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Tareq Ahram
Christianne Falcão *Editors*

Advances in Human Factors in Wearable Technologies and Game Design

Proceedings of the AHFE 2017 International Conference on Advances in Human Factors and Wearable Technologies, July 17–21, 2017, The Westin Bonaventure Hotel, Los Angeles, California, USA

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8th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences

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Preface

Successful interaction with products, tools and wearable technologies depends on usable designs and accommodating the needs of potential users without requiring costly training. In this context, this book is concerned with emerging technology of wearable devices with respect to concepts, theories and applications of human factors knowledge focusing on the discovery, design and understanding of human interaction and usability issues with products and systems for their improvement. This book focuses on the human aspects of wearable technologies and game design. It shows how user-centered practices can optimize wearable experience, thus improving user acceptance, satisfaction and engagement towards novel wearable gadgets. It describes both research and best practices in the applications of human factors and ergonomics to sensors, wearable technologies and game design innovations, as well as results obtained upon integration of the wearability principles identified by various researchers for aesthetics, affordance, comfort, contextual-awareness, customization, ease of use, intuitiveness, privacy, reliability, responsiveness, satisfaction, subtlety and user friendliness. The book is organized into three sections that focus on the following subject matters:

Section 1: Wearable Technologies and Sensors
Section 2: Accessibility, Wearability and Applications
Section 3: Game Design Applications

This book will be of special value to a large variety of professionals, researchers and students in the broad field of game design, human modeling, human computer interaction and human systems integration, who are interested in feedback on device interfaces (visual and haptic), user-centered design, and design for special populations, particularly the elderly.

Each section contains research papers that have been reviewed by members of the International Editorial Board. Our sincere thanks and appreciation to the board members as listed below:

Wearable Technologies

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We hope this book is informative, but even more—thought-provoking. We hope it inspires the reader to contemplate other questions, applications, and potential solutions in creating good designs for all.

July 2017

Tareq Z. Ahram
Christianne Soares Falcão

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Wearable Technologies: Sensors

A Wearable Flexible Sensor Network Platform for the Analysis of Different Sport Movements

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Abstract. In elite sports real-time feedback of biomechanical parameters is indispensable to achieve performance enhancement. Wearables including embedded data analysis are a suitable tool for online monitoring of movement parameters and might enhance the quality of training significantly. However, due to limited compute capacities for complex data processing on the sensor device itself, analysis can typically only be done afterwards using high-performance tools. This lack of immediate feedback may lead to slower training progress. We present a flexible, wearable system for the analysis of different sports movement including online-monitoring. It includes a modular, platform-based framework with a sensor node, an embedded software stack, Bluetooth Low Energy communication and an Android application. Data is analyzed on the sensor itself via embedded real-time algorithms. Results indicate that the device provides reliable and accurate measurements of movement parameters. In combination with adaptable algorithms and the BLE transmission, it offers solutions for real-time monitoring of athletic performance.

Keywords: MEMS · IMUs · Sports performance analysis · Real-time feedback · Wearable sensor devices

1 Introduction

The last decades were characterized by a strong progression of athletic performance. Besides the development of training methodologies, a rapid evolution of new technologies and engineering has proved to be a vital ingredient in enhancing sports performance. Improvements in technologies and engineering thereby include sports equipment (e.g. shoes, surfaces and facilities, balls, clubs or protection equipment) as well as instrumentation and measurement devices for movement analysis and optimization of human performance. Therefore, the main goal of peak performance in sports is being achieved by an increasingly integration of biomechanical measurement methods during daily training. Data obtained by biomechanical methods deliver highly

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reliable information that can be used by coaches and athletes as well to support their training activities. Additionally, kinematic, kinetic and physiological data of sport movements can be used to analyze effects of conditional or technique training, periodization, fatigue as well as aspects of expertise, to achieve a deeper understanding how to enhance the quality of training and optimize performance [1, 2].

Biomechanical diagnosis can basically be distinguished between laboratory and field based measurement scenarios with laboratory applications mainly using means like force plates, motion analysis systems (stereophotogrammetry), electromyography or optoelectronical systems (photo cells, light barriers) under highly standardized conditions. These methodologies allow precise and unobtrusive measurements of a variety of performance parameters, which yield important insights to human sport activities and techniques. However, data acquisition is limited to a restricted area (for example it is not possible to capture data of a complete 400 m race on the track), the required equipment is expensive, needs a time-consuming and elaborate installation and can influence the behavior of the athletes (e.g. because of marker or other attached equipment). Furthermore, the results are usually not automatically analyzed in real-time, stored in a database or assigned to a special athlete. Therefore, the application is even more restricted if more than one athlete should be analyzed at the same time.

