan is implemented through the behavioral process specified in the plan. There are corresponding error modes in the three cognitive phases: Slips generally occur during the executing process and are the errors that occur during the process of executing the established plan. Lapses occur during the storage process and mean the omissions or errors that occur during the plan behaviors and the plan storage. Mistakes generally occur during the planning process. The specified plans are not suitable for the completion of the target missions. Reason divided human errors into two categories: (1) the errors that occur during the process of executing the intentional plans, known as slips and lapses, and (2) the errors that occur during the process of establishing plans, known as mistakes or violation. Slips and lapses often occur during the execution of skill-based actions, which are mainly due to the loss of concentration or high automation of the operating environment [3–7]. Mistakes are often hidden and can be hardly found and restored within a short period of time. When facing information incompatible with their own formed judgment or concepts, people tend to reject and adhere to the previous viewpoints or decision. Therefore, errors are very difficult to be restored and need to be prevented with efforts.

Among the above-mentioned theories, Norman theory and S–O–R model are earlier models, which mainly simply classify human cognitive process and consider simple factors; however, Reason model is put forward on the basis of SRK model of Rasmussen, which not only considers the relation among missions, cognitive level, and cognitive process. So this research selects Reason model for the human error mechanism analysis of the astronauts' manual rendezvous missions.

3 Analysis on Manual Rendezvous and Docking Missions—Research Content

Like the other producing activities with purposes, the manual rendezvous and docking missions executed by astronauts shall generally go through three phases, namely perception of image information, decision of control strategy, and implementation of operation.

3.1 Perception of Image Information

The images that astronauts receive are from the TV cameras installed on the spacecraft. They take pictures of the target aircraft from the perspective of the spacecraft and send the image information to the display in the spacecraft. The display presents it to the astronauts in the form of two-dimensional image information. The astronauts need to reconstruct the spatial relation between the two spacecraft. That is to imagine the three-dimensional relative position and attitude relation based on two-dimensional image information. In the actual operations, the astronauts are easy to have errors in the perception of the current image information, including the wrong identification of the relation between attitude and direction, and the wrong identification of the spatial position relation, which results in the operation of wrong handle when making decisions operating the wrong handle and leads to increased fuel consumption and unsuccessful docking.

3.2 Decision of Control Strategy

After perceiving image information, the astronauts will make control decisions. The control decisions will determine the choice of the control handle, the operational direction, and operation volume. The decisions are based on the spatial cognitive model and the control rules of the handle the astronauts formed in the perceptual phase. The correct decisions are the premises and foundation of operations.

3.3 Implementation of Operation

The astronauts implement the operational actions according to the decisions. During this process, the astronauts specifically operate the control handle and control the spacecraft to adjust the relative attitude and relative position. This process will directly affect the rendezvous and docking result (Fig. 1).

4 Human Error Mechanism Analysis on Manual Rendezvous and Docking—Research Result

J. Reason established GEMS model (error-modeling system generic) based on the SRK model. Like SRK model, it divides human cognitive level into skill-based (SB), rule-based (RB), and knowledge-based (KB). Errors may occur in any level. Slips and lapses often occur during the execution of skill-based actions, which are mainly due to the loss of concentration or high automation of the operating

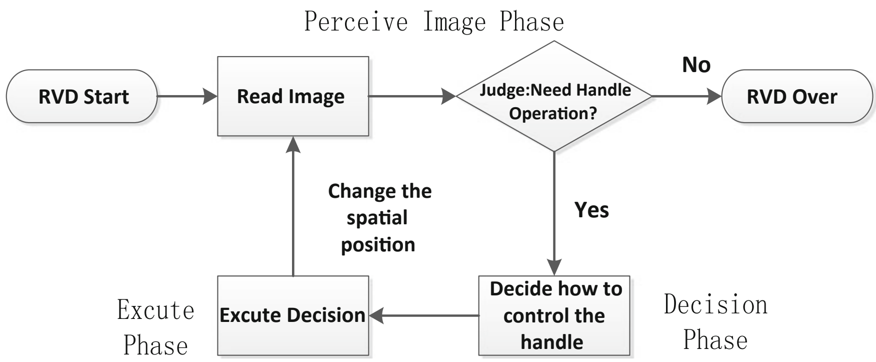

Fig. 1 Three processes of perception, decision-making, and implementation in manual rendezvous and docking

environment. Mistakes are often hidden and can be hardly found. Rule-based mistakes of cognitive level mainly mean selecting improper rules; knowledge-based mistakes of cognitive level mainly mean mistakes caused by incomplete and in accurate understanding of the system, confirmation bias, overconfidence, mental fatigue, etc. [8].

For the errors of the three types (SB, RB, and KB), their frequencies of occurrence are probably: SB >> RB > KB. The probability of SB error is about 67 % and that of RB and KB is about 27 and 11 %, respectively. This statistical result is mainly because people perform more SB missions than RB and KB missions; however, when executing the KB missions alone, the probability of human error is greater than that of SB and RB missions.

The astronauts mainly achieve the manual rendezvous docking of two spacecraft through multiple handle operations in the manual rendezvous docking mission. Every operation contains three processes, including cognition, decision, and execution. That is the identification of relative spatial positions of the two spacecraft, decision on handle control, and implementation of actual operations. Therefore, the mission type is mainly a type between RB and KB missions.

For the astronauts' completion of the manual rendezvous and docking, the operation mission is completed by controlling the field-of-view switch button, the translation handle, and the attitude handle.

The translational position relation reflects the relative position and distance between the two spacecraft. The astronauts identify the relative position information between the two spacecraft according to the image information. Then, the astronauts control the handle to make the corresponding engine of the spacecraft work and generate acceleration. When there is a long distance, the astronauts need to identify the positional bias according to the visible area on the side of the target spacecraft and other information; when there is a short distance, the astronauts need to identify the positional bias according to the distance between the scribed line of the chassis on the target spacecraft and the cross in the center of the target. Since the astronauts may have errors in the perception of the current image information, have wrong identification of the spatial positional relation, not consider the relation between current position and speed when making decisions and conduct disoperation in control, the spacecraft's translational position bias increases when it fly past the designated position. The translational position operation is more complex and is a KB mission.

The attitude relation reflects the angle of the relative attitude between the two spacecraft, including yawing, pitching, and rolling. For the successful rendezvous and docking of the two spacecraft, it must be required that the attitude of the spacecraft is consistent with that of the target spacecraft. Therefore, the astronauts need to adjust the flying attitude of the spacecraft in rendezvous and docking. For identification of the attitude, the astronauts need to reconstruct spatial relation between the two spacecraft according to the images. That is to imagine the three-dimensional relative attitude relation according to the two-dimensional image information. Therefore, the astronauts' abilities of space imagination and mental rotation are needed. During this processing and reconstructing process, the spacecraft's attitude relations must be correctly adjusted based on the imagination of three-dimensional space of the two spacecraft. In actual operation, it is easy to have errors in the perception of current image information, carry out wrong identification of attitude direction relation, or conduct disoperation in control when making decisions. These lead to large bias in spacecraft attitude, increased fuel consumption, and unsuccessful docking. From the whole controlling process of the attitude handle process, the astronauts need to carry out three-dimensional reconstruction for images, assign the plans to be executed, and implement them, so it is also a KB mission.

During the process of rendezvous and docking, the astronauts mainly observe the target spacecraft through the relevant image information captured by the view cameras of wide field of view and narrow field of view. The video cameras of wide field of view have larger field angles so that it is convenient for the astronauts to observe the target spacecraft and obtain the overall information of the docking access. The video cameras of narrow field of view have smaller field angle. Therefore, it is convenient for the astronauts to more clearly observe the targets on the target spacecraft and other information, so as to accurately achieve rendezvous and docking. During the actual rendezvous and docking, when the distance is long, through observing the images captured by the video camera of wide field of view, and when the target spacecraft appears in the central proper position of the display screen, the astronauts can switch the narrow field of view, in order to obtain more detailed image information. During the engineering design, there is bias between the position of the video camera of wide field of view and the target position of the target spacecraft. If the narrow field of view shall not be switched, docking only relying on wide field of view is at the risk of failure. During training, the astronauts are required to stabilize the spacecraft in the center of the field of view of the screen when the spacecraft is 30 m away from the target spacecraft. Switching of field of view needs to be achieved by an operating button. Identification and operation have very simple rules and are rule-based missions based on the analysis from the

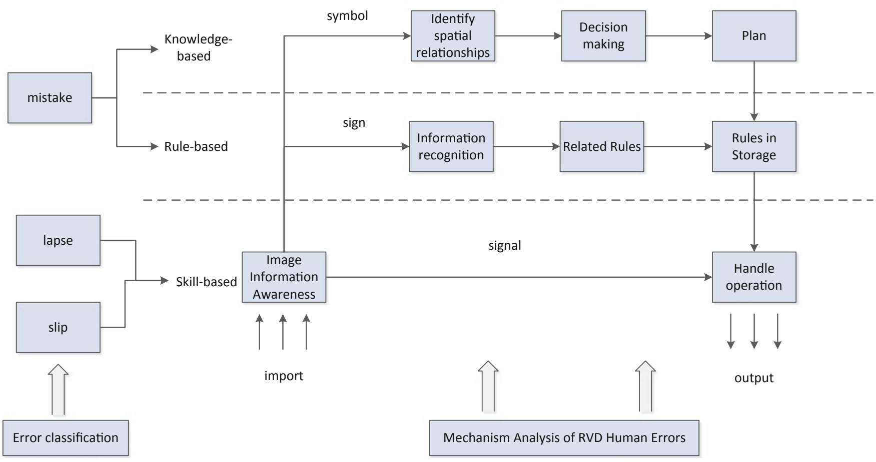

Fig. 2 Mechanism analysis of astronaut manual rendezvous and docking human error

perspective of cognitive level. Based on the error mechanism model of Reason, the human error mechanism of the astronauts' manual rendezvous and docking is analyzed as shown in Fig. 2.

5 Conclusion

The completion of the astronauts' rendezvous and docking missions mainly depends on the dynamic cognitive activities of the operators. According to the Reason model, the astronauts' errors are divided into knowledge-based, rule-based, and skill-based errors according to the cognitive level. The corresponding errors are classified as mistakes, slips, and lapses. When executing manual rendezvous and docking operations, the astronauts firstly carry out image perception mainly based on image information capture and receive and select the corresponding information on the display interface, such as shapes, colors, relative dimensions, and relative distance of the two aircraft, screen color, screen scale, cross-line, and other information. Only part of the information will be noticed. Most of the information will not be noticed and will quickly disappear, such as the relative position, relative attitude, and other information of the aircraft. The image perception errors are mainly lapses or slips caused by the astronauts' mental workload, etc. In addition to image recognition, for the astronauts' theoretical study of manual rendezvous and docking, many rules also need to be remembered, such as rules of handle control and rules of handle operation. The astronauts need to store these rules in their brain and form the long-term memory. During manual rendezvous and docking operations, the astronauts reconfirm the perceived graphics and make decisions, to form operating plans and combine them with the rules stored in mind. Finally, the handle operating behaviors are formed as output. Thus, an operation is accomplished. During the whole process of rendezvous and docking, the astronauts may execute dozens or hundreds of such operations. The astronauts' both physical load and mental workload are great. Although the cognitive process is correct, wrong handle operating method may be selected due to the lack of coordination of the eyes, hands, and brain during the executing process. Thus, for the mechanism research on astronauts' manual rendezvous and docking error, we not only need to study from the perspective of cognitive level, but also need to study the influence of the astronauts' mental workload, situation awareness, negative emotions, and other factors on missions during the behavioral process.

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List of Metacognitive Questions and Training Program Design in Manual Rendezvous and Docking

Jiayi Cai, Weifen Huang and Jie Li

Abstract It becomes a hot topic that metacognitive training theory combined with teaching in recent years. Metacognitive training methods were proposed in astronaut manual rendezvous and docking training in this paper. The list of metacognitive questions and training programs has been designed of astronaut hand control rendezvous and docking by summarized the current common metacognitive training methods and analyzed the cognitive processes. Relevant suggestions for training were made. Provide reference for future astronauts' training complex manipulation tasks.

Keywords Metacognitive · Operation training · Manual rendezvous and docking · Cognitive analysis

1 Research Objective

Rendezvous and docking technology refers to the technology that two spacecraft will be merged in the structure and integrated into a whole at the same speed in the same time and at the space orbit position [1]. Manual rendezvous and docking is an important component of the rendezvous and docking technology, and the research on its training methods has important significance to the space assembly of the future space station, astronaut members' transportation, materials supply, and optimization and reorganization of aircraft structure.

From the point of view of modern psychology, the rapidity and firmness of skills formation are closely related to the individual cognitive ability level and the learners' self-control and self-regulation processes play a critical role in the

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successful cognitive process [2]. In the process of training, the learners purposefully screen and retrieve the external information under the control of consciousness and receive the information from external instructors through visual sense, tactile sense, and auditory sense. The brain integrates information in the central nervous system through the extraction of the previous memory model, and then, the action information center codes and corrects the actions to form the latest model, and finally, the information forms the new memory after repeated feedbacks and reinforcement [3]. In the process of training, the instructors' teaching and the learners' learning are cooperated and interacted with each other so as to realize the mastering of skills. The mastering of skills is a complex cognitive processing process, and the behavior action is the result of information input, coding, storage, extraction, and a series of cognitive processing. The learners accept the feedback in the field of vision from the outside world based on their original learning experiences and judge and correct their own learning states to make the operation reach the scheduled requirements. In the process of skills formation, the self-control and self-regulation required is the connotation of metacognition.

The existing empirical research shows [4–8] that the individual's metacognitive level is closely related to the effect of training and learning and the learners with higher metacognitive level can monitor and adjust effectively so as to promote the improvement of learning and training efficiency. Consequently, based on the metacognitive theories and combining with the characteristics of the astronauts, this paper has designed a planned manual rendezvous and docking training program with scientific system.

2 Research Method

2.1 Metacognitive Theory and Training Analysis

The concept of metacognition was first put forward by Flaval [9], and he believed that metacognition was a higher cognition which reflected the individual's understanding and control of the process and results of cognitive activities. Its core meaning lies in the cognition of cognition.

The metacognitive training method combined with the subjects is the most common method, which combines with the specific subjects and domain knowledge and aims at improving the learners' academic performances of specific subjects in training. In addition, the learning efficiency and training effect can be improved through heuristic self-questioning and problem list and other methods.

Scholar Polya [10] first put forward heuristic self-questioning method and applied it into mathematics education. This method can be divided into four steps such as understanding of the problem scene, plan making, plan implementation, and reflection and review. At each step, the instructors need to combine with specific mathematical problems to prepare students the heuristic questions for its self-questioning, require the students to answer these questions when the students solve the mathematical problems, and cultivate the students' metacognitive abilities in sequence. The method of problem list is similar to the heuristic self-questioning method, which uses the problem list to replace the instructors' role and the students can ask themselves questions and answer them referring to the problem list in the process of learning. The instructors are responsible for recording and observing the students' self-questioning and self-evaluation links to assess the students' changes in learning strategies. Fisher [11] believed that the training method includes two steps: Firstly, carry out metacognitive theories training for the students to make the students understand the concept of metacognition; secondly, allow the students to use the list of metacognitive problems and metacognitive theories to strengthen the cognitive monitoring in the process of solving the practical problems. In China, Yang [5] makes use of metacognitive theories to train English listening and improve the students' listening ability more quickly comparing with the traditional methods through effective plan and monitoring means. Xiao et al. [7] carry out metacognitive theories training for the students and improve the students' independent learning ability and the students' academic performance taking College English Test Band 4 and Band 6 as the evaluation criterion.

The metacognitive training methods combined with the subjects have many advantages: First is the wide range of application. The students can master the corresponding learning strategies through metacognitive training, and the training methods have strong transferability; second, the combination of metacognition and specific subjects meets the thinking training principles of "contextualization and conditionalization," which is helpful to the improvement of the training effect.

2.2 Analysis on Training Process of Manual Rendezvous and Docking

People's cognitive process is the process for people to recognize the objective things and also the psychological activity for people to reflect the characteristics of the objective things and the internal relations between objective things [12]. In the operation of manual rendezvous and docking, the basis of execution operation of the astronauts is established on the cognitive activities, and if the errors occur in the cognitive link, the operators' execution results will be affected. Based on the cognitive psychologist Gagne's opinions and taking this as the theoretical basis of the analysis of the operators' cognitive process in manual rendezvous and docking tasks, this research combines with the analysis results of cognitive tasks and builds the manual rendezvous and docking cognitive processing model.

When the astronauts implement the manual rendezvous and docking operation tasks, it firstly enters the perceptual phase focused on image information capture, receives, and selects the corresponding information on display interface. For example, in the perceptual phase, the astronauts will receive a large amount of information into sensory memory, such as two aircraft's shape, color, relative size, relative position and distance, screen color, screen ruler, and cross-curve; only a small portion of information will attract attention and most of the information such as relative position and attitude and other information will disappear rapidly due to lack of attention. The small portion of information attracted attention will become the objects of the selective perception and be carried out further perceptual processing, making the information obtain significance and enter the working memory. This is the first phase of cognitive processing process. After that, the astronauts will extract the judgment rules of image information in the memory and match them with the information received in the perceptual phase to make judgment decision of relative spatial direction relations such as the position and attitude deviation and others characterized by relative relation, which is the second phase of cognitive processing process and also the first phase of the decision-making activities of the astronauts. The second phase of the decision-making activities of the astronauts is to reflect the operation decision in the selection of stick control mode, such as the selection of operating shaft and operating direction and control of operation amount and other decisions.

The astronauts can make judgment of relative spatial orientation of two aircrafts based on the results of the decision in the first phase, extract the memory related to operating control strategy rules from the information storage, and make the operation decision after the judgment of the matching. The third phase of cognitive processing process is the process for the astronauts to implement the corresponding operation based on the results of the decision-making activities. After the implementation of the operation motion of the handle, its results will be displayed through rendezvous and docking images, which will affect the perceptual processing again to form the feedback loop in the model (Fig. 1).

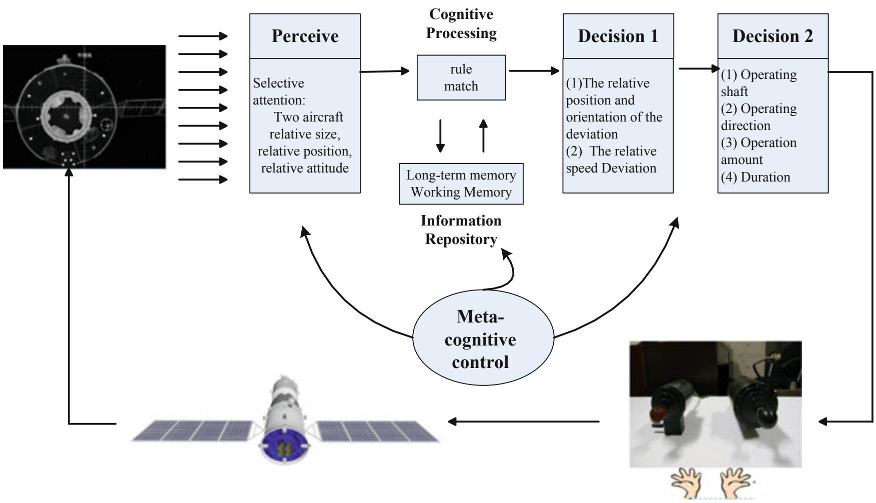

Fig. 1 Manual rendezvous and docking cognitive processing model

3 Research Results

The manual rendezvous and docking cognitive processing model obtained above can be designed to obtain the three-phase cognitive training program through combining with the metacognitive theories (Table 1).

3.1 Training Preparation Phase

The training preparation phase includes the following contents: (1) Test the astronauts' personality and cognitive characteristics and enhance self-cognition. (2) Teach the astronauts about operation task characteristics, operation mode, and operation strategy of manual rendezvous and docking and enhance their cognition of task objects. (3) Impart metacognitive theoretical knowledge and enhance metacognitive experience in training consciously.

Through the tests on personality and spatial cognition, mental rotation and other cognitive abilities, carry out an analysis on data results, guide and help the astronauts to correctly face their strengths and weaknesses in the cognition, and enhance the understanding of their individuality and know both your opponent and yourself to provide reliable guarantee for the effective training.