Biomechanical performance analysis under field-based conditions is given a similarly high priority, in particular if a high ecological validity has to be guaranteed. For this reason, it is necessary to capture data in settings as realistic as possible (in training sessions or competition) and to get a valid, easy-to-use and (nearly) real-time monitoring of the executed movement. The aforementioned inventions in the field of sports technology and engineering facilitated the development of methods for field-based performance analysis. Particularly, the use of microelectromechanical systems (MEMS) with microcontroller units (MCU), and wireless data transmission led to decreasing restrictions for field based performance analysis. Therefore, such systems and applications became more and more common in elite sports and for high- performance sports monitoring [3, 4].

When designing a system for in-field performance analysis, some challenges must be considered to overcome the restrictions of laboratory-based settings. Scientists mainly have high requirements regarding the quality of the data. This means that the choice and acquisition of relevant performance parameters must be as accurate as possible, as fast as possible and as demonstrative as possible at the same time. Spatial restrictions should be avoided and it should be possible to monitor the results of more than one athlete at the same time. Additionally, to be accepted and used by the athletes, the system should not influence the movement (e.g. because of its weight or the like) [5, 6].

Recently, the availability of miniature inertial measurement units (IMUs) offers large opportunities to overcome these restrictions and open new possibilities for in-field diagnosis. It is possible to equip more than one athlete with IMU sensors simultaneously and these sensors merely affect athletes during performance due to their small size and weight. Additionally, they can also be used without any spatial restrictions even during competition. In combination with wireless data transmission, IMUs offer solutions for online-monitoring that provides athletes and coaches with accurate and nearly real-time performance measurements. IMUs have already been used in several sports and fields of applications such as the detection of movement and movement frequency, the identification of movement errors or for the assessment of forces during collisions because of their capacity to withstand high mechanical stresses. The suitability of IMUs for analyzing sport movements is clarified by the fact, that recent solutions for in-field diagnosis were published during the last years. However, technical specifications such as sampling rates or ranges vary (for example depending on the manufacturer) and must be adjusted for a special field of application [7–10].

In gait and running, IMUs have already been used to analyze kinematic movement parameters [11, 12] and show valid and reliable results. In contrast to gait and running, high dynamic sport movements lead to increased peak accelerations and forces which makes the process of parameter extraction even more sophisticated [13, 14] and especially large measuring ranges must be realized. Additionally, on-board computing power is very limited in comparison to PCs and workstations, and it is a big challenge to develop complex algorithms that meet these requirements. An alternative is the monitoring of raw data (e.g. triaxial accelerometer and gyroscope data) for qualitative analysis of the entire training or competition session or for post hoc analyses. However, the cost of additional processing power and time must than also be considered [15]. Only a few systems have been established which enable both scenarios: (1) automatic parameter extraction based on sensor data for online monitoring of performance parameters and (2) monitoring of raw sensor data [16]. Based on the current knowledge and the expanding opportunities of IMUs we present a flexible, wearable system for the analysis of different sports movements. The wearable sensor network platform supports the ability to capture raw sensor data (store it on an internal SD-card and transfer it to an end device like a PC, smartphone or tablet) as well as the integration of embedded real-time algorithms for fast online-monitoring of performance parameters, with the same hardware.

The article is structured as follows. In section Methodology and System Design, we propose our procedure to design detection algorithms, which extract performance parameters of given sport scenarios out of IMU sensor data. The subsequent section expounds how these *off-sensor processing* (Off-SP) algorithms are transformed to real-time capable *on-sensor processing* (On-SP) algorithms, running on the MCU of our sensor node. In Applications section, we show which sport disciplines our system has been applied to as well as the results that have been achieved with our algorithms. The article is concluded by a discussion about summarizing the broad application field and future work.

2 Methodology and System Design

A flexible, wearable inertial sensor unit was developed to support easy adaptability to diagnosis scenarios in different sports movements without changing the hardware. Our system includes a modular, platform-based framework consisting of a sensor node, based on an ARM Cortex M3 MCU, an embedded software stack, a Bluetooth Low Energy (BLE) communication and an Android application [17].

The methodology to develop new algorithms for different sports scenarios is based on the following steps:

(1) Scenario definition and performance parameters determination
(2) Raw sensor data recording with the sensor node (9-axis IMU, 16 bit, ±16 g, ±2000 deg/s, 80 × 56 × 24 mm^3, 63 g) on an athlete's body as the sports scenario is performed
(3) Off-SP using high performance statistical analysis tools like MATLAB or R and development of a performance parameter extraction algorithm for the scenario
(4) Transformation of the algorithm to a sequential, On-SP implementation that is able to accomplish performance parameter extraction in real-time

During step (1), the type of sports scenario or exercise that has to be analyzed is defined. Key events (e.g. ground contact after a jump) and performance parameters (e.g. contact and flight time for drop jumps) are specified along with athlete-specific performance influences.