Strengthen the concept of space consciously, help the astronauts to understand the relationship between the operation and the motion changes of spaceship in principle, and enhance the understanding of the tasks while the instructors teaching the astronauts about relevant knowledge of operation tasks.

Pay attention to guiding the cultivation of metacognitive ability to integrate into general training, help awaken the astronauts' independent consciousness, and enhance their self-monitoring and self-regulation abilities in the training process while teaching the metacognitive theoretical knowledge.

3.2 Implementation and Monitoring Phase

Implementation and monitoring phase mainly focuses on the metacognitive strategies. The training can be divided into six steps of image reading, image

Table 1 Metacognitive training phase

Training phase	Training preparation phase	Implementation and monitoring phase	Evaluation phase
Training focus	Teaching metacognitive theory	Plan	Evaluation
		Monitor	
		Adjust	Self-reflection
		Execution	

Table 2 Training step

	Mental activity	Training step
Metacognitive strategies	Characterization	Reading image
	Monitor	Repeating image
	Monitor	Simulate
	Plan	Plan how to do
	Execution, monitor	Performing operations
	Reflection	Verifying operations

repeating, model placement, plan operation, operation implementation, and operation verification based on the steps for solving the problems in manual rendezvous and docking training (Table 2).

The first step is the characterization of image information, including the perception in cognitive phase and the decision and judgment for image information. In this process, the astronaut will receive a large amount of information into sensory memory, such as two aircraft's shape, color, relative size, relative position and distance, screen color, screen ruler, and cross-curve. The necessary information such as relative position and attitude and other information of the aircraft shall be retained and carried out the further perceptual processing through perceptual screening. The second step is the monitoring of judgment of image information. Through repeating the image information, the astronauts can monitor whether there are the problems in the perceptual phase and decision and judgment phase and strengthen the understanding of image information through information repeating. Then, the received information will obtain the significance and enter the working memory and get the judgment decision of spatial direction relation of two aircrafts through comparing with the astronauts' operation rules and operation strategies in the long-term memory. The third step is the model placement. The astronauts will place the models of two aircraft in accordance with the theory of image information. In the process of model placement, the astronauts will further monitor the spatial direction relations formed in their cognition by themselves. The fourth step is plan operation. The astronauts will make control decisions of operating handle, operating shaft, operating direction, and operation amount based on the decision judgment of the current image information and operation rules. The fifth step is operation implementation. The astronauts will be required to monitor the rationality of self-decision in this process based on the movement of operation decision and control model. The sixth step is operation verification. The whole process needs to be checked and considered whether there are missing or wrong steps.

Make a list of metacognitive questions (see Appendix) based on the above-mentioned steps, remind the astronauts to monitor their own cognitive link in the form of self-questioning, and strengthen the astronauts' training in the implementation and monitoring phase using the list of metacognitive questions. In this process, the instructors should gradually hand over the monitoring rights in the training process to the astronauts as that the astronauts are able to judge by themselves whether their selected and used strategies are appropriate and can help them achieve their objectives. If the astronauts can realize that they make error judgment in the perception of image information or operation decision in the process of model placement or image repeating, they should change their cognitive strategies and judgment methods. If the astronauts continue to strengthen the self-regulation like this, optimize the learning process and find and master the learning strategies suitable for them, and thus, they will learn how to learn.

3.3 Evaluation Phase

Evaluation phase can help the astronauts to learn to evaluate the learning effects conclusively, including the evaluation for the image identification strategy and skills training effect. Reflection is an important link to judge the astronauts whether they have effective metacognitive training in the whole process of cognition and operation. The instructor should guide the astronauts to make a reasonable evaluation of progress and achievements. On the one hand, evaluation makes the astronauts reflect the training process and effect, adjust the teaching strategies based on learning rules, and guide the astronaut to develop their autonomous learning abilities; on the other hand, it makes the astronauts reflect the learning process, adjust the learning objectives, and form the effective learning strategies.

Complete the metacognitive training of manual rendezvous and docking through preparation phase, implementation and monitoring phase, and evaluation phase. It is worth emphasizing that three phases of metacognitive training are not a linear process isolated from each other, their orders do not always stay the same, and they interact and interpenetrate with each other which may occur at the same time. When carrying out the metacognitive training, metacognition shall be penetrated into each link of manual rendezvous and docking training and become one part of the teaching process.

4 Application Suggestions

For manual control rendezvous and docking tasks of this type, there are complex cognitive processes included in the tasks and it is not enough to rely solely on the instructors' unilateral teaching but requires the astronauts to have deep understanding of the whole process to ensure the safety of each operation. The research provides relevant suggestions of metacognitive training while designing the metacognitive training methods as shown above.

4.1 Emphasize Metacognitive Experiences and Combine Metacognitive Training with Cognitive Level that the Astronauts Already Have

The metacognitive experiences will directly affect the astronauts' emotional experiences and confidence of self-learning ability in the training process. If it lacks confidence in the success of the tasks, the training will be in vain. As a result, when carrying out targeted training for the split tasks, the astronauts' original knowledge needs to be combined to make the astronauts be able to make full use of their own cognitive characteristics, master the training materials, make the training plans that fit themselves, successfully solve the training obstacles they encountered, and feel joy and happiness when the completion of the training. Rich metacognitive experiences will promote the astronauts' learning and understanding of metacognitive knowledge as well as their self-monitoring of the training process.

4.2 Insist on Long-Term Metacognitive Training

The individual learning of metacognitive strategies and cognitive strategies is a gradual process. The metacognitive strategies can be mastered through combining with the practical learning tasks and conducting the repeated training. If it lacks a large number of practical activities, it is difficult for the astronauts to master the metacognitive strategies reaching the automation level. As a result, in the metacognitive training process, we cannot be anxious for success but integrate the metacognitive theories into the daily training tasks.

4.3 Focus on Training Feedback

The astronauts' cognitive and metacognitive process has the characteristic of implicitness, and the analysis on these activities needs the astronauts to give timely feedback in an oral and written forms. In the initial training stages, the instructors should play a guiding role and help the astronauts to establish the feedback consciousness. Then, the astronauts will gradually form a perfect training feedback mechanism and realize self-learning, self-monitoring, self-evaluation, and self-regulation.

5 Conclusion

In this paper, the problem-solving model of manual rendezvous and docking image identification and decision-making process of the astronauts shall be obtained through analysis on task characteristics of manual rendezvous and docking process. The metacognitive training program of manual rendezvous and docking shall be designed through combining with metacognitive theory. In addition, the relevant recommendations put forward for the application of training methods will provide the theoretical guidance for the design of training method for manual rendezvous and docking tasks and operation tasks of mechanical arm in the future space station.

Appendix

List of metacognitive questions

I. Remove reading image (reading image phase)

1. Cue words: Please read the pictures and answer 『I get it』 after you think you have understood the meaning in the pictures
2. Observe and record the astronauts' behaviors in the process of reading
3. After removing the pictures, conduct the following interview:

   (a) What are you thinking about?
   (b) Do you understand the meaning of the pictures and do you need to read the pictures again?
   (c) Why do you think so?
   (Make a recording of the answers)

II. Retell the images (problem representation)

1. Cue words: Please use your own languages to describe the position relation expressed in the following pictures
2. Purpose: Survey the monitoring degree of the understanding of the astronauts who accept the test to the pictures
   (Make a recording)
3. Conduct the following interview after the test objects complete the retelling:

   (a) Do you think whether you have master the meaning of the pictures correctly?
   (b) Where do you think is the most critical step in the judgment on the position relation just now?
   (c) What information is redundant?

(d) Which parts do you think are still not clear enough?
(e) Do you think the picture is difficult to you or not?
(Make a recording of the answers)

III. Mold placement (visualization of representation problems)

1. Cue words: Please place the position relation expressed in the pictures in accordance with their own languages
2. Purpose: Survey the transformation degree between the picture information and stereoscopic image conducted by the test objects
(Make a recording)
3. Conduct the following interview after the test objects complete the retelling:

(a) Why do you place it this way?
(b) Which parts do you think are still not clear enough?
(c) Do you think whether you place the position relation shown in the pictures correctly?
(Make a recording of the answers)

IV. Plan implementation proposal (plan solutions)

1. Cue words: Based on your understanding, how to adjust the current position relation.
2. Purpose: Survey the test objects' understanding of their own thinking
3. Attention: After the test objects retell the picture information, give the pictures to the test objects
4. Conduct the following interview after the test objects complete their expression:

(a) Do you think your judgment is right or not?
(b) Do you think you have missed any critical information?
(Make a recording of the test objects' answers)

V. Operation implementation (execution plan)

1. Cue words: Place the real teaching aids in accordance with the expression.
2. Observe and record the astronauts' behaviors when placing the mold or teaching aids.
3. The test objects can be asked the following questions when placing:

(a) What are you doing?
(b) Why did you do that?
(c) What else do you think you need to do?
(Make a recording of the test objects' answers)

VI. Inspection operation (review and check)

1. Cue words: Do you think you have placed the position relation correctly or not?
2. Purpose: Observe the astronauts' behaviors when check.
3. Cue words: Can you explain to me why you place it this way?
4. Purpose: Survey the monitoring degree of the results after answering. (Make a recording of the test objects' explanations).

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The Man–Machine–Environment System Evaluation Method During the Maintenance Process Based on Virtual Prototyping

Qiufang Wang, Shulin Liu, Jinlong Zhao, Sijuan Zheng and Na Jiao

Abstract At present, the maintainability qualitative parameters of the vehicle can only be evaluated depending on the material object, and the evaluation result is also qualitative. According to the different characteristics of the maintainability qualitative parameters which affect the man–machine–environment system during the maintenance process, this paper puts forward the different evaluation methods, such as the contact accessibility and maintenance operating space evaluation method based on the virtue prototyping, the visibility evaluation method, the maintenance working posture, and the maintenance working load evaluation method. By means of the above methods, the designer can judge whether the maintainability design of the vehicle reaches the demands or not, and then improves the design.

Keywords Maintainability · Man–machine–environment system · Evaluation

1 Analysis of Current Situation of Vehicle Maintainability Evaluation

The maintainability evaluation parameter system of vehicle includes qualitative and quantitative requirements. The maintainability qualitative requirements and design parameters that need to be considered during the vehicle design process are as follows: simplified design, accessibility, standardization and interchangeability, error preventive design, maintenance safety, human factor engineering, testability, and the reparability of valuable parts [1]. At present, the maintainability analysis and evaluation for vehicles can only be effectively carried out on physical prototypes. That is, the maintenance personnel shall simulate the maintenance process on physical prototypes to achieve their analysis in accessibility, visibility, stress and fatigue, safety, and other aspects in actual maintenance environment. Due to the dependence on specific physical prototypes, actual assembly verification for vehicle

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maintainability is often carried out later in the development phase, which may lead to the result that some maintainability tasks lag behind the product design and design defects cannot be found earlier. Moreover, it is difficult to ensure the safety of the maintenance personnel during the demonstration process. Maintainability evaluation based on the virtual prototypes is to carry out the maintainability evaluation in the vehicle design phase, determine whether the vehicle maintenance design meets the requirements and feed back the maintainability suggestions to the designers, so as to further improve the designs [2]. In the vehicle maintainability evaluation system, human is a very important factor. For different characteristics of several maintainability qualitative parameters which affect the man–machine–environment system during the maintenance process, this paper puts forward the evaluation methods based on virtual prototypes, including the contact accessibility and maintenance operating space evaluation, visibility evaluation, maintenance operating gesture evaluation, and maintenance working load evaluation.

2 Method of Contact Accessibility and Maintenance Operating Space Evaluation

Contact accessibility and maintenance operating space reflect the effect of maintenance operating space, maintenance access, and other factors on maintenance part. Maintenance operating space is mainly affected by the layout of maintenance operating area and placement of the maintenance parts. Using virtual prototypes to carry out accessibility evaluation is mainly to determine whether the maintenance part is in the accessible range of the upper limbs of the maintenance personnel. The operating space of the maintenance personnel shall be a three-dimensional area.

When the contact accessibility and maintenance operating space evaluation are carried out, first determine the maintenance parts to be repaired, build the geometric model with the similar geometric shape of the physical prototype, meeting the simulation requirements on the basis of CAD data modeling software, through the assembly the simulation based on the geometric model, and then make the virtual maintenance prototype have the space supporting vehicle maintenance and the movement properties and physical properties restrained by degree of freedom through building the assembly relation, quality, material, and other information of the model, so as to create the complete virtual model containing maintainability information. To facilitate the rapid real-time simulation, the model needs to be led into the simulated environment after the CAD information of the model which is not related to the maintenance accessibility evaluation is removed through lightweight of the model. The body posture of the virtual maintenance personnel shall be adjusted to ensure there is no interference with the other parts. The operating range of the human body shall be set and generated, and generally given in the form of sphere envelope surface. Through repeatedly determining whether the maintenance parts are completely in the operating range of the human body and whether there is any interference with the maintenance access, and combining the given criteria for contact accessibility evaluation, the result of the contact accessibility evaluation can be finally obtained. For the evaluation process, see Fig. 1.

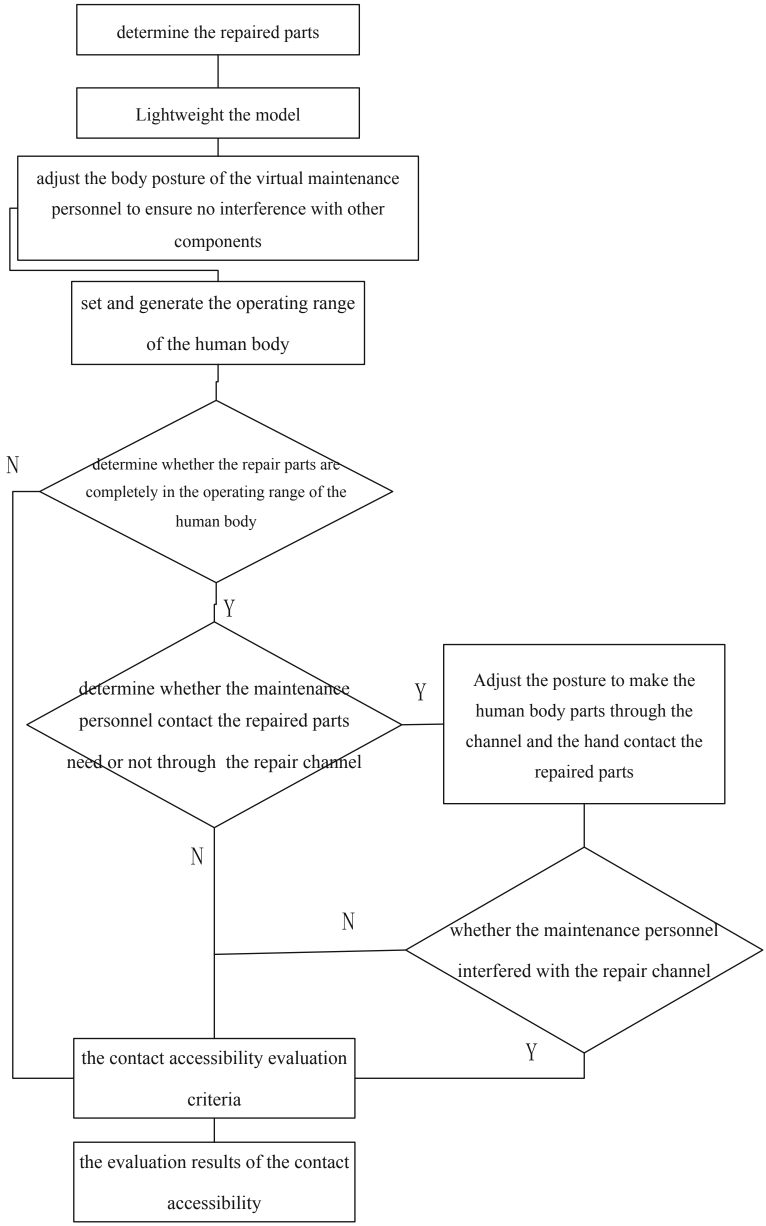


Fig. 1 Evaluation flow of the contact accessibility

3 Method of Maintenance Visibility Evaluation

The maintenance visibility is evaluated by taking the advantage of virtual maintainability evaluation platform and using 3D checking method, so as to restore the real visual range of human eyes and evaluate whether the visibility of the maintenance parts is qualified from the perspective of three dimensions. To analyze from the physiological perspective, the scope of the human vision, the visual range of human eyes, is an enveloping space curved surface spreading outside in angers with the center of human eyes. The section of the curved surface is an ellipse. Being analyzed from the spatial perspective, the curved surface is an elliptical cone, namely the visual cone of human eyes. The space formed by the visual cone is the visual range of human eyes. The area within the range of the visual cone can be seen by human eyes. The parts that cannot be covered by the visual cone and the areas outside the visual cone cannot be seen by human eyes in this posture. For maintenance visibility evaluation, the basic idea is to determine whether the maintenance part is in the cone space, so as to determine whether the maintenance visibility is good [3]. For the maintenance visibility evaluation flow, see Fig. 2.

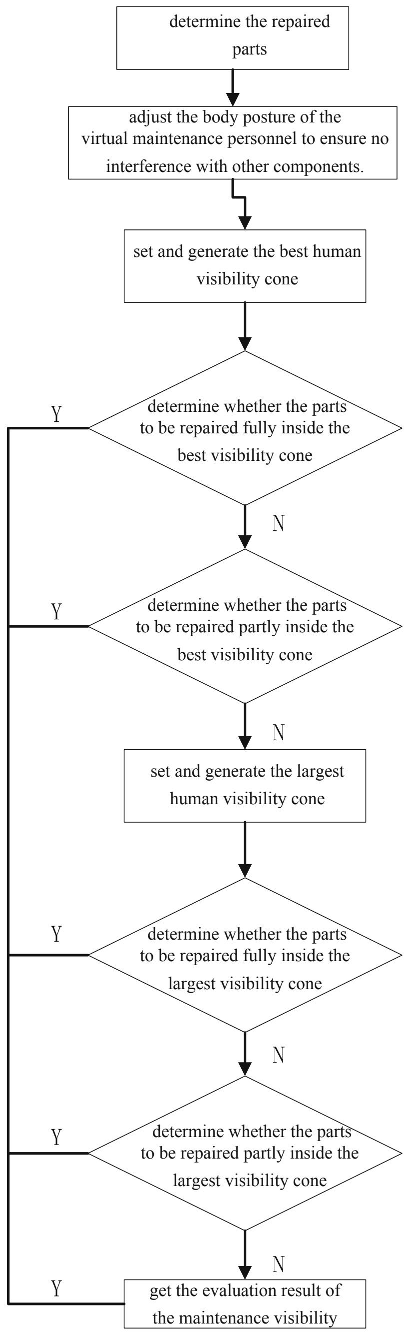
4 Method of Maintenance Working Posture Evaluation

At present, the common method for evaluation of maintenance posture is the observation method, that is, to evaluate by taking the advantage of the evaluation form and observing the operating posture of the maintenance personnel on the maintenance site. In this paper, the REBA method has been improved to be a theoretical method appropriate to the verification and evaluation of vehicle maintenance operating posture. The evaluation flow for the maintenance operating posture is shown in Fig. 3.

In the process of using REBA, the working posture shall be firstly observed. The rating standards for the operating postures of the trunk, the neck, the legs, the arms, the forearms, and the wrists shall be established, respectively. Then, the magnitude of force of the postures and the status of using muscles shall be observed. Taking the trunk as an example, the rating standard of working posture of trunk shall be used according to different operating postures of trunk. The operating standard of the trunk is shown in Table 1.

The evaluation flow of REBA is shown in Fig. 4.

Fig. 2 Evaluation flow of the maintenance visibility



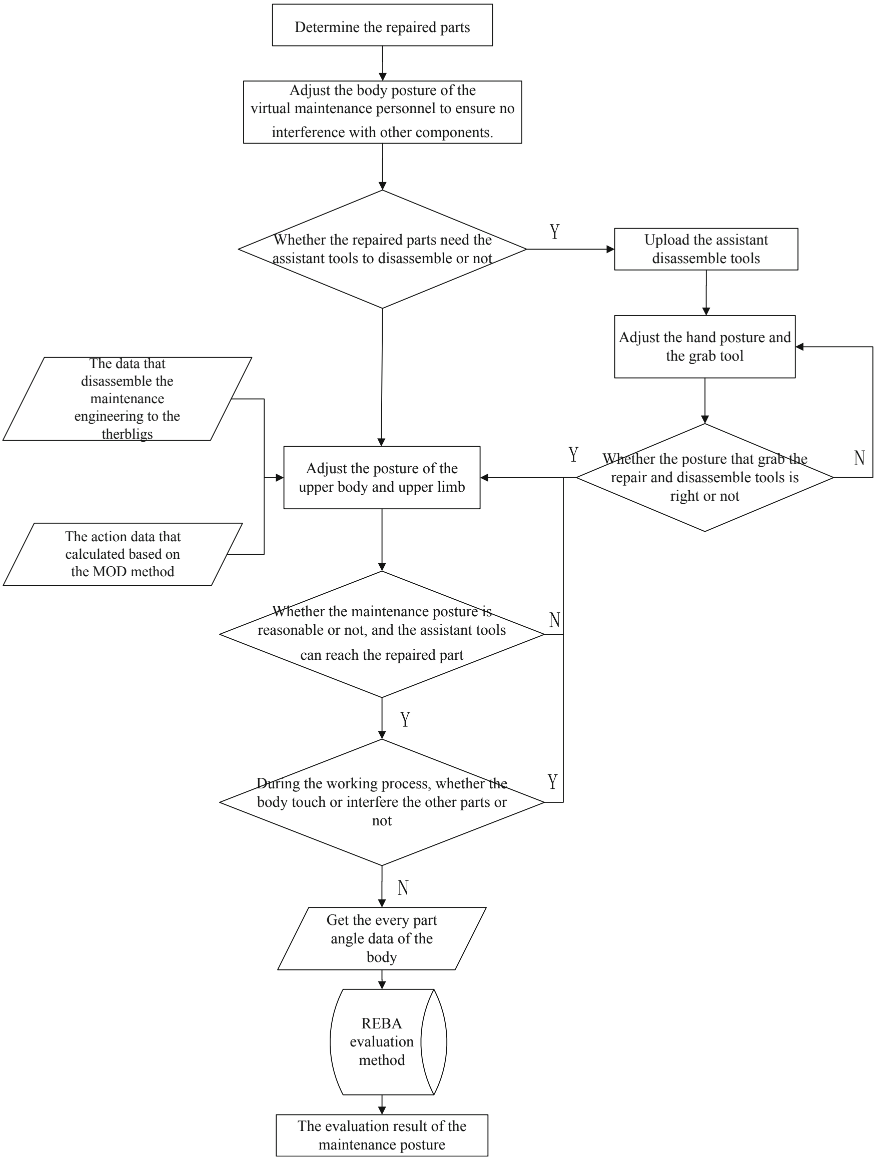


Fig. 3 Evaluation flow of the maintenance operating gesture

Table 1 Body score chart

Body posture	Score	Additive score
Perpendicularity	1	+1 the body turn or bend toward the other side
Lean forward 0°–20°	2	
Tilt back 0°–20°		
Lean forward 20°–60°	3	
Tilt back >20°		
Lean forward >60°	4	

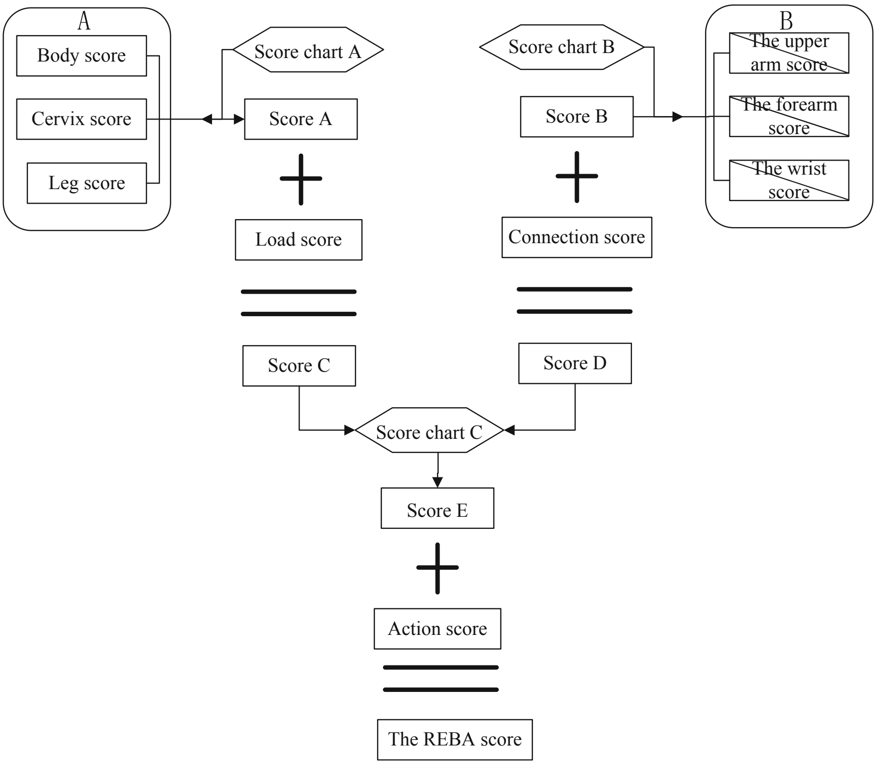


Fig. 4 Evaluation flow of REBA method

5 Method of Maintenance Working Load Evaluation

The quantitative analysis method for working load adopted in this paper is the prediction model for energy consumption of human actions. The prediction model divides the energy consumption of human body into two types. One is the operating energy consumption. The maintenance operation is broken down into basic therbligs based on the action decomposition method. The energy consumption of each

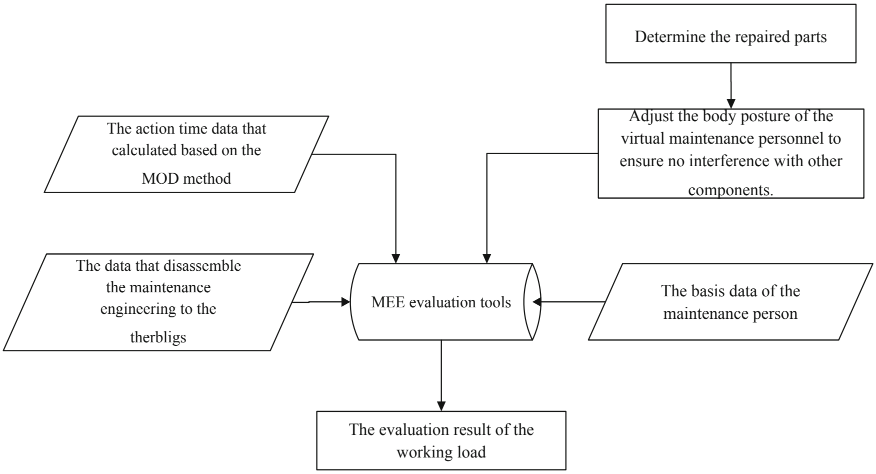


Fig. 5 Evaluation flow of the maintenance working load

basic therblig has been determined. The total energy consumption of the operation can be obtained through the accumulation of basic therbligs. The other is the posture energy consumption which is divided into the energy consumption for standing posture, the energy consumption for sitting posture, and the bending energy consumption. Time percentages of standing, sitting, and bending operation can be obtained through the analysis of the whole operation process. The posture energy consumption of unit time has been determined. The posture energy consumption can be calculated according to the time of each posture. The total energy consumption of the operation can be obtained by the superposition of the operating energy consumption and the position energy consumption.

Figure 5 shows the evaluation flow of the working energy consumption of the maintenance personnel. The energy consumption shall be calculated by the computational formula selected according to the type of each action.

For the evaluation of energy consumption of the operation carried out according to the calculated total energy consumption rate, see Table 2.

6 Application Verification of Engine Compartment of Certain Type

To verify the engineering applicability of the above-mentioned several methods of maintainability qualitative parameter evaluation, a certain engine compartment has been selected as an application example. The maintainability verification and evaluation have been carried out for the integral lifting process of the engine compartment. The engine compartment is mainly composed of power, transmission,

Table 2 Physical force work grade based on the energy consumption level

Work grade	Energy consumption (kcal/min)	Energy consumption for 8 h (kcal/d)	Heart rate (beats/min)	Oxygen demand (L/min)
Rest (sit)	1.5	<720	60–70	0.3
Very easy work	1.6–2.5	768–1200	65–75	0.3–0.5
Easy work	2.5–5.0	1200–2400	75–100	0.5–1.0
Medium difficult work	5.0–7.5	2400–3600	100–125	1.0–1.5
Burdensome work	7.5–10.0	3600–4800	125–150	1.5–2.0
Very burdensome work	10.0–12.5	4800–6000	150–180	2.0–2.5
Excess burdensome work	>12.5	>6000	>180	>2.5

and auxiliary devices, mainly including the diesel engine, integrated transmission device, generators air filter, sump, radiator, cooling fan, all kinds of pipe and cable assemblies, and other parts. During the process of applying the example, the verification and evaluation have been carried out for the accessibility, visibility, and other qualitative parameters.

In virtual environment, the human body model of common maintenance personnel for vehicles shall be used. About 90 % of visual human has been added to the digital prototypes to simulate the accessibility and visibility of the maintenance position of the engine compartment. The enveloping graph of the largest accessible range of the upper limbs of the visual maintenance personnel can be created by establishing the simulation process of virtual maintenance (see Fig. 6), that is, to intuitively reflect the operating space of the upper limbs of the maintenance personnel and grade according to the evaluation criteria. When the part is in the enveloping curved surface, the score is 1; otherwise, the score is 0. The score for contact accessibility of 24 maintenance activities of integral lifting has been obtained in the virtual environment [4], as shown in Table 3.

The average score of the 24 maintenance activities is used as the final score of contact accessibility evaluation of the integral lifting process of the engine compartment, that is, 0.875 points (out of 1).

By analogy, visibility evaluation shall grade according to the positions of maintenance parts distributed in the observed visual range. For the other qualitative parameters, each item of the checklist shall be graded by combining the evaluation criteria. The score of single item of each maintainability parameters can be obtained. All the maintainability parameters shall be summarized. The weight of each element is inside the maintainability evaluation parameter system of the engine compartment [5]. There are 13 qualitative requirements in the system. The scores and weights are determined as shown in Table 4.

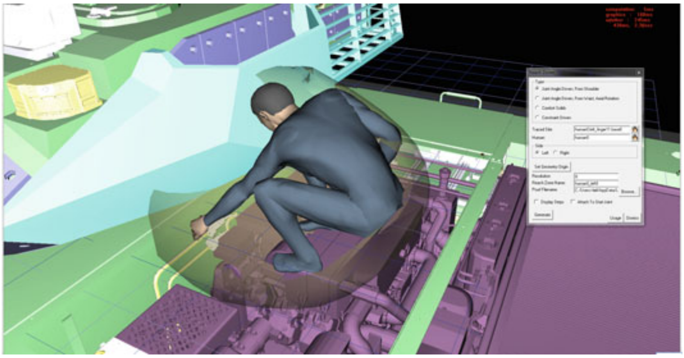


Fig. 6 Envelop diagram of virtual human upper limb

Table 3 Score of the contact accessibility for an engine compartment

No.	1	2	3	4	5	6	7	8	9	10	11	12
Score	1	1	1	1	1	1	1	1	1	1	1	0
No.	13	14	15	16	17	18	19	20	21	22	23	24
Score	0	1	1	0	1	1	1	1	1	1	1	1

Table 4 Individual score and weight of the maintainability qualitative parameters for an engine compartment

Maintainability qualitative parameter	Individual score	Total score	Weight
Contact accessibility	0.875	1	0.077
Repair visibility	0.833	1	0.077
Repair operation space	0.875	1	0.077
Repair work attitude	0.80	1	0.077
Repair work load	0.55	1	0.077
Standardization	0.850	1	0.077
Interchangeability	0.935	1	0.077
Anti-error design	0.980	1	0.077
Identification mark	0.970	1	0.077
Simplification	0.825	1	0.077
Testability	0.860	1	0.077
Repair security	0.930	1	0.077
Valuables repairable	0.880	1	0.076

According to the linear weighting theory, the comprehensive score calculated from the data in Table 4 by the method of comprehensive evaluation of maintainability parameters is 0.859.

If there are multiple design schemes, multiple schemes can be sorted and selected to obtain the best. Multiple design schemes shall be evaluated according to the above-proposed methods for maintainability evaluation to obtain multiple results of the comprehensive evaluation of the qualitative parameters, respectively. The designer can carry out scheme optimization on the basis of experience and concerned emphasis.

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Design and Application of Ergonomic Virtual Experiment System for the Armored Vehicles

Shunwang Xiao, Haiyan Niu, Yaofeng He and Lei Zou

Abstract Armored equipment had a leaping change from mechanization to intelligent. The interactive mode of equipment and crew innovated with it. Relying on the crew cabin ergonomic virtual test system constructed based on virtual reality technology, crew were devoted to different cabin design plans of a new generation of equipment. The subjective scale filled by crew after the completion of the task and performance analysis of crew in the process of operating was combined for efficiency analysis through the crew planning mode of completing operating test and cooperative task. A plurality of passenger compartment design was selected to get the best, and this provided the basis of experimental verification for the overall design of cabin.

Keyword Armored vehicles · Virtual simulation · Ergonomic evaluation

1 Preface

The armored vehicles have had a leap-type change from mechanization to intelligence. The high degree of automation and intelligence may lead to the change in the combination mode of people and equipment. On the one hand, it manifests as the reallocation of functions of people and equipment. People and equipment each have their own advantages, characteristics, and boundaries. The shortcomings of each other shall be made up for to achieve a reasonable matching between people and equipment. People have creativity, foresee ability and adaptability, learning capacity, and other high intelligence factors. Corresponding reconnaissance, decision making, command, and other core tasks of information warfare will be handed over to the crew. High-load and mechanical operational tasks will be handed over to the intelligent operating system [1]. On the other hand, it manifests as the reallocation of the tasks between the crew of armored vehicles. Driven by intelligent

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technology, it is possible to reduce the crew. The reduction of crew can not only be conducive to optimization of the overall vehicle layout optimization and utilization of internal space, but also effectively reduce the overall dimensions and weight, so that intelligent technology will certainly become an important research direction. To be specific to armored equipment, the control interface, battlefield awareness, battlefield management, and other things have all changed. The display and control interface, fire strike, commanding communication, and other systems need to be reconstructed.

The traditional man–machine ergonomic evaluation is to analyze and evaluate after the crew completed the operation tasks on the physical entities. However, a new generation of equipment is under continuous exploration both from the perspective of operational requirements and from the perspective of the technical system. In the independent innovation development model, man–machine interactive mode has more uncertainties. Its physical entity can be hardly fixed in the demonstration phase and needs to be constantly revised and verified according to the basic scheme. The immersive ergonomic virtual testing system shall be constructed based on virtual reality technology. As shown in Fig. 1, on the one hand, multidimensional, appreciable, measurable, and realistic virtual operating environment for the crew shall be given full play to. On the other hand, the flexibility of the virtual reality technology shall be made full use of to make the system have quick replacement, customized operating scenario, performance evaluation of operating tasks, and other means of a three-dimensional cabin model. After the completion of the virtual test, the ergonomic analysis shall be carried out by combining the subjective scales that the crew fill in after the completion of the tasks and the performance evaluation of the crew during the operating process, so as to optimally select multiple designs of crew cabin and provide the basis of experimental verification for the overall design of the cabin, which is of guiding significance for the development of hardware-in-the-loop physical model.

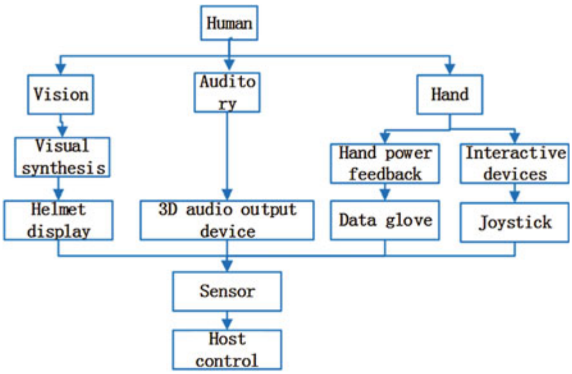

Fig. 1 Crew awareness diagram in the virtual test system

2 Design of Virtual Test System

From the perspective of the physical structure, the ergonomic virtual test system developed in this paper is composed of three parts: the function deployment subsystem, the AR virtual unit subsystem, and the virtual cabin subsystem. The control host (server computer) mainly serves as the function deployment subsystem. The function deployment subsystem is the central unit of the whole system and is mainly used by the main experimenters to design, modify, and release the functions of virtual crew cabin. The AR virtual unit subsystem consists of two modules. One is the crew module, and the other is the optical tracking module. The hardware of the crew module is 2 scene computers which are responsible for overall planning of the whole behavior of the vehicle and release of all the operating commands. It contains 2 crew subsystems which are the platoon leader subsystem for platoon leader vehicles and the conductor subsystem for main battle tanks, respectively. They are mainly used for crew simulation tests and design verification. The tracking module is mainly to provide tracking services for virtual environment creation. The virtual cabin subsystem is used to simulate 2 operating seats of different vehicles within the system. The 2 side-by-side seats simulate the platoon leader seat for platoon leader vehicles and the conductor seat for main battle tanks, respectively. The cabin structure is consistent with the vehicle structure. The operation panel of the cabin displays virtually and can change according to the adjustment of specific functions from time to time. Figure 2 shows the hardware equipment of the conductor seat subsystem of the main battle tanks. The seat is equipped with a helmet-mounted display, a data cap, a pair of data gloves, and a gun lever [2].

The data gloves and data caps are combined with the optical tracking system and are mainly responsible for capture and determination of the hand and head poses of crew and the data transmission to the server computer. The console transfers the data information to the two crew computers for conversion and then output the data information to the virtual hands and view points of the virtual scene, which not only makes the virtual hands consistent with the crew's hands to achieve the button

Fig. 2 Conductor seat hardware system

clicks, screen-touch, and other man–machine interactions, but also makes the viewpoints consistent with the crew scene to achieve the perspective conversion. The scenario inside the cabin and the scene outside the vehicle, the crew's hand positions, and other man–machine interactive information are displayed in the helmet-mounted display in real time through the video capture card. The proportion of the simulated scenario that the crew see is consistent with that of the actual tank layout and scene, so as to fully guarantee the true feelings of the crew. The gun lever is used to track and shoot the target.

3 Design of Virtual Test Scheme

3.1 General Idea

For the new generation of information equipment, the emphasis of the man–machine ergonomic research is the rationality of the allocation of man–machine functions. The specific research content focuses on matching researches on the multi-level coordination among the crew within the system, the planning of display and control resources of the cabin, the crew operating tasks and operating procedure, the operating load of the crew, and other aspects. To verify and optimally select the rationality of the designs in the virtual test system, the operational performance data during the test process need to be collected after the crew accomplished the typical operating tasks. It shall be compared with the subjective feelings of the crew after the test, so as to achieve the scheme optimization and to verify the credibility of the simulation system.

3.2 Design of Software System

The main functions of the system software mainly include the constructing the immersive cabin environment, realizing man–machine interactive operations, and collecting the performance data of the crew. They mainly include module for realizing the display and control panel functions, the module for realizing multiple display modes in driving and battling status, the input module of attitude information collection (including virtual hands, helmet-mounted display, lever), module for executing operation task scenario, the module for editing operation task scenario, the crew communication module, and the module for collecting operational performance (the movement time/reaction time of movements of the crew during the process of accomplishing the task).

3.3 Design of Test Scheme

For the two layout schemes designed in view of the above-mentioned research content, the test system achieves the reconstruction of the two layout schemes in virtual environment. In Scheme 1, there are 3 displays in front of the two passengers in the cabin and 1 display below, in front of, and between the two passengers. In Scheme 2, there are 5 displays in front of the two passengers in the cabin and 1 display below, in front of, and between the two passengers. That is to say, in the two design schemes, for different division methods for display and control content of display and control resource planning, the specific display and control content include battlefield perception and reconnaissance, target capture, target tracking, transmission of battlefield management information, command transmission, and other aspects. In addition, the interior color of the cabin of the armored vehicles has certain effects on the subjective feelings of the crew [3]. In this test system, 6 sets of color schemes have been designed, including beige, blue, brown, dark gray, light greenish blue, and dark green. The color schemes can be changed by one key during the test process. The color scheme optimization can be achieved through subjective description of the crew.