For step (2), the sensor node is attached to a predefined position on an athlete's body. As the athlete performs the sports scenario or exercise in field, the sensor node records raw IMU sensor data to an internal memory.

Reference systems like high-speed cameras or force plates are installed in field, simultaneously obtaining reference values of the athlete's performance parameters. These reference values are required to optimize the accuracy of the detection algorithm.

In the sensor node, the full-scale ranges of the IMU must be dynamically adjusted to the desired scenario detection to utilize the highest possible dynamic range. Inadequate settings can lead to a reduced data-intrinsic information content, i.e. sports performance details are insufficiently represented in the raw data. As a result, the achievable precision of the detection algorithm that is designed for this scenario later on, declines.

In step (3), the recorded raw sensor data is analyzed by Off-SP. That means, prerecorded data sets are downloaded from the sensor node and analyzed on high performance platforms (e.g. a PC) using statistical analysis tools like MATLAB. Scenario-specific detection algorithms that extract the performance parameters out of the sensor data are designed utilizing these tools. In the algorithm design, multiple detection methods, ranging from trivial threshold-exceeding recognition over signal-derivation analysis to pattern matching techniques, are applied.

Moreover, the particular algorithm design highly depends on the specific movement and how athletes perform it. For example, a handball player executes a drop jump in another style than a track and field athlete. In order to make the algorithm work for every type of athlete, a parameterizable implementation is pursued. The respective parameters are determined successively by applying multiple sensor data sets to the algorithm, gathered from different athletes.

Step (4) is about transforming the detection algorithm from Off-SP to On-SP. In Off-SP, data processing is done on a platform different from the sensor node itself. Whereas in On-SP the sensor data is processed just-in-time on the MCU inside the sensor node.

Off-SP usually provides precise results, because almost any platform that meets the compute power requirements, can be chosen as compute platform. However, with Off-SP the effectiveness of the training enhancement is limited, since performance feedback can only be provided after training and subsequent data analysis. In contrast, On-SP can provide feedback in real-time and thereby enhance the effectiveness of the training significantly. But the precision of the results is restricted due to the resource limitations of the embedded compute platform.

3 Designing Embedded Real-Time Algorithms

To obtain precise and reliable results with detection algorithms that provide real-time feedback and come with resource-efficient implementations suitable for On-SP, new design patterns and implementation approaches are required.

The high precision of the Off-SP algorithms relies on three fundamentals. High-end tools that provide advanced statistical analysis functionalities, high-performance compute platforms and high-precision data formats. But the embedded MCU of the sensor node is constrained in compute performance and data format precision. In order to port Off-SP algorithms to the sensor node, computations inside the algorithm need to be changed and mapped efficiently to the characteristics of the MCU of the sensor node.

Computation simplifications are required to lower the computation time. Complex computations like non-2^n divisions or square roots need to be simplified and mapped to conventional basic calculations. The data format must be changed from double precision, as usual in statistical analysis tools, to suitable formats for the MCU.

The mentioned techniques lead to precision drawbacks of the detection algorithms. Therefore working out the proper tradeoff between precision and computation time is a major challenge in On-SP algorithm design. Since the complexity of detection computations as well as the precision requirements differ from each other for different disciplines, it is impossible to design generically applicable tradeoffs. That's why this challenge can only be faced effectively by designing detection algorithms, which are dedicated to single sports disciplines.

Beyond the functional and precision point of view, individual optimizations of the On-SP implementation are important to archive energy-efficient designs that enable long battery life times of the sensor node.

On-SP detection algorithms, designed according to the described manner, still are not capable of providing performance feedback in real-time. Detecting events (e.g. a ground contact of an athlete after a jump) in real-time requires changes in the control flow of the usually batch-based Off-SP algorithms. But these algorithms even come with a further problem. Since batch-based algorithms are applied on an existing set of data (e.g. an array of sensor samples), data processing is done after recording, not subsequently. Thus only events that take place during recording can be detected by the algorithm. Events that occur during processing are not recognized. So athletes would have to perform their discipline within a predefined time frame, leading to an inconvenient and error-prone system usage.

One possible way to solve this problem is to simultaneously start recording a new data batch, meanwhile the algorithm processes the previous one. This way, also events that occur during processing can be captured. However, events that take place just between two subsequently recorded data batches (*inter-batch*) will still be missed, since batch-based algorithms can only detect events that lie within one single data batch.