3.4 Test Method

The test process is shown in Fig. 3 [4]. The specific test procedures are as follows: (1) selecting the subjects: The 20 selected subjects are divided into 10 groups. There is 1 subject for each platoon leader seat for platoon leader vehicles and 1 subject for each conductor seat for main battle tanks. The subjects include 6 demonstrating staffs, 4 scheme designers, 6 ergonomic analyzing staffs, and 4 software developers; (2) The training before test and preliminary test: In order to eliminate the test bias resulting from the interfering factors, the subjects shall be trained till gaining experience in operating the tasks; the preliminary test can

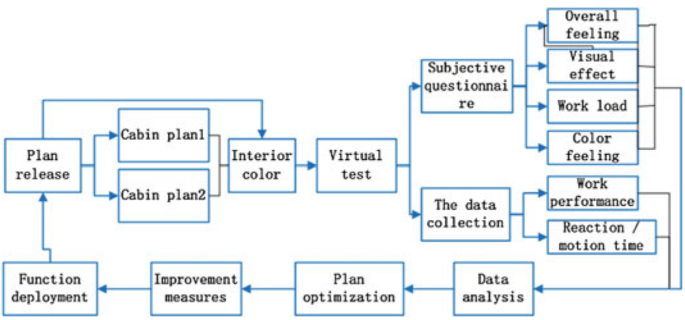

Fig. 3 Test process

be familiar with the skilled tasks and with the test system. The preliminary test shall be carried out; (3) system calibration; (4) the two subjects of each group shall wear helmet-mounted display and data gloves, and the test tasks shall be begun; (5) accomplishing test tasks. For the 2 layout schemes, the subjects of each group shall cooperate and accomplish the typical task of "expelling and annihilating the enemy for alert." The time is about 20 min; (6) collecting performance data: During the process that participants completed the tasks, the backstage collects people's reaction time/movement time of movement to analyze the operating performance of the crew; (7) filling in the subjective questionnaire: After the test, the subjects shall complete the subjective scales, including the overall feelings of the cabin layout, visual effect of the display and control terminals, operating load, and color for accomplishing the operating tasks; and (8) Data analysis: The test conclusion shall be formed through the analysis of the subjective and objective data.

4 Analysis on Test Data

4.1 Operating Performance Data

The performance of the subjects for accomplishing the operating tasks is represented by the reaction time/movement time. The sample means are mainly used for data analysis. The test data are divided into in-group data and inter-group data. The in-group data are the summarization of reaction time/movement time data for accomplishing the certain task of the same seat. It is used to analyze the subjects' adaptability to the virtual system. The inter-group data are reaction time/movement time of the same subject for different screen allocation scheme. It is used to optimize two sets of screen design schemes [5].

Operating load analysis: As shown in Table 1, after analyzing the number of tasks for the conductor seat and the platoon leader seat in the typical task of "expelling and annihilating the enemy for alert," the total tasks for the conductor and the platoon leader are 20 and 21, respectively. They are basically the same. To specific task types, the conductor's tasks include screen-touch operation (command processing), key operation, and lever operation (acquiring and striking), whereas the platoon leader's tasks include screen-touch operation (command processing) and key operation. According to the action types, statistics shall be carried out for the time needed for subjects on the conductor seat or the platoon leader seat to accomplish the actions. It can bee seen, on the one hand, for the subjects on different seats that the time needed for the same type of actions are almost the same. There is no significant difference. On the other hand, for the striking tasks (lever operation) exclusive to the conductor, the duration is the longest. It manifests that the task load of the striking task is the heaviest and the operability of the lever is not as good as the screen-touch operation.

Table 1 Work performance data

	Conductor screen	Conductor blow	Conductor keys	Platoon leader screen	Platoon leader keys
Task number	9	3	8	9	12
Time (s)	15.0567	18.9819	146.3575	15.9641	17.1500

4.2 Scheme Optimization

Statistics have been carried out for the total time of the conductor and the platoon leader for accomplishing operating tasks in Scheme 1 and Scheme 2, respectively. The duration distribution is shown in Table 2. Among them, the duration is the average of duration of each test sample. It is obviously shown in the figure, for the same passenger, time needed for Scheme 1 is lees than that of Scheme 2. It manifests that based on the analysis of objective data, Scheme 1 is more reasonable and easier to use than Scheme 2. For the comparison of different passengers with the same layout scheme, it can be found the conductor significantly needs more time than the platoon leader. It manifests that based on the analysis of objective data, the task load of the conductor is heavier than that of the platoon leader.

4.3 Subjective and Objective Data Contrast

After accomplishing the test tasks, the subjects shall fill in the subjective questionnaire. Table 3 shows the subjective and objective data contrast.

Table 2 Subjects to finish the homework time under different schemes

	Scheme 1		Scheme 2	
Subjects	Conductor	Platoon leader	Conductor	Platoon leader
Time (s)	705.9117	335.5616	837.3032	351.5347

Table 3 Subjective and objective data contrast

<table>
<tr><td rowspan="4">Plan optimization</td><td colspan="3">Proportion of personnel think the plan 1 more optimal</td><td rowspan="3">Work load</td><td colspan="2">Proportion of personnel think conductor homework load more weight</td></tr>
<tr><td></td><td>Subjective questionnaire</td><td>Objective data</td><td>Subjective questionnaire</td><td>Objective data</td></tr>
<tr><td>Overall feeling</td><td>0.6</td><td>0.7</td><td>0.9</td><td>1</td></tr>
<tr><td>Visual effect</td><td>0.6</td><td>0.6</td><td>Color</td><td colspan="2">Dark gray first and, secondly, cyan</td></tr>
</table>

5 Test Conclusion

The following conclusions can be drawn from the test. Firstly, the objective performance data and the subjective feelings of the subjects in the test data are highly consistent, indicating that the immersive ergonomic virtual test system used for test has high data reliability; secondly, the research conclusion on interior color is consistent with that of previous research achievement; thirdly, Scheme 1 is better than Scheme 2, which is consistent with the preliminary analysis and assumption of the demonstrating staffs and the scheme designers; fourthly, it can be seen that from the operating load, further development of intelligent fire-control system that can recognize, lock, track, and resolve is needed. The system can effectively reduce the operating load of the crew.

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Implementation of Ergonomic Virtual Experiment System for the Armored Vehicles

Haiyan Niu, Shunwang Xiao, Lei Zou and Yaofeng He

Abstract Under the conditions of integrated joint operations, it is required that a new generation equipment integrated seamlessly into the joint warfare architecture, the span of armored equipment intelligent control technology would produce a new model of human–computer interaction, with virtual reality technology, building a "man in the loop" of the crew cabin ergonomics virtual test system; it has the characteristics of quick change among the three compartment models such as job scene custom, job task performance evaluation, and ergonomic assessment tools of combination of subjective and objective; the system relies on a new generation of equipment cabin design, it could achieve design optimization, crew workload assessment, the verification of crew job tasks and processes, and ergonomic studies, to provide assessment tools of the overall cabin design.

Keywords Armored vehicles · Virtual simulation · Ergonomics evaluation

1 Preface

The army shall innovate the new generation of equipment with the world's advanced level to provide backbone equipment for future integrated joint operation and diversified missions of the army. As one of the key technologies, intelligent manipulating and controlling technology can directly result in innovation of interactive mode. It is the hot spots of the concern to develop "human" as the core of the battlefield and how to maximum the combat capability of the equipment. As the cross-generation equipment, changes have been taken place in the focus content of research on human–computer ergonomics. Platform has been one node in network under the combat mode of the system, crew on the platform becomes one of the system, and the crew's perception and controlling ability of the information becomes the focus of the research, so restrictions shall be given toward the usability

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of the equipment form the perspective of “human” ability. To be specific, that is, a series of demands are put forward on the rationality of human–computer function allocation, multi-level collaboration between crew within the system, planning of display and control resources in the compartment, job task of the crew, the setting of operation procedure, and so forth. The new generation of army equipment, characterized by new combat concept and cross-generation technology, is used to carry out the exploratory test and analysis of the new mode of human–computer interaction, and it takes the crew’s perception and controlling ability of information as the criterion to construct the evaluation environment for test, to provide evaluation means for overall design of the compartment during the research and development of the new generation of army equipment, and to attain the goal of loop iteration and circular rise [1].

2 Functional Requirements for System

Traditional ergonomics evaluation refers to evaluation by the crew conducting test on physical entities while when it comes to cross-generation equipment, its physical entity is hard to be solidified in the stage of exploration, which requires to construct a more flexible evaluation environment for test. Therefore, virtual reality technology shall be applied to ergonomics research to construct the virtual test system for ergonomics of the compartment, to realize seamless integration of the scene of virtual battlefield outside the vehicle and the scene of the compartment inside the vehicle and form a vivid virtual battlefield environment so as to make the crew immersed in the virtual compartment of the new generation of army equipment to finish the typical combat missions, in which case it can not only give the crew sufficient subjective feeling, but also analyze the performance of the crew by recording the process of human–computer interaction, and can both give full play to the initiative of the crew and the flexibility of simulation.

The virtual test system of ergonomics constructed shall have the following functions for easy ergonomics analysis:

1. It can realize collaboration between the crews

By realizing the information interaction of “man in the loop,” the system can be used to judge the quick reaction capability, decision-making ability, executive ability, and so on of human in the platform layer and judge human ability in information acquisition (perception), information processing (decision making), and information utilization (execution) in the system layer. In that case, the test environment designed is required to hold at least 2 crews, and the combat task designed shall include collaboration between the crew and the system, the crew and the platform, and the crew and crew in the system and other elements.

2. It can realize flexible alterations in design plan of compartment

It has the functions of quick change and custom in terms of layout of 3D compartment of the crew compartment, inner decoration color of the compartment, planning of display and control resources, display and control interface, operating procedure of the crew, combat scene, and so on.

3. It can record the performance of the crew

It can assess the crew's adaption to controlling the information interface by recording the performance parameters of the crew and analyze the operating time and misoperation rate.

3 Plan Design of System

According to functional requirements for the system, specific design plan is shown in Fig. 1, in which the equipment can hold 2 crews in the constructed environment for virtual ergonomics test, of which the one crew simulates the platoon leader of vehicles for platoon leaders in the system while the other crew simulates the vehicle commander of the capital tank, which can realize the collaboration between the crew on different platforms in the system. Design the scenes in the compartment according to the compartment design plan of the new generation of army equipment, including inner decoration color, planning of display and control resources and display and control interface; design the combat scenes inside the compartment according to the scenario of combat missions and use modular design concept to enable the design plan to have the function of quick change; and the test function of crew performance shall be built in the virtual reality system to collect the operation time/reaction time and misoperation rate of the crew in the mode in the typical combat scenario in the process of finishing combat missions. The test system can provide the crew visible and real combat experience and can also analyze the task performance of the tested personnel , collect the subjective evaluation scale of the tested personnel after the test, and evaluate the plan design of the compartment through combination of objective and subjective evaluation [2].

4 Hardware Composition of System

System hardware is mainly composed of control host (server computer), crew subsystem, optical tracking subsystem, and communication network subsystem [3]. Every crew subsystem includes a visual computer, a pair of data gloves, a data cap, a helmet display, a video capture card, a LED controller, and a joystick. Of which, the data gloves and data cap are used to determine the poses of hands and heads of the crew and transmit the data information to the server computer. Master station

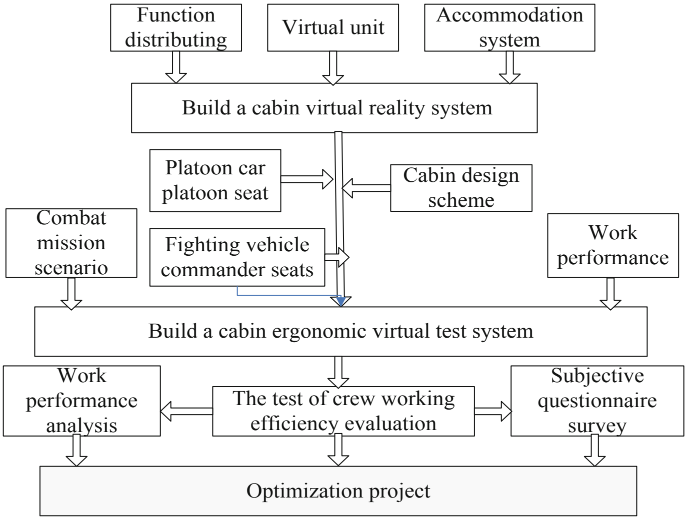


Fig. 1 The overall schemes of research

transmits the data information to two crew computers for transfer and then output to the virtual hands and viewpoints of the virtual scenario to connect the virtual hands with the hands of the crew. Display content will be displayed on the helmet display in real time at a certain frame frequency. Hardware framework of the system is shown in Fig. 2.

1. Server computer

Server computer, as the control center of the entire system, can receive data information (poses of hands and head) from the tracking equipment and can start the computers of vehicle commander and platoon seat via remote control.

2. Crew subsystem

Crew computer is mainly used to run each crew test procedure. Crew can watch the views outside the vehicle and inside the compartment through the helmet display and can display the video information on the helmet display in real time through the view screen collector. The scale of the simulated scene as the crew can see is quite consistent with that of the actual layout inside the compartment to guarantee true feelings. In the system, the platoon seat of the capital tank is equipped with commander joystick for enemy target researching and shooting.

3. Optical tracking subsystem

Optical tracking subsystem provides virtual environment tracking services of crew poses to determine hand movements and direction of viewpoint of the crew during operation. As shown in Fig. 3, tracking module applies PhaseSpace system and the system converts the poses of hands and heads of the crew in real world to

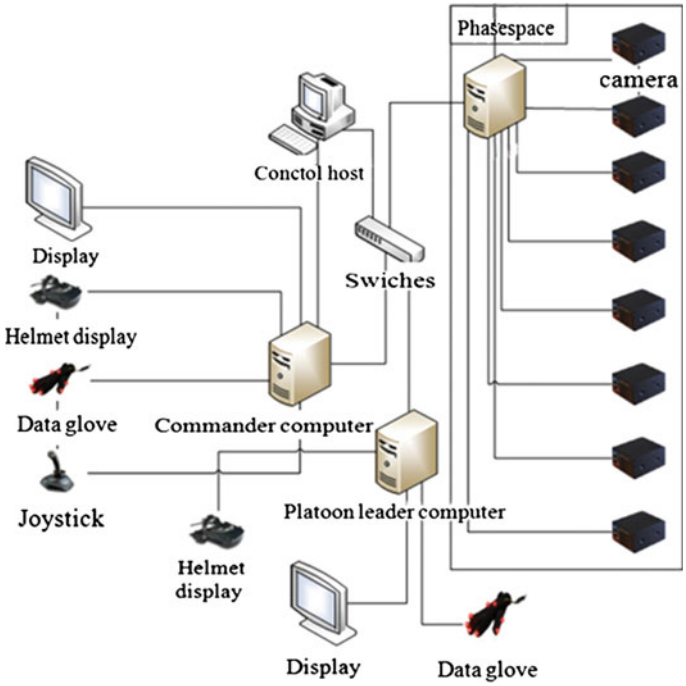
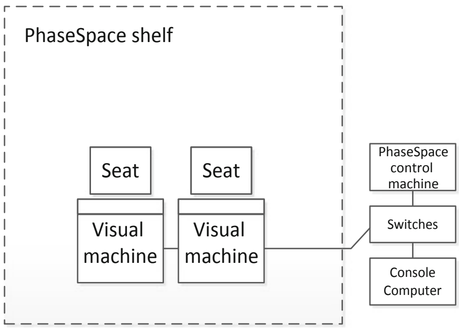


Fig. 2 System diagram

Fig. 3 PhaseSpace and system structure diagram



virtual scenes to make movements in virtual scenes consistent with those in real world so that the crew can conduct virtual scene operations.

4. Communication network subsystem

To satisfy the cooperative communication between different crews inside the system and data transmission between different hardware equipments, it is required to set up the network system based on server–client pattern. Server computer constitutes a LAN with two crew computers through switches, and the server computer is connected to the tracking server in PhaseSpace tracking module. The system obtains the following three sets of input data via optical tracker and joystick:

(a) Platoon leader and vehicle commander separately input the position and pose information of the virtual hands through two data gloves;
(b) Platoon leader and vehicle commander separately obtain the position and pose information of the heads through the helmet;
(c) Input of vehicle commander's joystick (material object), including firing and aiming (movement on two axes).

5 Software System

Main functions of software include the following: First, simulate the external scene of the vehicle and internal environment of the compartment; second, design scenario editor to realize that users can define the process of combat missions; and third, record the work performance of the tested personnel during operation [4]. When the program is running, optical tracker transmits head and hand poses of the crew to the server computer, and the crew computer receives data through the network to realize synchronization of heads and hands in virtual environment with the poses of the crew. As the vehicle moves, the crew shall wear helmet display to observe the scenes outside the vehicle and inside the compartment in real time, and the scenes outside the vehicle are displayed on the display model inside the compartment and vary in real time as the vehicle moves. Scenes inside the compartment are displayed on the display of visual machine and vary with the viewpoints of the tested personnel. Head and hand poses obtained by the optical tracking system interact with virtual parts, and head movements of the crew are fed back as changes in viewpoints rendering the scene to make the crew observe every direction of the compartment through head movements. It can realize control over virtual objects through hand movements, and the commander can use the joystick to move gun turret and choose kinds of bullet and conduct strikes against the enemies and other operations. Commander and the platoon leader can realize mission issuing and uploading through network communication. Specific software structure of the system is shown in Fig. 4.

Software system module is shown in Fig. 5 and is mainly composed of 3D object modeling, unity simulated effect, background script, and other subsystems. 3D object modeling is mainly used to realize building of virtual scenes of software system to finish drawing external model of vehicles, terrain, scene animation, and compartment model. Unity effect simulation system is mainly used to be responsible for corresponding property setting of the model to realize special effects of physical simulation. Background script system mainly includes control script of model and scene animation, data storage script, and motion control script of model maps. Position information of the tested personnel obtained by the optical tracking module through the tracking system shall be input into the control module and

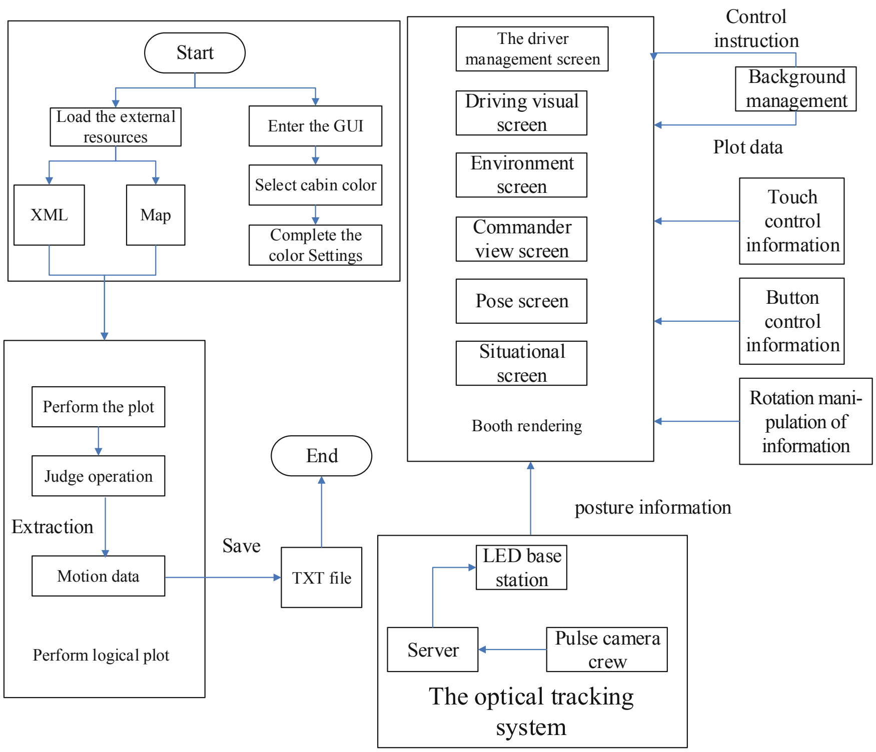


Fig. 4 The software structure diagram

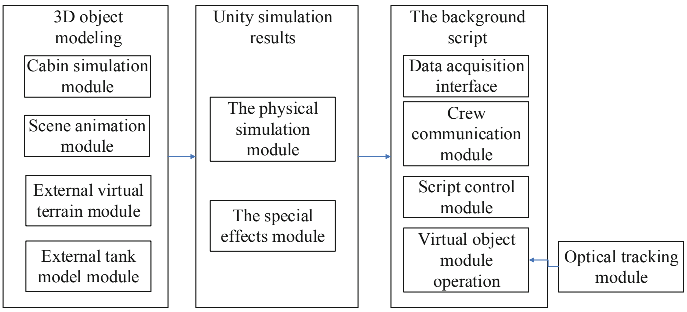


Fig. 5 Software module block diagram

eventually the control module shall exercise control over the virtual hands in the system. It specifically includes display module, control module, input module, work performance collecting module, scenario execution module, scenario editing module, tracking module of head and hand poses, and crew communication module [5].

6 System Realization

It can be divided into functional deployment subsystem, AR virtual unit subsystem, and virtual compartment subsystem by the physical structure of the system and Fig. 6 is the schematic diagram. Functional deployment subsystem, as the core unit of the entire system, is connected with AR virtual unit subsystem and virtual compartment subsystem. Major testing personnel uses the functional deployment subsystem to design, modify, and publish the function of the crew's virtual compartment. AR virtual unit subsystem includes two modules, the one is crew module and the other one is tracking module. Crew module is mainly used to verify crew simulation experiment and design plan. Tracking module mainly provides tracking services for environment building. Crew module includes 2 crew subsystems, separately are platoon leader subsystem of the platoon leader's vehicle and commander subsystem of the capital tank, responsible for arranging whole behaviors of the vehicles and issuing all operating commands. Virtual compartment subsystem is used to simulate 2 operating seats of different vehicles in the system, and the two seats in parallel layout by the right and left sides are used to separately simulate the platoon leader seat of the platoon leader's vehicle and the commander's seat; the compartment structure is consistent with the vehicle structure and the virtual display of operation panel inside the compartment can change at any time according to adjustments of specific functions. The crew facing the commander's seat is equipped with gun joystick for tracking and shorting the targets.

From system function, the testing system can be applied to optimal plan of design of the new generation of equipment compartment, workload evaluation of the crew, job task of the crew, verification of operation procedure, and other ergonomics researches. From system function, to fully guarantee, the crew can experience the sense of reality of battlefield in the testing environment, the system applies active optical tracking, and the precision of hand tracking is 0.8 mm and

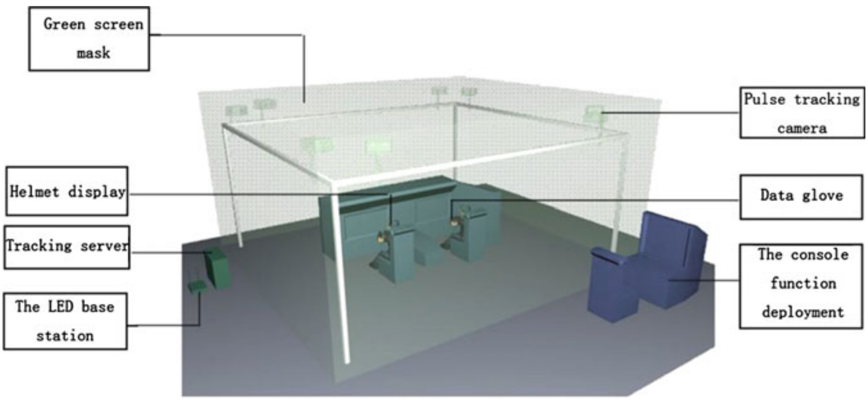


Fig. 6 System schematic diagram

that of head tracking is 0.8 mm, which guarantees the sense of reality of system operations in real time. Meanwhile, in the combat missions, the crew can observe the whole screen of display and control interface and the field angle is 60°.

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Research on Desktop System of the Space Flight Training-Simulator

Shang Huan, Suqin Wang and Hua Deng

Abstract *Objective* The purpose of desktop system of the space flight training-simulator is to minimize the cost of training on ground. *Methods* Various methods can be explored, these include the object-reduced, mobile-control, and virtual reality, these can maintain an operation's situation awareness level through optimize the training arrangement. *Results* It is so useful that almost half the training tasks are taken by object-reduced system and mobile-control system; although the VR training system is in the trail stage, it did its work quickly. Furthermore, the astronaut satisfies the desktop system and gets a better workout. *Conclusion* Desktop system is able to support training effectively at minimal cost by miscellaneous auxiliary, it will be widely applied to the area of large simulator for ground training.

Keywords Space flight · Simulator · Desktop

1 Overview

Space flight training-simulator ("Simulator" for short) is a kind of training equipment for ground simulation of the space flight mission. It helps the astronauts perceive the mission environment, master the skills of the mission, and deal with the fault correctly [1, 2]. The full-mission Simulator of our country has complete equipment configuration, comprehensive simulation dimensions, and realistic simulation effect. It plays an indispensable role in the SZ-5 to SZ-10 missions. With

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the normalization of flight missions, especially during the period of constructing the space station, the training demand increases with each passing day. The supporting resources of the Simulator are in short supply. However, the full-mission Simulator is large-scale ground training equipment with high development cost, large occupied area, and high support requirements. Batch allocation is obviously not a good solution. Therefore, the Simulator need to be transformed into desktop systems, so as to provide various auxiliary training methods, greatly enhance the support capability and reduce the training cost. Desktop training system means properly simplifying the large-scale training system into training simulation system which is not subject to space and time limitation and has certain portability and can be run on the desktop, meet the specified efficiency.

2 Method of Desktop System

The direction and degree of the desktop versions of the Simulator are guided by human perceptive characteristics. On the basis of man-machine-environment relation, the desktop system and optimization of the Simulator shall be used. The researches show that human sensations are divided into external sensations including vision, hearing, taste, smell, skin, and internal sensations including motor sensation, equilibrium sensation, and organic sensation. Vision and hearing, respectively, account for 80 and 14 % in sense impression. It is thus clear that human sensations mainly originate in vision and hearing. In case of simultaneous input of a variety of auditory information, people tend to pay attention to one and ignore the others [3]. Therefore, the training system can strengthen the simulation fidelity of the concerns, weaken and even cut the simulation of the other aspects. In this way, the training system will be greatly simplified and miniaturized. Fechner Law points out that the sensory quantity is in direct proportion to the logarithmic value of the physical quantity. That is $S = K\lg R$, among which S is the sensory intensity, R is the stimulus intensity, and K is a constant. It shows that the perception intensity of human is in direct proportion to the logarithm of the corresponding intensity of physical quantity and is not in direct proportion to the corresponding intensity of physical quantity. This indicates that although the simulated physical quantity has bias in intensity and amplitude, as long as it is within the range of differential sensory threshold, people' sensory effects are consistent. In this way, a theoretical basis is provided for the use of alternative methods in the training system. Since human perception is integral, selectable, understandable, and constant, the trainees may be guided to focus on the key points and ignore the other details through strengthening scenario prediction. In the case of lacking other details, the trainees can still correctly understand and complete specific missions.

Combined with human perceptive characteristics and the space flight training characteristics, the methods of desktop system of the Simulator include object-reduced, mobile-control, and virtualization.

3 Object-Reduced

From the perspective of accomplishing the missions, the perceptive objects are divided into key objects, common objects, and the objects that need no perception. For key perceptive objects, the objects shall adopt real components or high-fidelity simulation; for common perceptive objects, the objects shall be cut or scaled down; for the objects that need no perception, the simulation can be simplified or omitted. In short, the simulation fidelity shall be determined by the importance of the objects in specific missions, in order to achieve the goal of desktop system. Manual rendezvous and docking training-simulators are mainly used for training of the astronauts of controlling manned spacecraft to track the target spacecraft and controlling handles to accomplish manual rendezvous and docking by real-time observation of the target and parameter changes in TV image. During this process, the astronauts mainly rely on vision, hearing, and dermal sensation to perceive the dynamic information of spacecraft docking. The vision perceives changes of the instrument parameters and the target in TV images; the hearing perceives the working status of the engines and voice prompts; the dermal sensation actually perceives the operating range and force feedback of the translation and attitude control handles of spacecraft. The astronauts integrate the above-mentioned information to make judgments and decisions and control the spacecraft to dock with the target spacecraft in the best moving attitude. In this mission, the TV images and the handles are the key perceptive objects; the engine sound and the instrument panel are the common perceptive objects; the cabin environment and the body position are the objects that need no perception. According to the reducing rule, the manual rendezvous and docking ("RVD" for short) training-simulator applies the following methods to desktop system: The instrument system carries out consistent simulation for the TV images, which are presented by the notebook display. The handle is the original part. However, the handle bracket has been removed. The sound effect of engines changes from the space surround stereo into output of notebook speakers. The relevant components of the whole instrument are virtualized and can be displayed by switching- screen in the notebook; the cabin environment and the body attitude to control the spacecraft are not simulated. For the software part, the original flight program, GNC software, database software, and TV simulation software have been integrated together. The instructor software has been cut to retain the core functions to run simulation program, and the other software has been removed. In this way, the whole manual RVD training-simulator is integrated into a high-performance notebook (see Fig. 1). Not only the hardware cost has been greatly reduced (only the handles are retained), but also the training can be carried out anytime and anywhere without space constraints.

For the efficiency evaluation of the desktop manual RVD training system, the manual RVD training-simulator is taken as a reference. Twelve people with manual RVD operating capacity shall be selected to concurrently execute the same easy, normal, and hard training subjects on the two kinds of simulators, respectively. And

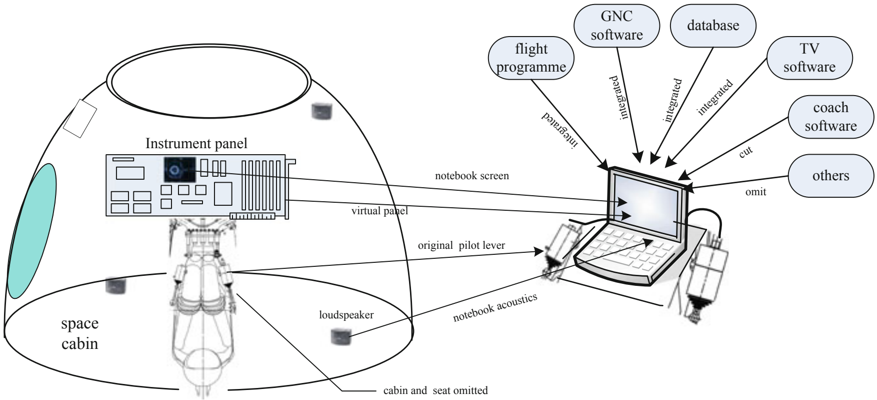

Fig. 1 Sketch of manual RVD training-simulator reduction

the same efficiency evaluation index shall be selected. The evaluation results show that the efficiency of desktop system is above 95 %.

Desktop manual RVD training system (see Fig. 2) has been successful applied to the astronauts' manual RVD training and bears nearly 50 % of the training missions. From the perspective of statistical evaluation of training effect and the astronaut's subjective feedback, the desktop manual RVD training system has full capacity of manual RVD training.

The method of object-reduced is especially suitable for special operations training. For this type of missions, the perceptive objects are centralized, and the simulated objects are mainly the visual images. Furthermore, the astronauts need to

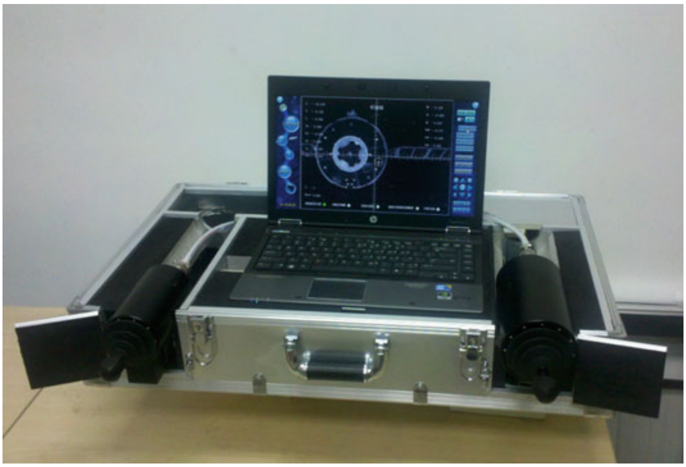

Fig. 2 Desktop manual RVD training-simulator

go through repeated training before being skilled, such as the manual teleoperation docking training and space robot arm operation training.

On this basis, it is further portable and low cost that the system software is integrated into the Pad, scaled down TV images, and miniaturized handles. But there are also certain differences in operation mode and force feedback, and its efficiency evaluation needs to be further tested.

4 Mobile-Control

At present, generally, the astronauts, the instructors, and the auxiliary personnel may jointly participate in the process of simulated space flight training. The astronauts are responsible for the flight mission operations in the cabin. The instructors and the auxiliary personnel may command and assist them behind the instructor's desk. Among them, the instructors may simulate the ground control and be responsible for curriculum, program control, and effect evaluation; the auxiliary personnel are responsible for system status monitoring and technical support [4, 5]. Although the training control mode based on the instructor's console perfectly simulates the space flight mission status, however, it takes up lots of human resources. Therefore, the training implementation is subject to time, personnel, and other factors constraints, which is not good to bring the autonomy of the astronauts into play. The mobile-control training-simulator is to transplant the core functions of the instructor' console into the hand-held terminals and give the commanding power of the flight training to the astronauts and carry out autonomous training. The astronauts can set up their own training subjects and the difficulties and evaluate by themselves in the cabin without help of anybody else.

The hand-held terminal is developed based on Ipad platform and gives full play to portability, friendly man–machine interaction, and other characteristics of Ipad. The functions of the instructor' console is performed by running the simulator App on Ipad and taking over the emulation server through dedicated interface software. The technology architecture of the control terminal is as shown in Fig. 3. For different training systems, the corresponding applications and interface software (running on the emulation server) shall be developed, to make the instructor' console mobile and transfer the commanding power to the trainees.

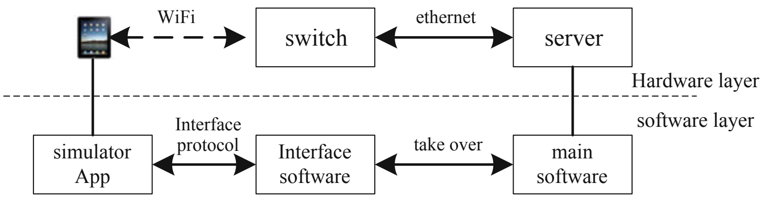

Fig. 3 Technical architecture of control terminal

The method has passed the tests in different space training systems, and the expected application effect has been reached. It is especially suitable for the full-process training systems with lots of important operation objects because these systems cannot be fully transformed into desktop systems.

5 Virtualization

The spacecraft, especially space stations consisting of multiple cabins, have complex internal structure and lots of equipment. It often takes a long time for the astronauts to experience and know the cabin layout, equipment operation, and working path. It is obviously neither economic nor realistic to completely rely on physical simulators. Based on the virtual reality technology, the 3-D model of spacecraft shall be constructed and dynamically presented in real time through interactive devices. In addition to the visual perception generated from the computer graphics technology, supplemented by hearing, force sensation, and even motion perception, people may have a sense of immersion, so as to achieve the effect of training. In Fig. 4, through capturing human posture and movements, the virtual training system presents the scene that is inside the core cabin from the first-person perspective. The astronauts may autonomously inspect each cabin, check by the electronic manual and perceive the whole layout inside the spacecraft, so as to start the hand gesture recognition system and be able to experience the virtual interactive operation. Therefore, environmental perception, equipment operation, assembly and maintenance, and other training missions can be effectively completed with the help of the virtual training system.

The virtual training system has significant auxiliary effects on the astronauts for their comprehensive understanding of the aircraft. As for the mission operations, although there are differences in grasp modes and operating force sensation, its functions of operation tips and electronic manual (augmented reality) can quickly help the astronauts to understand the internal structure, functions, and operation process of the equipment which are not equipped in the physical training system. Therefore, the virtual training system can bring new learning experience to the astronauts and achieve almost all of the functions with the cost much lower than that of the physical training system.

6 SA Strategy

In the space flight missions, the astronauts obtain the perception of the external environment by image, graphics, text, voice prompt, and other information on the man–machine interface of the spacecraft. They also make decisions, judgments and carry out the operations according to certain principles. In a complex, dynamically changing man-machine-environment system, situation awareness (SA) is a key

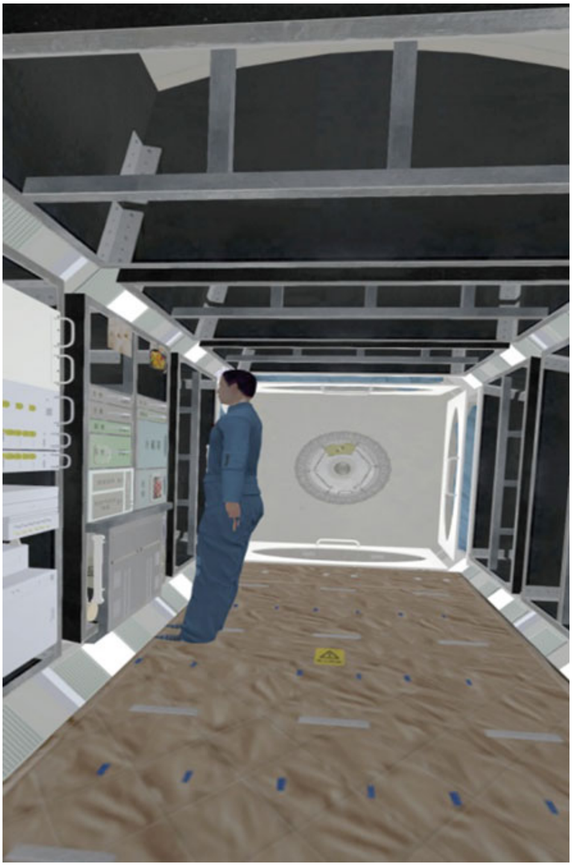

Fig. 4 Virtual interactive scenarios of core cabin

factor that affects the operators' decision making and performance [6–8]. Space flight simulation training is to improve the SA of the astronauts from the three levels, including perception, understanding, and prediction. Since situation awareness is a kind of complex high-level cognitive activity, it has multiple influencing factors, among which the cognitive characteristics of the operators and the characteristics of man-machine interface are important factors affecting SA level [9]. After the desktop systems of the Simulator are developed, they lacks in the man-machine interface, but they can be made up for in cognitive competence by taking scientific training arrangement.

For object-reduced, mobile-control, virtualization, and other methods of developing desktop versions of the training systems, they, respectively, scarify the adaptation of man–machine to different extent while greatly reducing the cost of ground space flight training. Such as object-reduced desktop system, although the important perceptive objects are retained, the influences of secondary perceptive objects on the missions are ignored; for the mobile-control desktop systems, the trainees are required to have certain basic capabilities; moreover, there are differences in operating perceptions among virtualization systems. To keep the SA level, different training strategies shall be adopted for different desktop systems. Firstly, the object-reduced desktop system shall require the trainees know the important objects of operation in advance, guide the allocation of concentration, and reduce the demand for secondary information. In the aspect of training arrangement, it shall be alternately used with the full-simulation training system. The constancy of cognition from the full-simulation training system shall be made full use to reduce or even ignore the influences caused by the simplification of the man–machine interface of the desktop system. Secondly, the mobile-control desktop system shall be arranged in the middle and later raining phase. At this time, the operators may have already formed a mental model of the system and mission cognition; furthermore, the new autonomous training method may have stimulated the operators expected performance, which means to get better SA level. Finally, the virtualization desktop system is mainly used in the former and middle training phase, to make the operators know the whole mission and operation process well, through the visual and auditory information and limited interaction. In the strengthening training phase, the previous cognition shall be enriched and corrected by the physical simulation system. In this way, SA is improved and training effect is enhanced.

7 Conclusion and Prospect

Based on the human cognitive characteristics and the characteristics of space flight training, object-reduced, mobile-control, virtualization, and other approaches are adopted to develop desktop systems of Simulator, so as to be able to provide various forms of auxiliary training equipment and meet the increasing training demands with a low cost. Corresponding training methods shall be adopted to keep or even enhance the astronauts' SA level and make the cost-effectiveness optimized through the analysis on the important influencing factors of situational awareness. According to the 2 years' service evaluation, object-reduced system and mobile-control system have achieved the expected goals. Preliminary attempt of virtualization system has also been carried out. It is not only very helpful in the aspect of making the trainees know the spacecraft well, but also effective in the fights against space motion diseases.

The space station mission simulator is a complex engineering. The training demand cannot be satisfied only by a full-physical simulator. Secondly, it cannot be perfectly limited by the ground gravity environment. For example, without 3-D weightless environment, the training of running space robot arm cannot adopt full-physical system on ground. Therefore, there are urgent requirements for desktop training system. More types of desktop training systems will be applied to the training of space station missions. In particular, the application of virtualization systems will have a broader prospect.

The desktop methods can also be applied to the other fields, such as aviation flight, submarines, special military vehicles, and other driving training. It not only provides various auxiliary training equipment and methods, but also significantly reduces the training cost.

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Analysis and Research on Information Security for Military Academies

Shisheng Cheng, Yongqing Zhang, Qianqian Wu and Rong Liu

Abstract With the rapid development of information technology including network technology, military academies are confronting new problems and more and more threaten in information security field. So many cases about loss of secrets in information technology domains have occurred at home and abroad times and now. In this way, the effective and positive measures should be built, and related standards and restrictions should be set up to overcome the corresponding problems to clear and define the secret-related persons' actions regulations. As we know, the military academies are the departments full of abundant information resources, and the possibility of loss of secrets is more and more. By the way, we should pay more and more attention to this phenomenon and should take available actions to dissolve the new puzzles in time.

Keywords Academy · Information security · Analysis and research

"WikiLeaks," "Snowden," and other events have sounded an alarm to information security and secrecy work of military academies. The network's own openness, virtuality, interaction, secrecy, and other characteristics have brought convenience to the soldiers and officials' life, work and study and also become an important channel for hostile forces to steal information, infiltration, and sabotage. The military academy is the place where all kinds of information highly concentrated, its secret-related range is wide, and its degree of security classification is very high; there are many scientific research personnel there and the scientific research places are separated; the office automation level is improved continuously and the storage

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carriers are increasingly diverse; external exchange and cooperation become more frequent and there is increasing number of personnel dispatched in other areas or to a foreign country. These new characteristics have brought new threats to information security and secrecy work of military academies, which must be solved timely [1].

1 Demands for Information Security and Secrecy of Military Academies

With the development of information technology with rapid changes, the information security and secrecy work of military academies has presented the following several outstanding features.

I. The object for the work of safeguarding secret information is more diverse. The secret-related information's generation, transmission, storage, collection, utilization, and others have extended from tangible paper document to intangible sound, light, electricity, magnetism, and other carriers. The way for safeguarding secret information has extended from the traditional single paper document for secrecy to the computer, network and mobile storage carrier for secrecy, showing the difficulty has been further increased.

II. The uncontrollability of the secret-related information is gradually increased. With the continuous renewal and replacement of network technology, information technology, and communication technology, the use (especially the wide application of smartphones) of the computer, digital copier, fax machine, printer, scanner, and other office automation equipment makes the channels for losing and divulging a secret continuous increase. The rapid application and promotion of high and new technology make the technology for stealing secret information more advanced and concealed than ever before [2].

III. The harm caused by losing and divulging a secret is more destructive. The USB flash drive, mobile hard disk drive, and other secret-related carriers have small size, are easy to carry, have large storage capability, and are easily lost. Once these carries are stolen, it will inevitably lead to the leakage of a large number of secret-related information, the loss and harm incurred by this is difficult to be measured, and once the secret-related information is put online, it will bring irreparable consequences. Similar cases have occurred many times in the military system.

2 Information Security and Secrecy System of Military Academies

Military academies have taken more measures in secrecy propaganda, but there are no unified standards in the specific information security and secrecy technology, system establishment and implementation; military academies have carried out more theoretical research and inspection but less effective countermeasures, so the actual results can be achieved which are not very ideal. In a word, there is no unified secrecy management system.

From the point of view of system construction, research organization and management system, technical prevention system, service support system, and standard specification system of information security assurance system of military academies, analyze the deficiency in the construction of information security assurance system of military academies taking this as the reference, strengthen the research on the specific measures and precautions for the construction of information security assurance system of military academies from the model, method, strategy and process, and other aspects, combine with the demands of security assurance of military academies, and carry out in-depth research on how to implement information security engineering of military academies and how to carry out the corresponding security risk management and avoidance.

The information security of military academies is sudden and dynamic to a certain extent. In the process of building the information security and secrecy system, except for the consideration of the above-mentioned management system, it still needs to establish the emergency response mechanism that can deal with the emergent crises and include it in the additional content of the information security and secrecy system. This emergency response plan designs and formulates the corresponding treatment measures mainly in accordance with various possibilities of losing and divulging secret information which can be predicted by different information carriers, in different information environment, through different information channels and in different information places as well as determines the responsibilities and tasks of each information security department of military academies. Once the information security leakage event happens in military academies, it can calmly and effectively control information security and secrecy crisis if there is adequate preparation for emergent crises and reduce the damage and loss of losing and divulging secret information to a minimum [3].

3 Information Security and Secrecy Mechanism of Military Academies

The research on information security assurance mechanism of military academies mainly includes two aspects of technical prevention mechanism and personnel management mechanism of information security. In terms of technical prevention, it mainly focuses on design and arrangement of prevention strategies in the operating system security, application system security, patch management security, firewall installation deployment, intrusion detection system, vulnerability scanning system, antivirus system, terminal monitoring and design and precautions for selection of information security products and other aspects; in terms of personnel management, the key is to determine the information security level of personnel with different identities and ensure the information security personnel to be assigned in place, mainly including three types of personnel like system administrator, security administrator, and security auditor who are responsible for the system operation, security and secrecy, and security audit work, respectively. For non-professional information security and secrecy personnel in military academies, except for the prevention of its violation operation under the restraint of secrecy provisions and system, it still needs to assist the related personnel with regular information security education training and propaganda and other activities to continuously strengthen the information security and secrecy consciousness of the personnel with different identities in military academies [4, 5].

Build the information security assurance model of military academies from the two aspects of general secrecy principle and core secrecy principle; focus on microcosmic, middle and macroscopic and other levels to build the hierarchical security assurance model; combine the technical prevention mechanism and personnel management mechanism taking information security assurance strategy and mechanism as the core, information security assurance service as the support and standard specification, and security technology and organization management system as the specific content; and change the existing management mode and make up for the deficiency in technology, institution and system, and other aspects. Form the comprehensive information security assurance ability from the standard, technology, management, service, strategy, and other aspects. Moreover, build the operation and management mechanism of information security and secrecy of military academies from three aspects of technology, management, and personnel.

The main research objects of information security and secrecy mechanism of military academies are secret-related carriers, secret-related computer system, secret-related network, secret-related personnel and their activities, and so on. The research focuses on strengthening the secrecy management for secret-related matters, including risk management mechanism, security control mechanism, early warning mechanism, workflow management mechanism, personnel prevention mechanism, technical prevention mechanism, and so on.

4 Information Security and Secrecy Scheme of Military Academies

"The top priority of the army is to keep secrets." The combat training of the army is to avoid war and the combat is to win; keeping secrets is the top priority of the army. There still exist many problems in information security and secrecy work of military academies, and the information security-related system, the matching, real-time capability, pertinence, validity, operability, and others of the scheme need to be further strengthened. The effective countermeasures, system regulations, and specific implementation scheme shall be found based on information security and secrecy work of military academies as soon as possible and implemented concretely. It is a political task and also a practical problem must be solved.

Firstly, in the top-level design, research information security assurance implementation scheme of military academies from the overall situation and taking the information security and secrecy as the core, establish an assurance system with clear levels, upper and lower cohesion and strict structure, develop computer-aided classification system, secret-related carrier supervision system, secrecy management system, secrecy evaluation system, and so on, which basically realize the unified supervision and whole process audit for secret-related matters; secondly, from the two aspects of technology and management, the practical solutions are provided to establish the perfect information security assurance system and strengthen the information security assurance capability of military academies from two levels of decision-making level and operation level; lastly, formulate the *Information Security and Secrecy Provisions of Military Academies* with stronger operability from the personnel, technology, equipment, place, management, and other aspects [6].

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Part VIII
Theory and Application Research

Application of Man–Machine–Environment System Engineering in Coal Mine Accident

Xing Zhao and Shangquan Ma

Abstract China is a big country of coal production and consumption, and coal production in the economic interests of the coal mine accidents occur frequently. The author believes that human factor is the direct cause of the accident. In this paper, the research on the human–machine operation behavior and on the human–machine–environment system of man–machine–environment system engineering (MMESE) is studied by the analysis of the causes of coal mine accidents. Through the analysis of the causes of illegal violation of the basic model of the security problem, this paper puts forward to reduce the occurrence of unsafe operation behavior of coal mine workers from the perspective of system management and control, and improve the safety production level of coal mine.

Keywords MMESE · Human–machine operation · Human–machine–environment · Safety model · Safety

1 Introduction

Modern coal mine system includes three elements of man, machine, and environment. Man–machine–environment system engineering uses the theory of system science and system engineering method, the correct treatment of human–environment subsystem, man–machine system, and machine–environment

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subsystem comprehensive disciplines. Accidents of coal industry are mostly due to poor site management and workers and workers' regulations [1].

In this paper, the author mainly analyzes the coal mine safety operation behavior and the unsafe behavior of employees system conditioning underground, in order to provide theoretical support for safety production. The illegal behavior of coal mine is mainly manifested in the illegal operation and illegal command, man–machine operation in the unsafe operation is generally referred to as illegal operation behavior. In the environmental system of coal mine human machine, people are the main body and the core of the production system. Human error of the system is to make the human–machine–environment system failure, not the normal operation of the event, is a violation of the objective laws or regulations of the wrong behavior, and is the cause of the accident. It may occur in the organization management, technology design, production, operation, maintenance, and other aspects of the system.

2 Characteristics and Performance of Human–Machine Behavior Operation

2.1 Characteristics of Human–Machine Behavior Operation

Human–machine operation is the behavior of employees in the work, and the main research in the accident is not safe operation of human behavior. In the view of system security and coal production system people is an element of this system. When people play the function as a system of elements, they are likely to make mistakes. People in the production activities, behavior has caused or may cause accidents, were unsafe behavior. According to the theory, we can come to Heinrich incident: Unsafe behavior control of people can prevent accidents [2]. The factor of the material is also the main cause of the accident, but it cannot eliminate the conversion function of the human's behavior failure. Therefore, the characteristics of correctly grasping the unsafe operation behavior of human–machine system are particularly important.

The characteristics of human unsafe behavior in coal mine production operation human–machine system are summarized as follows:

A. Collection and integrity.
B. Hazard concealment.
C. Difficult control.
D. Difficult predictability.
E. Difficult distinction.
F. Difficult radical.

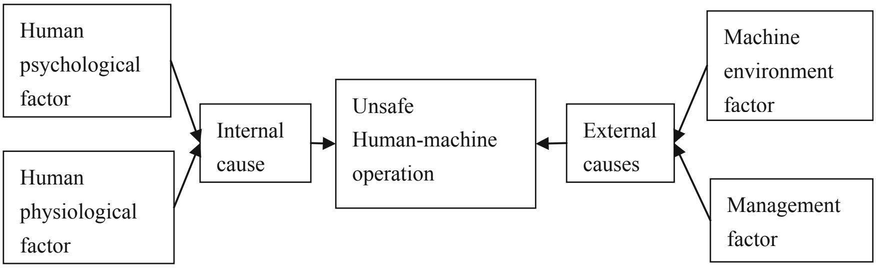

Fig. 1 The causes of unsafe human–machine behavior

2.2 Performance of Human–Machine Behavior Operation

Because of individual differences, the quality and the living environment of the coal mine workers are different, and the safety behavior is different in the production process. Some of their behavior to meet the safety of the law is conducive to the safety of production behavior, and some do not meet the laws of safety production and hinder the safety of production behavior [3]. Human is a very complex animal, especially human physiology and psychology, is one of them the two most critical factors, the two are indispensable, complementary, see Table 1 and Fig. 1[4]. Through the analysis of people's behavior, we can sum up the following aspects:

(a) Physiological aspects.
(b) Psychological aspects.
(c) Knowledge level.
(d) Operation response.
(e) Man–machine matching.

3 A Safety Model for the Establishment of Human–Machine Operation

3.1 Analysis of Unsafe Human–Machine Operation Reason

In the process of coal production unsafe human–machine operation has a great impact on the coal mine safety production. Unsafe human operation can be divided into intentional and non-intentional behavior, that is, in the process of operation,

Table 1 Influencing factors unsafe human–machine operation behavior

The main factors affecting the human–machine operation	Physiological factor		Physiological parameters
			Biologic rhythm
			Biomechanics
	Psychological factor		Feeling, perception
			Personality differences
			Organizational psychology
			Motivation
	Environmental factor	Physical and chemical factors	Temperature
			Humidity
			Lighting
			Dust concentration
			Noise
			Vibration
		Social factors	Interpersonal relationship
			Time quota
	Management factor		Management system
			Leading factor
			Team structure

some of which are negligence, are forgotten, are errors, and are intentionally violated [5]. Through the analysis of the accident, we can see that the unsafe human–machine operation is mainly concentrated in the holidays, before and after the handover, in the morning, and after the three points to six points [6]. Coal mine workers in the production process, the intentional operation is difficult to pay attention to. So it's hard to tell which is the operation and intentional violation. We can draw from the following several kinds of work in the general rule of unsafe human operator.

Unsafe human–machine operation is not only caused by the accident of personal safety and equipment to cause direct damage, but also to the enterprise to bring potential risks and other indirect hazards. The continuous occurrence of unsafe operations, to the enterprise has brought a huge risk and trouble, and will threaten the lives and safety of workers (Fig. 2).

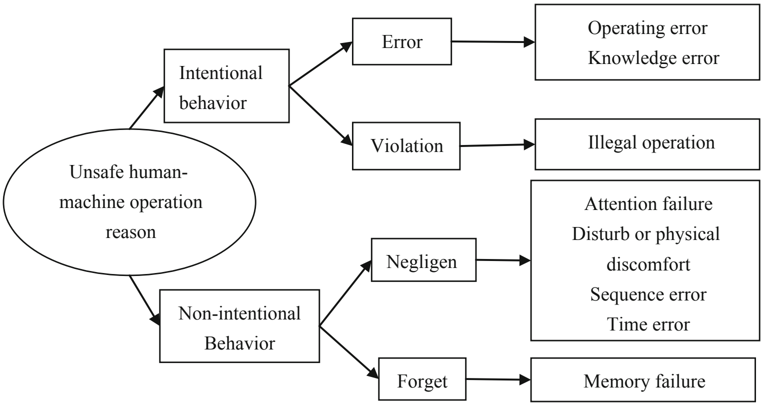

Fig. 2 Unsafe human–machine operation reason

3.2 Basic Model of Human–Machine Operation

Safety production is an important link in the production process of the enterprise, and how to better control the factors that affect the safety is the people's pursuit. From the overall view of the security problem, the security problem is determined by many factors. Whether the system can achieve the purpose of security during operation is the main problem that we care about. Security is a fuzzy concept, and in order to better clarify the factors related to security issues, the establishment of a security model is very important. So this paper is to establish the basic model of the safe operation by the analysis of the unsafe factors in the process of operation. In order to better measure the safety of different types of human–machine operation, the following models are established.

The basic model for the safe operation of the machine is:

$$w_{ij} = f\left(A_i, \theta_j\right) \quad i = 1, 2\ldots m;\ j = 1, 2\ldots n. \qquad (3-1)$$

In the formula,

A_i Controllable factors for security;
θ_j Uncontrollable factors for security;
W_{ij} Safe controllable function value.

According to the basic model of the security problem, types of security problems can be divided as shown in Fig. 3. According to the difference of θ_j, four types of security that can be obtained are the most basic and the most common.

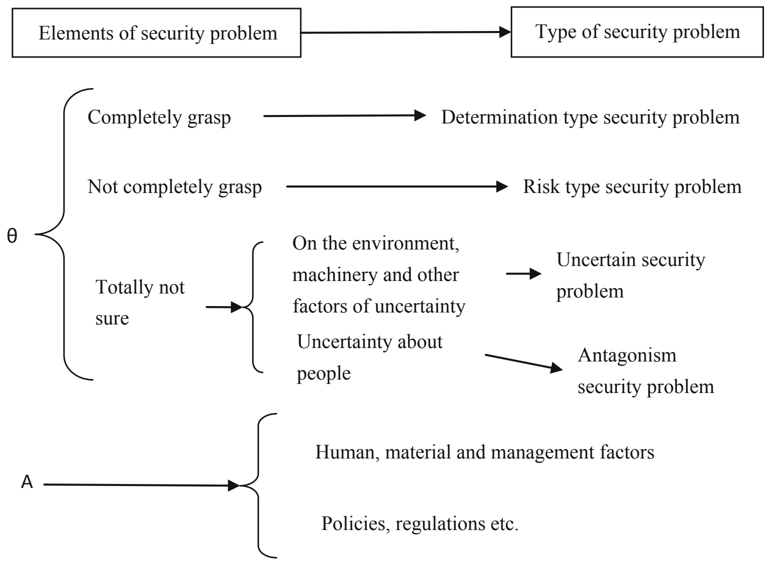

Fig. 3 Schematic diagram of the type of security problem

4 Methods for Controlling the Unsafe Human–Machine Operation

The occurrence of unsafe human–machine behavior is caused by the combination of human, environment, and machine. However, the main cause of the unsafe operation is the staff itself. So, in the coal mine production, strengthen the management and supervision of the staff. No matter in any environment, the operating environment how complex, the operator will put the error probability is controlled in a reasonable range [7].

The control behavior of people who are not safe, at the same time need to consider from the perspective of the system. Strengthen the education of accident cases [8]. To improve the management level, strengthen inspection, supervision, as far as possible to reduce illegal behavior.

1. Strengthen safety training and improve the safety awareness of coal mine workers. At the same time, improve safety education, safety knowledge contest, and safety skills training.
2. Establish a good management atmosphere, to ensure the smooth implementation of coal mine safety system. We must earnestly implement the standardization work, according to the scientific standards to regulate people's behavior.

3. Whether it will leave a trace of behavior is the key point of control. Therefore, there is no trace of unsafe behavior of the monitoring which is the main measure of control. Management should strengthen the supervision and management of the site, analysis of the unsafe behavior observed, seize the key reasons, to take control measures.
4. Improve production environment. The quality of production environment factor not only affects the improvement of production efficiency, but also has direct relationship with the physical and mental health of the operator. It is necessary to bring the environmental management of the production site into the safety management of coal mine.
5. Improve the employment system. To control the human error, good people are employed, to achieve the safety of people [9]. Strengthen management, to achieve the safety of equipment and protective equipment, so that the operation of safety.

5 Conclusion

Through the analysis of unsafe operation behavior of coal mine, the two aspects of the behavior intention and the non-intention of the unsafe operation are taken into account. Control the occurrence of unsafe operation behavior. By using the basic model of human machine operation, it can be concluded from the coal mine safety problem system classification that the coal mine safety problem can be prevented. The human behavior of the controller is the key to prevent the accident and at the same time the center of the safety management. Human–machine operation fault can be reduced or eliminated by a variety of methods.

Coal mine safety is a kind of multi-factor, multi-link, dynamic, and complex system engineering, in coal mine safety management, to reduce the human error and prevent coal mine disasters, and is the important link to ensure the healthy and stable development of coal industry.

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Research on the Characteristics and Expression of Modern Hospital Design

Zhen Li and Fang Liu

Abstract Chinese medical system is going through the conversion period. The rebuilding and extension work is becoming the focal point in present hospital's development. This paper uses case analysis method. Based on the practical example of the hospital design, it analyzes the new trends of modern hospital design from different aspects such as the layout of the function, ideas of humanization, and returning to the nature. The purpose of this study is to explore the general rule of medical architecture design and summarize the experience of planning. The basic principle of hospital building design is to take the patients as the center. It should reflect the people-oriented spirit and create a good environment for medical treatment.

Keywords Modern hospital · Humanization · Environment · Function · Patient

1 Introduction

In the new century, with the development of social economy and the improvement of people's living standards, the demand for medical care is increasing. At the same time, the facilities and overall environment of the early medical buildings are significantly backward in our country. It is unable to meet the needs of development. Under this background, China is entering a peak period of hospital construction. It should be pointed out that hospital architecture belongs to a complex type with a high level of professional and technical standard. It involves a wide

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range of disciplines. And besides, the emergence of new medical concept of treatments has also put forward higher requirements for hospital design. So, how to improve the medical environment and regulate the process of hospital construction cannot be avoided. Only in this way, it can suit the new requirements. Recently, we have had the honor to participate in the process of Xiaogan Central Hospital design. This paper intends to discuss the method of medical building design, combined with our creative experience.

2 The Development Trend of Modern Hospital Buildings

2.1 Respecting the Human Nature

"If there is such a place in the world, which embodies the science, the space and the human carefully, it is just the hospital", said Marie Christine Loriers [1]. Hospital is the place where everyone is born and eventually lost. We are also treated when we fall ill. However, the feeling of emptiness and indifference is hidden behind the latest and efficient medical equipment. Therefore, how to seek the balance between high technology and high emotion has been a hot topic in hospital design. The old medical mode is cold, heartless, and lack of care. It has been replaced by the new mode which cares for the patient's spiritual feeling. The thought of focusing on patients is becoming the center of the whole process of modern medical treatment. In order to reflect the care for humanity, we should achieve the integration of the technology and the humanistic spirit. The physical therapy and psychological treatment ought to be united. At the same time, the layout of the medical building should create attractive public space and beautify the medical environment.

2.2 Clear Logic and Order

There are usually a lot of complex internal departments and facilities in medical buildings [2]. Moreover, different departments not only have their own special requirements, but also should establish a convenient contact. In view of this, the architects must use a logical and simple design method to establish a sense of order, so that the efficiency and the safety can be unified. Therefore, logic and order are other characteristics of the modern hospital. To achieve the purpose, it is necessary to design the layout of medical function well, detail the medical process, and plan the traffic flow well. In addition, the safety of health should be paid special attention, which is mainly reflected in the process of the careful analysis of people's flow and the logistics process. The diversion principle must be strictly followed to avoid the cross-inflection.

2.3 *Paying Attention to Environment and Returning to Nature*

Large hospital is easy to make people terrified and increase the psychological pressure [3]. So the overall environment of the hospital directly affects the medical staff's and the patient's feeling. The relaxed and comfortable atmosphere can reduce the patient's mental burden and realize the unity of physiological and psychological treatment. It also helps to ease the psychological state of the workers in hospital and improve their efficiency of work. This shows that a good environment is necessary for modern hospitals.

Generally speaking, human longs for nature. The core of the hospital design is to emphasize the return to green [4]. To this end, the layout of the medical buildings must strive for a good orientation, natural lighting, and ventilation, so as to let patients close to nature. It also needs to design the outdoor courtyard greening well. Well-furnished landscape is necessary. We should try to make the medical environment look like a garden. In addition, the environmental arts design should be detailed. It should combine the aesthetics with behavioral psychology and use different elements, such as color, decoration, materials, lighting, and sound in the design.

3 The Overview of Project

Xiaogan Central Hospital is located in the center of the city of Xiaogan. It is a large modern hospital. The main building in the hospital was built in the early 1990s. Due to the limited land, various medical buildings are mixed like other old hospitals. The facilities are relatively outdated too and cannot meet the requirements of the development. For this reason, the hospital intends to plan and design a new operating building. The building's site is behind the old inpatient building with a total construction area of 24,000 m^2. The total number of beds required is 500. At the same time, the hospital will transform the old inpatient building properly, so as to make it matched with the new building.

At the beginning, we analyzed the condition of design comprehensively and decided to follow the principle of humanization design. For this, we try to combine the architecture design with the environmental transformation and shape a space with high quality. So, we have determined the following principles of design.

It includes the implementation of the "people-oriented" concept, designing a reasonable layout of medical treatment function, creating a green environment, and showing the image of a garden-style hospital and that the overall planning should meet the requirements of long-term development.

4 Overall Layout of the Hospital

The condition of the project construction is not ideal as an expansion project of an old hospital. The design is restricted by many conditions at the beginning. On the one hand, there are some low houses behind the inpatient building, which have occupied the construction space. On the other hand, several narrow streets have been built in the outlying land, which have not been connected with each other and cannot meet the requirements of the new building. In addition, due to the insufficient attention to the environment construction, the overall landscape of the hospital is dull and lacks distinctive features. In view of the above situation, we decided to use the rational plan and change the overall appearance of the hospital's environment.

While retaining the old inpatient building, we adjusted the existing facilities. The old low houses are removed, and the road network is broadened to improve the traffic condition. Since the old inpatient building has nine floors and owns a large body, it is difficult to coordinate the relationship between the new building and the old one. Considering the sunlight condition, we determined that the distance between the two buildings should be 36 m which ensures that the old inpatient building will not interrupt the view from the new one. At the same time, the functional relevance decides on their close relationship of the use in the future. Therefore, we adopted the "overall planning" strategy. The layout of the old inpatient building's function has been maintained. Moreover, the space between the new and old building is designed into a shared hall. And it will be the main entrance in the future. This can connect the new building with the old one, which makes the medical treatment more convenient.

Another problem is how to deal with the relationship between different traffic streamlines. It needs a reasonable arrangement for the entrance's location. Based on the principle of the separation of people and vehicles, the auto streamline is located in the periphery and forms an outer circular driveway. There constitutes an internal barrier-free walking space, which is from the south to the north and across the inpatient building, the shared hall, and the operating building. The layout of the main entrance is based on the separation of people and logistics. The main stream of people is designed from the central shared hall to the operating building as well as the old inpatient building. The supply of surgical goods is arranged in the east side of the new building. The outlet of the medical waste is located in the southeast corner of the building so as to avoid the pollution of the environment. The overall layout is orderly and efficient. And the identification is clear, which will lay a foundation of improving the overall environmental quality of the hospital.

5 Architectural Plane Design

The challenge of the architectural design is that medical buildings usually own many different departments, which is hard to coordinate with each other. So, designers need to understand the staff's methods of working in different medical departments. And besides, it also needs to analyze the activity patterns of hospital administrators, doctors, nurses, and the patients [5]. Only in this way, can we design the building successfully. Such plan has a reasonable function division and a clear movement direction and can let patients feel convenient and comfort.

In accordance with the requirements of the hospital managers, there are seventeen floors in the new operating building. According to the characteristics of the medical process, we arrange the public service function on the first floor, which includes the public seating area, the medical payment, the Chinese and Western pharmacy, and the store. It can connect with the old inpatient building through the shared hall. The operation rooms are on the second and the third floor uniformly. There are eight operation rooms on each floor, which are equipped with relevant facilities. The surgical equipment room is arranged on the fourth floor, just above the ordinary operating room. And then, we use the remaining area as the ICU ward, which is independent of other rooms. At the same time, the inpatient department is the biggest part in the hospital, particularly the common nursing units. The design will influence the whole quality of the hospital directly. Therefore, we place the in-patient department on the fifth floor and above. There are eighteen sickrooms and an emergency room on each floor. The sickrooms are divided into four types according to the number of the beds in wards. They are the suites, single rooms, double rooms, and triple rooms. Each floor owns a nursing station and related healthcare rooms to ensure a good recuperate environment. It is necessary for the new building to have a reasonable overall function and establish a convenient flow lines.

The flow line is a difficult problem in the design of operating space. The key to its success is to make different types of flow lines independent relatively. People can get to different functional areas in different ways quickly and avoid crossing with each other. To this end, we arrange the rooms according to the orders of different processes.

Firstly, the flow line of the medical staff is from the central elevator to the operating room and ward area. And on the operating floors, the flow lines of staff and patients are completely separated. The medical staff must change the ordinary clothes for scrub suit and have a shower before entering working space. Furthermore, a necessary buffer space has been designed to ensure that the flow line is from the clean area to operating rooms.

Secondly, the flow line of patients is from the spacious hall and elevator. When they arrive at the operating floor, their bed will be changed and then be pushed into the operating room. During the process of operation, the patient's family members can wait in the foyer on the west side so as to avoid disturbance.

Thirdly, we design a special dirt passage outside the operating room, by which the medical waste can be moved to the dirt treatment area on the east side of the building. The things which can be recycled will be picked out and packaged and then be taken to the special warehouse after being disinfected. At the same time, the rest will be moved to the dirt outlet by a special elevator and be treated. The arrangement of the flow lines emphasizes the clean and pollution partition. The functional division is based on that the clean area is separated from the unclean area so as to ensure the building's efficient operation.

6 Architectural Appearance Design

A hospital's appearance shows its interior space directly. If we follow the fashion blindly, the building's appearance will be slick [6]. A successful design is not to curry favor by claptrap but in art and functionality to satisfy both sides. Thus, the scheme stresses the harmony of the building's characteristics with the surrounding environment in the appearance. We abandon the so-called fashionable style of design to show the hospital's inner charm. We use the white as the building's main color, because it is a symbol of holiness and beauty. It expresses a lively atmosphere through the concise and asymmetric façade of the building (Fig. 1). People can feel the beauty and modern flavor of the building by its curved body combined with the rhythmic stripe windows and its simple shape, which will create Xiaogan Central Hospital's new image.

Fig. 1 The appearance of the building

7 Conclusion

In the creation of the operation building of Xiaogan Central Hospital, we try to express the inner spirit of medical architecture through the interpretation of the relationship between the science, technology, and cultural environment. And besides, we have deeply felt in the process of design that the hospital construction must be based on the reality. The designers should analyze the features of hospital's use carefully, update the design concepts and techniques constantly, and choose the best way to design. Only in this way, can we keep pace with the times and create a real good program which can meet the needs of the hospital. This research has used the method of theory combined with practice. Its purpose is to find a general rule which can be applied in the design practices of hospital architecture. We hope that this program can arouse more attention to the study of medical buildings and promote the construction of China's medical facilities to a higher level.

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Research on Modern Office Chair Design Based on Human–Machine–Environment System Engineering

Yifeng Du

Abstract This research applies the theory of human–machine–environment system engineering, using the measurement method to analyze the relationship between the user and the various components of the office chair in the sedentary condition. The measurement and analysis of the numerical value of the Chinese office crowd, find the basic design criteria of the modern office chair, which is seat height, seat width, seat depth, seat angle, seat back, and seat armrest. The research aims at optimizing modern office chair design and combining with human–machine–environment system engineering to make the design more scientific and reasonable.

Keywords Human–machine–environment system engineering · Office chair · Design research

1 Research Objective

Sitting posture, as the most common physiological posture of human beings, helps blood circulation and can effectively eliminate fatigue of human body. For the population involved in fine work, sitting posture is the most suitable one that can enable the body of the operator to maintain balance and stability. Sitting posture is the most common posture applied by modern office crowd. However, it also has some inevitable shortcomings: Long-time working at the desk can easily make people feel unwell or sore in lumbar vertebra, cervical vertebrae, and upper and lower arms, especially in the shoulders, which not only impacts the work efficiency, but also may cause muscle injury in lumbar spinal cord, lumbar disk herniation, and other injuries.

A. Kilboms' tabulation of professional disease [1] is made by P. Magnus toward Swedish management and operators, in which it points out that "static work posture" is the main cause of occupational injury at present. It is increasingly

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recognized that comfortable office chairs directly relate to the health, safety, and work efficiency of the users; therefore, it is a subject worth studying that how to design the chairs suitable for modern office crowd from the perspective of human–machine–environment system engineering.

Purpose of the research is to adopt the theory and principle of human–machine–environment system engineering technology, start from human anatomy and physiology of sitting posture and analyze the design of modern office chairs to find out the seat height, seat width, seat depth, seat angle, seat back, seat armrest and other basic design scale and criteria for modern office chairs suitable for Chinese office crowd. The research aims at striving to optimize the design of modern office chairs and combining with human–machine–environment system engineering to make the design of modern office chairs more scientific and reasonable.

2 Research Method

The design of modern office chairs shall put the actual use value of chairs in the first place, and the design shall put its emphasis on physical and mental damages modern office chairs cause to human body in the course of using based on the principle of human–machine–environment system engineering and the actual size of human body measurement. Starting from the theory of human anatomy and physiology of sitting posture, the research uses the principle of human–machine–environment system engineering to analyze the office chairs and adopts the measurement method to analyze the relationship between the user and the various components of the office chair in the sedentary condition. In addition, it measures and analyzes the numerical values suitable for Chinese office crowd to enable the design of modern office chairs to really meet the physiological characteristics of human beings.

3 Research Result

3.1 Analysis of Human Anatomy and Physiology of Sitting Posture

3.1.1 Spine Structure

Spine, pelvis, legs and feet and other parts constitute the main structure to support human body in sitting posture. The most critical part is spine, located in the midline part of the human back.

Analysis chart of spine structure is shown in Fig. 1, and it thus can be seen from the chart that there are 33 vertebras in total, including 7 cervical vertebras,

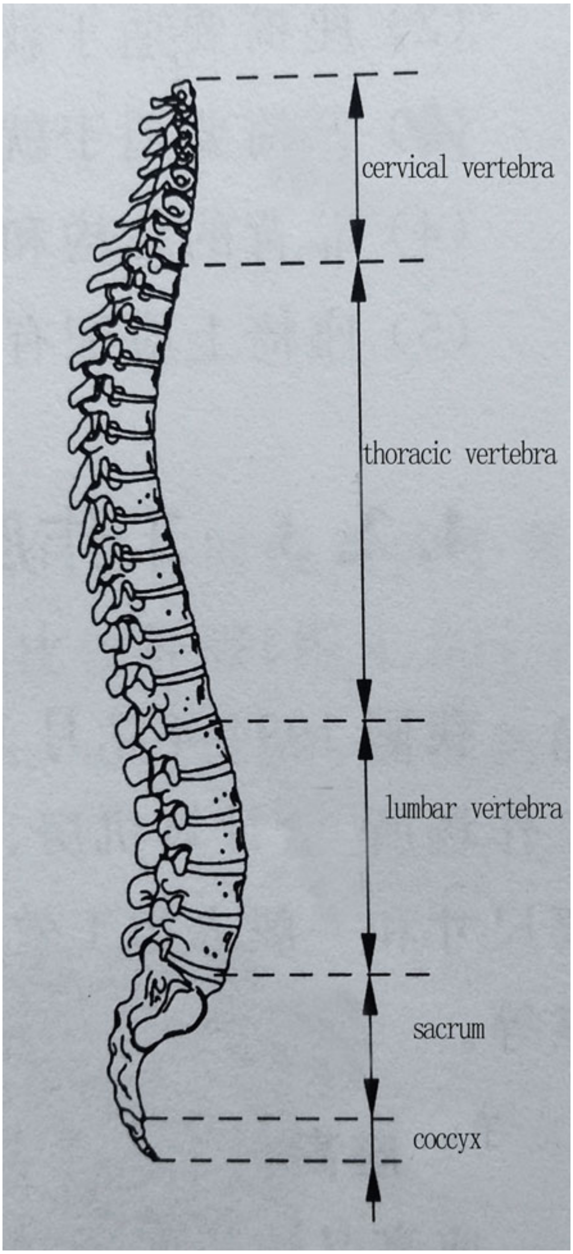

Fig. 1 Spine structure analysis

12 thoracic vertebras, 5 lumbar vertebras, and 2 coccyxes [2]. Structures are connected via muscle tendon and cartilage. As for design of modern office chairs, the most important thing is to know that lumbar vertebra, sacrum, intervertebral disk, and soft tissue are the parts bearing most load of the upper body in the physiological state of sitting posture.

3.1.2 Curve of Lumbar Flexure

It can be observed from the physiological anatomy of the spine that it has 4 physiological flexures including cervical flexure, thoracic flexure, lumbar flexure, and sacral flexure. People can have comfortable sitting posture only if they keep the normal shape of curve of lumbar arch. The curve of lateral posture in the relaxed state is the normal curve of lumbar arch. To enable human body in sitting posture to form the normal curve of lumbar arch, the angle between the trunk and thighs shall be more than 90°, preferably with lumbar support.

Curve of lumbar arch with slight protrusion is the normal curve of lumbar arch. If you want to keep the minimum deformation of curve of lumbar arch as the human body is in sitting posture, be sure to provide two supporting points in the part of lumbar vertebra when designing the office chairs. The height between fifth and sixth thoracic vertebras should be equal to the height of shoulder blade [3], and the shoulder blade can bear higher pressure due to larger area; therefore, we can put the first supporting point here and call it shoulder rest and put the second supporting point in the height between fourth and fifth lumbar vertebras and name it waist rest and put seat back and shoulder rest together as the seat backrest.

3.1.3 Muscle Activity

Stability of vertebra is the result of the acting force of muscle tendon, and if the spine deviates from the natural state of body posture, the tendon tissue will be under great pressure and cause fatigue to human body to increase muscle activity.

Repeated experiments have shown that it is a state of activity as the tendon tissue is in stress state. As the human body sits in straight and upright posture, the muscle of lumbar vertebra now may show a high motion state because the forward straightening state of lumbar vertebra may render muscle tissue under pressure. If we provide an effective support in the part of lumbar vertebra, the muscle activity shows a decreasing trend at that time. In addition, experiments show that as the trunk of human body is in anteverted state, the activity of muscle in the upper back and upper shoulder is significantly increased.

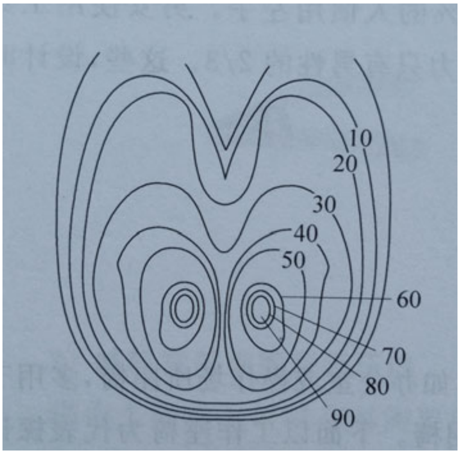

Fig. 2 The ideal body pressure distribution curve (*Unit* 102 Pa)

3.1.4 Body Pressure Distribution

Body pressure distribution refers to the distribution value of pressure of body weight on chair back and surface as the people sits on the chair. In the state of normal sitting posture, it is the shoulders and the hip supporting the body weight and the sitting posture at this moment is the most comfortable sitting posture. Normal body pressure distribution shall be in a smooth transition from small to big to avoid pressure jump, and ischial tuberosity shall be the part with most pressure. The curve of body pressure distribution shown in Fig. 2 is comparatively ideal and drawn based on data in the figure: The sitting posture is liable to cause fatigue of human body as the trunk is in straight and upright or anteverted state; proper backrest can make the body less fatigued.

3.2 Analysis of Human–Machine–Environment System Engineering of Modern Office Chairs

3.2.1 Characteristics of Modern Office Chairs

Modern office crowd refers to the crowd working in the sedentary condition and they need to work in sitting posture for a long time, so they adopt the sitting posture as much as possible and the sitting posture can effectively maintain the balance of human body and helps blood circulation. However, it also has many problems and one is liable to result in waist problems.

When people work in the office for a long time, they will suffer from various waist pains due to not enough spinal curvature that may increase the pressure on intervertebral disk. The design of reasonable office chairs can help people to reduce uncomfortableness of the sitting posture and lower the burden of the spine. Seat height, seat width, seat depth, seat angle, seat back, seat armrest, and some other design parameters are the most critical ones.

3.2.2 Design of Human–Machine–Environment System Engineering of Modern Office Chairs

Basic design form of modern office chairs is shown in Fig. 3. According to the principle of human–machine–environment system engineering and GB/T 10000-1988 *Chinese Adult Human Body Size* formulated by State Bureau of Quality Technical Supervision and National Standardization Management

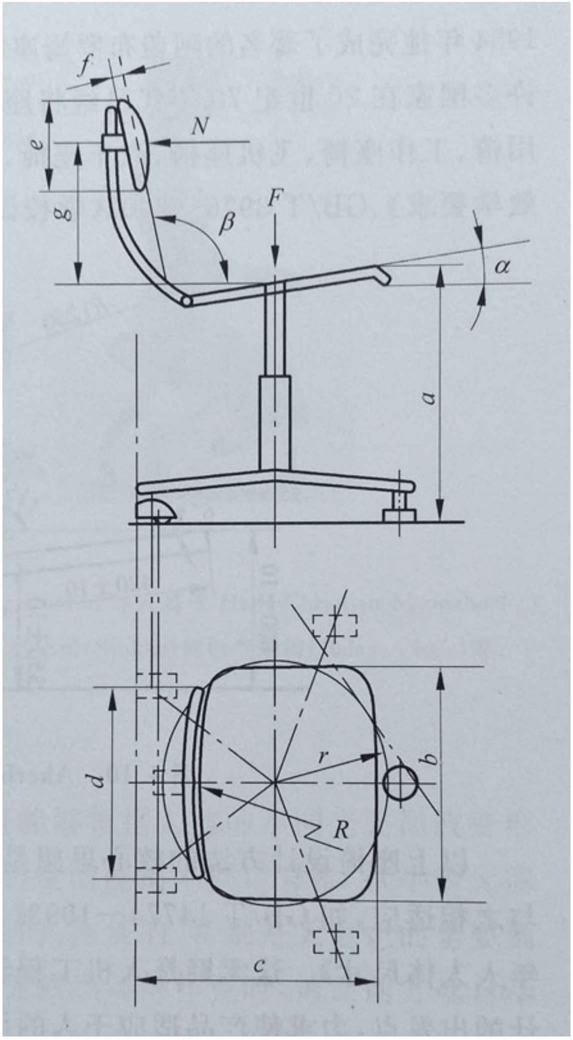

Fig. 3 The basic design form of the modern office chair

Committee [4], measurement method is adopted to obtain the following basic value setting via experiment:

1. Seat Height

Anterior height of the seat is also known as seat height, so be sure to pay attention to that the thighs of human body shall be level while the shanks shall be vertical to the ground when designing the seat height of office chairs. In addition, the edge of hip and the thighs posterior to popliteal fossa shall have favorable support on the seat surface; at the same time, make sure that the popliteal fossa bears no pressure. In practical design, be sure to choose the crowd who are short as the reference for design.

With reference to human dimensions of Chinese adults in sitting posture [5], the anterior height of seat surface practically measured and calculated shall be 30–50 mm lower than the height of knee of human body and it shall has certain radian with a radius of 25–50 mm. In addition, the seat surface shall not be too lower in design; otherwise, the pelvis of those with longer legs will be in the retroverted state, resulting in waist sore and discomfort.

With regard to the upper limit of seat height of modern office chairs, take the dimensions of those office workers who are short under the circumstance of fixed office seat surface. Different from the requirements for general working chairs, seat height of office chairs shall be higher and the height is closely related to that of the office seat surface and adjustable seat is even better, in which case it can better satisfy the operators with various different needs. Through experiment, measurement method is adopted to figure out that the 360–480 mm is the seat height (a) of office chairs suitable for Chinese adults in the sedentary condition for a long time.

2. Seat Width

When designing the seat width, it should be considered that if the office chair is for single use, the size shall be larger than the hip breadth in sitting posture of the horizontal size of human body, with regard to the data, body size of females shall be larger than that of males, so we shall take female hip breadth in sitting posture as the upper limit design basis. At the same time, it shall also be noted that in case of long working hours, the arms and shoulders of the office workers shall have effective support, so the seat shall not be too wide; otherwise, it may cause shoulder fatigue. The seat width b of office chair without armrest shall be 370–420 mm after measurement. The seat width of office chair with armrest shall not be less than 500 mm.

3. Seat Depth

When designing the seat depth, it should be noted that the seat depth shall meet the following criteria, that is, the seat surface shall have necessary support area, in which case the edge of hip and thighs can help to stabilize the upper body on the seat surface to reduce the burden on back muscle. In addition, under the condition of no pressure on popliteal space, waist and back can easily get the support of waist rest.

Moreover, the standard for seat depth goes that "shallow rather than deep" and the seat depth of modern office chair shall be slightly greater than that of the work chair.

To make shorter people work in comfortable state, the design dimension of seat depth shall be designed based on the crowd accounting for a smaller percentage. The seat depth of office chair suitable for the country finally measured via measurement method shall be 360–390 mm, and the recommended value is 380 mm.

4. Seat Angle

Firstly, set the value of seat angle as α, when office workers are working in anteverted posture, the seat angle α is positive, the part of the thighs on the seat near the popliteal space will bear uncomfortable body pressure, and the abdomen will also be in bad condition of being pressed; while the seat angle α is set negative, such as $\alpha = -15°$, the body pressure on seat is evenly distributed at the moment and the body pressure is centered on the tip of ischium, so the seat angle has a close relationship with the working posture, that is, the anteverted degree of the upper body in working. The seat angle of general office chairs shall be set as $\alpha = 0°\text{–}5°$, and the value normally used is set as $\alpha = 3°\text{–}4°$.

5. Seat Back

Shape and angle data of the seat back play an extremely important part in design. Seat back can effectively help the spine maintain in normal state. Through experiment, the length d of seat back after final measurement shall be 320–340 mm, 200–300 mm, width e of seat back shall be 200–300 mm, thickness f of seat back f shall be 35–50 mm, seat back g shall be 165–210 mm, arc radius R of seat back shall be 400–700 mm, overturning radius r shall be 195 mm, and the angle β of seat back shall be 95°–115°.

6. Armrest

The key data of armrest design lie in its height, and the armrest can support the body as people get up, sit down, or need to change body postures; in addition, it can support the arms and reduce shoulder burden. If the armrest is designed too high, it may discomfort the shoulders; if it is too low, it will fail to support the upper and lower arms and may render the shoulder muscle in the tension state. The height of the armrest suitable for Chinese office chairs after final measurement with the measurement method shall be 230 ± 20 mm.

4 Research Conclusion

The core idea in the design of modern office chairs is to strive to make the product match the dimensions and characteristics of human body according to the basic human body dimensions and physiological characteristics of modern office workers, that is, taking human factors as the basic starting point for design.

The research gives an analysis of the characteristics of office crowd based on human anatomy and physiology of sitting posture and reasonably design the modern chairs for office crowd according to numerical values in GB/T 10000-1988 *Chinese Adult Human Body Size* formulated by State Bureau of Quality Technical Supervision and National Standardization Management Committee and in combination with relevant principles of human–machine–environment system engineering to improve the sitting posture of human beings so as to reduce the pressure on the spine of office crowd and enhance their health. At the same time, it should be noted that the basic value setting and design scale issues involved in the research are only one aspect of design of office chairs and many problems remain to be solved with regard to research on modern office chair, such as whether the front-tipping design is adapted to modern office chair; whether modern office chair requires seat pedal and other problems still requires further investigation.

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Application Prospect of Big Data in Military Physical Education and Sports

Jingran Huang and Weiming Deng

Abstract Big data is a big trend in the development of informatization construction in the world. Big data brings a revolution to the work, life and the way of thinking. It also causes the deep thinking for the development of military physical education and sports with the trend of big data. Based on the trend of big data's development and the conception of military physical education and sports, by the method of documentation and logical analysis, this article discussed and analyzed the application prospect of big data in military physical education and sports, pointed out its potential problems, and countermeasures. This article is aimed at combining advanced Big data technology and Military Physical Education and Sports, so as to improve the fighting capability of PLA.

Keywords Big data · Military physical education and sports · Application prospect

1 Research Objective

The development of science and technology makes people, machine, and environment highly integrated, brings an exponential growth in data scale, and makes the world enter the era of big data [1]. In recent years, big data has attracted wide attention from the government departments, economic circles, and academic members. Big data has not only been successfully applied in the commercial field and the field of information industry, but also been gradually penetrated into education, medical, media, and other fields, and military physical education and sports science is no exception. Currently, the research on domestic military physical education and sports focuses on theory and training methods, but the sensitivity to

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emerging technology is not enough and there is no research on how big data is applied to military physical education and sports. This paper starts with the basic concepts of big data and military physical education and sports, focuses on the discussion of change of thinking of military physical education and sports brought by big data, and carries out the preliminary analysis on problems and solutions existing in the process of applying big data technology in military physical education and sports.

2 Research Method

The basic concepts and characteristics of “big data” and military physical education and sports are analyzed by the method of documentation and logical analysis, the change of thinking of military physical education and sports brought by big data is researched, and the problems and challenges existing in the process of applying big data technology in military physical education and sports are carried out by the preliminary analysis to pave the way for its specific application.

3 Research Results

3.1 Concept of Big Data

The renowned consulting agency McKinsey & Company released a technical report titled Big Data: *The Frontier of the Next Innovation, Competition and Productivity* in May 2011, thought that big data refers to the data sets in which sizes are beyond the typical database software acquisition, storage, management and analysis and other abilities [2]. Guojie Li, the Academician of Chinese Academy of Sciences, thought that in a general sense, big data refers to the data sets which cannot be carried out by the perception, acquisition, management, processing and service with traditional information technology, and software and hardware tools within a tolerable time [3]. The concept of big data in this paper refers to the data sets in which sizes are beyond the typical database software acquisition, storage, management and analysis and other abilities and can be carried out by the perception, acquisition, management, processing and service with the information technology, and software and hardware tools. From the perspective of information science, International Data Corporation (IDC) summarized the characteristics of big data as 4 V, that is, Volume (large volume), Variety (various models), Velocity (rapid generation), and Value (great value with low density) [4]. Mayer-Schonberger, the Professor of University of Oxford summed up three characteristics of big data, that is, integrality, hybridity, and relevance [5].

3.2 Concept of Military Physical Education and Sports

Military physical education and sports is a series of special physical education and sports forms closely related to combat skills and focused on physical training methods which is adopted to prepare for national defense security and war and comprehensively improve the combat capability of the combatant main body. The training contents have strong military characteristics, the training objects have obvious unicity, the training effects have clear directionality, and the implementation processes have certain enforceability [6]. Military physical education and sports has the basic characteristics of sports, very clear purpose, and it is the basic constitution of the combat capability.

The general functions of military physical education and sports mainly reflect in the following aspects: (1) improve the physique, enhance the physical quality of soldiers and officials, and improve the military combat capability; (2) effectively promote the soldiers to master military technologies and tactical skills; (3) develop soldiers' good ideological morality and brave and indomitable combat spirit; (4) make the soldiers and officials' life active and promote the construction of military culture. The modern military physical education and sports also has the following special functions: (1) promote the communication among the troops; (2) promote the popularization and improvement of military sports [7].

3.3 Discussion and Analysis on Application Prospect of Big Data in Military Physical Education and Sports

3.3.1 Big Data and Establishment of Military Physical Training Models

The research on traditional physical training is greatly influenced by modern natural science especially physiology, biochemistry, medicine, biology, management, theory of training and mathematics, and other science. The research method adopts small data research mode and logical thinking analysis method in modern science. The research on traditional military physical education and sports focuses on using simple model to simulate the actual situation and random sampling method to replace the overall sampling method. It has made many achievements in small data research mode, but still has some shortcomings in the face of new demands.

Military physical training is sports training in the training mode, and the sports training is essentially a complex system. The complexity of sports training is specifically embodied in the following aspects: (1) the complexity of sports training factors, such as physiology, psychology, technology, tactics, nutrition, health, hygiene, injury, heredity, environment and society, and other factors; (2) the complexity of sports training relationships, namely the nonlinear correlation of interrelation and interaction existing between factors and factors, factors and system as well as system and environment of the above sports training; (3) the complexity of sports training structures, that is, the complexity of sports training relationship in the space structure is shown as the complex network structure of sports training; (4) the complexity of sports training function, mainly represents the whole function of sports training system rather than the simple sum of each part or factor; (5) the complexity of sports training state, that is, sports training state not only has balanced state and periodic state, but also has quasiperiodic state, chaotic state, and so on; (6) the complexity of sports training environment, mainly represents that its environment is open, that is, sports training system carries out materials, energy and information exchange with the external environment continually [8].

These complex association characteristics of sports training have determined the limitation of small data research mode; similarly, the research on military physical education and sports needs to adopt a new data research mode. Any one of the military sports items is an organic whole and the relationship between each factor or part of military physical training is interrelated, interacted, and mutually restricted. Sometimes the military sports science problems with real values are from the special details. The traditional database can only use 5 % of structured data and the remaining 95 % of unstructured data cannot be used [5]. Under the perspective of big data, the development of data mining technology provides the possibility for storage and processing of unstructured data and avoids missing data in the extraction process of the traditional structured data, so as to make it possible to build complex and precise military physical training models.

3.3.2 Big Data and Monitoring on Changes in the Soldiers' Physique

Physique is the quality of the human body and is an integrated, relatively stable characteristic of the morphological structure of the human body, physiological function and psychological factor reflected on the basis of heredity and acquired character [9]. The basis for research on soldiers' physique is from the research on the national physique, but it has its own characteristics and requirements by comparison. Countries in the world have a clear requirement for soldiers' physique and many countries not only have requirements for physique when selection of soldiers, but also have the corresponding standards of physique when promotion.

The soldiers' physique has a direct impact on the military combat capability. It not only needs to investigate the present state of soldiers' physique, but also to pay attention to its change and development. Our soldiers' current physique investigation focuses more on investigation and analysis on the present situation, and the interval of time longitudinal comparison is larger [9]. As it will consume huge manpower and material resources to carry out the soldiers' physique investigation and take military training time to conduct the related testing, such investigation cannot be carried out frequently. The traditional data analysis methods can only deal with the structured small data sample, but cannot carry out real-time and comprehensive data monitoring in a large range. Nowadays, with the quick development of technology, we can use all kinds of sensors, obtain the required data through fixed-point, real-time, and non-contact monitoring, combine with the big data technology to analyze other unstructured data, and build comprehensive soldiers' physique index monitoring system. Master the dynamic changes of soldiers' physique and adjust the strategic deployment timely.

3.3.3 Big Data and Evaluation on Effect of Military Physical Training

The most intuitive way to evaluate the military physical training effect is training grades. However, the improvement of the training grades is a gradual, progressive, and fluctuant process; the training result is delayed and the training effect cannot be measured immediately, so it needs to measure and evaluate with modern means. In modern sports training, it often uses some physiological and biochemical indicators to evaluate the training effect, which is not easy to be achieved on a large area in the actual operation process and not easy to be carried out by real-time monitoring.

With the development of science and technology, some companies have researched and developed minimally invasive, micro and rapid analysis methods to detect the biochemical indicators. Making use of big data technology to integrate these sensors can make it possible to build real-time sports effect feedback. American excellent gymnasts can complete the data entry through professional software program in the computer that fixed on training field, and at the same time convert its visualization to curve chart and make the coach grasp the training situation in time [10]. In the process of military physical training, as there are more trainees and relatively few of group training personnel, it cannot monitor every person's training effect better and cannot make the training plan according to the training situation. Through the analysis of big data on all personnel's indicators, it can not only make evaluation for the individuals, but also make the integral analysis for the group, so as to guide the implementation of military physical training better.

3.3.4 Big Data and Soldiers Selection Criteria

According to the provisions of *Military Service Law of the Chinese People's Liberation Army*, the ways for the soldiers' selection in the conscription work are mainly political examination and physical examination. In addition, the selection of Air Force pilot has relatively perfect and systematic indicators. For physical examination, people who are in good health and having strong physique will be screened out through body shape indicators and health indicators. Different posts require the personnel to meet different requirements for each quality. As the selection materials for all specific arms and services have no comprehensive and systematic subdivided selection indicators, it causes the selectors to tend to focus on physical quality indicators and select by experiences in the process of actual materials selection operation.

If we can use the means and methods of big data technology, carry out comprehensive and synthetical evaluation and prediction through the testing of the objective indicators, select the talents who have superior conditions and are suitable for a specific military post and provide a systematic cultivation, it will greatly shorten the time for generation of combat capability. In the era of big data, there are important changes in research thinking. Big data has focused more on the relevance between things rather than the causal relationship between things. We can make use of this point to compare the excellent soldiers and the ordinary people, explore the differences between them, and make use of the differences to select the soldiers. For the soldiers who have been trained for a certain time, we can use the prediction of large data technology to build its matching degree, so that people can do only what they can do best.

3.3.5 Big Data and in-Depth Informatization of Development of Military Physical Education and Sports

In the development process of military physical education and sports, as long as it involves related research, due to the limitation of technology and other factors, except a very small number of major projects are carried out by the overall data collection, it mainly conducts the research by the sampling survey method. Although the sampling survey method has developed to be very mature, the "part" can never completely replace the "whole." Big data technology is a technology of collection, processing and analysis of all data, and its corresponding storage, processing, and mining methods are gradually mature. Through big data technology, we can see lots of detailed information that the samples cannot reveal. The comprehensive collection and quantification of the data can lead to the transformation of military physical education and sports from "empirical decision" to "scientific decision."

Report on Development of China's Military Power in 2013 released in the USA said, "to completely realize the command and control informatization, the Liberation Army needs to overcome the following problems: lack of the trained personnel and centralized and micro management command culture" [11]. Our army always has the tradition of paying more attention to strategy and less attention to data. The progress of the army in the future is gradually relying on the establishment of such a precise management and decision system. In-depth informatization, that is, carries out reprocessing and deep mining for the generated information data based on the existing various information system through the data's acquisition, sorting, storage, processing and analysis, and other process, so as to discover the valuable patterns and knowledge, providing references for policies and guidelines of army building accordingly or perspective prediction and others for military development achievements [12].

3.4 Potential Problems and Countermeasures of Big Data in the Application of Military Physical Education and Sports

3.4.1 Problems for Data Collection

The data resources construction is a systematic, long-term, and comprehensive engineering, involving many departments with deep level. In the process of building the big database of military physical education and sports, how to ensure the effectiveness and comprehensiveness of data collection has become the first important problem. To avoid the problems of waste of materials and low efficiency, only the establishment of a scientific and reasonable system structure can effectively form a resultant force. The key is to pay adequate attention to the top-level design of big data construction, build the data organization structure that met our army's organizational establishment system, make all levels of function tasks and related data collection process clear.

3.4.2 Problems for Storage of Big Data

In the IT-based warfare, it not only needs to collect, process, and release the battlefield data, but also processes the missive real-time data timely and mine the valuable information. In the process of big data technology applying in the military physical education and sports, there must exist contradiction between massive data and real storage space. The specialized agency shall be set up to solve the storage problems of big data of military physical education and sports. In view of the characteristics of big data of military physical education and sports, the related planning development policies are formulated to encourage the scientific research institution to carry out the related topic research, or the thinking of military-civilian combination is adopted to encourage the private IT enterprises to provide technical support and jointly carry out the research on storage problems of big data.

3.4.3 Problems for Cultivation of the Talents with Thinking of Big Data

If there is only large-scale data, but the data cannot be exploited and formed effective information, it can only be called massive data rather than big data. Big data not only requires a great volume of data, but also focuses more on its internal relation. The application of data in our military is not much deep, the starting is very later, and the data professionals are scarce. To make better use of big data, it is urgent to cultivate the talents who have new thinking way of big data and strengthen the construction of the professional and technical talents team. The way of combining cultivation and introduction can be adopted to cultivate the related personnel of military physical education and sports. Lectures of science popularization can be held in a wide range to provide new thinking way for commanders and fighters of our army.

3.4.4 Security Issues of Big Data

Big data technology can analyze the relevance between the data and predict certain behaviors, accordingly; the users' information and privacy exposed problems become more serious. In the analysis process of big data, it can link up the two information easily and how to use this relevance to protect the users' privacy becomes particularly important. The protection of the users' information and privacy in military information is stricter. In the process of analysis and processing of big data of military physical education and sports, it is necessary to make the range of data collection clear and formulate the strict grading and layering rules of data analysis and processing.

4 Conclusion

Although big data has become a hot topic in many research fields and marks the arrival of a new era, the research on big data currently is still in the early stage and many fundamental problems need to be solved. Carrying out the research and application of big data of military physical education and sports is very beneficial to the development of military physical education and sports of our army and can provide data support and new thinking way for the research of military physical education and sports. Under the background that military organizations of developed countries have take big data technology as strategic development, we should clearly realize the development trend of big data, actively explore the application of big data technology based on the fact of our army.

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