Increasing the batch size would reduce the probability of an event to be located between two data batches. However, the delay between an event taking place and the algorithm detecting it would increase significantly, thus making real-time feedback impossible.

Our solution to ensure real-time feedback capability is to reduce the batch size instead of increasing it. To face the thereby rising *inter-batch* event probability, we developed techniques to detect these events by passing status information from one algorithm execution to its subsequent one. This however resulted in a quite complex control flow that came with non-deterministic timing behavior. To reduce this complexity, the data batch size was minimized down to 1. The result is a sequential algorithm that is processing data subsequently to each sensor data sample and thus being capable of detecting events just in time with their appearance. Admittedly as a consequence of the sequential control flow, timing requirements became very strict. All data processing must be finished before the next sample is acquired. With the sample rate of 1 kHz among all applications, less than T_i = 1 ms is available for the entire algorithm to process the data. Operations that require more time will cause the algorithm to crash and the entire real-time detection to fail (Fig. 1).

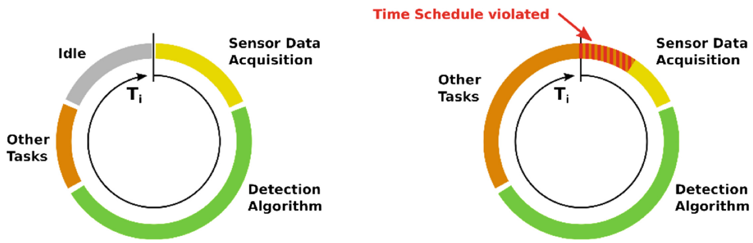

Fig. 1. Strict time schedule of the sequential algorithm. On the left side, the stability of the algorithm is ensured, whereas it is violated on the right side due to a task that requires more time than available.

To control the strict timing, a well-conceived basic control flow structure was designed for sequential On-SP algorithms. By introducing event control and event detection blocks, the non-deterministic behavior of the sensor values is turned into a controllable manner. The event detection blocks are furthermore partitioned into elementary event patterns, which also creates a generic base for future algorithms.

In the presented control flow structure, an event is specified as a coherent motion event of an athlete, perceived by a sequence of sensor data acquired during this motion (e.g. a ground contact as a part of a jumping movement). In a data analysis point of view, an event is split into multiple sub events (e.g. a slope in the acceleration signal waveform as a part of a ground contact detection).

In order to detect events and sub events out of sequentially acquired sensor data, Event Progress Control (EPC) units are designed, dedicated to the respective event. Events that have successfully been detected by their EPC are defined to form a checkpoint. Once a checkpoint is passed, a timestamp and characteristic values of the event like slope rise times or peak values are saved and assigned to this checkpoint.

The entry point of the algorithm for the subsequent sensor data sample is shifted to start the detection of the subsequent event, that is (for the given sport discipline) expected to take place next. In case the expected consecutive event cannot be detected within a given time window, the last checkpoints are discarded and the entry point of the algorithm is reset. In this case, the detection is valuated as false detection or incomplete performance of the respective discipline (Fig. 2).

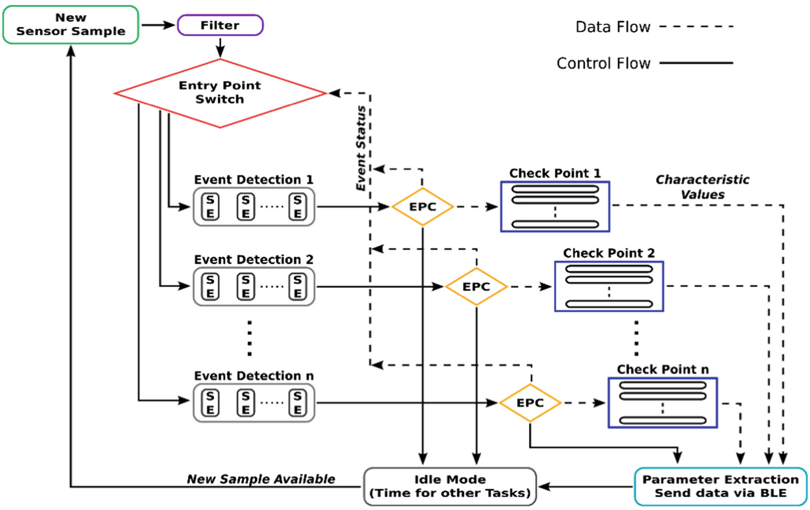

Fig. 2. Structure of the proposed sequential embedded algorithm (SE: Sub Event, EPC: Event Progress Control).

However, in case all checkpoints have passed, the predefined sports discipline is considered to be detected. The parameter extraction process is entered subsequently after the last checkpoint has passed. It computes the performance parameters out of the characteristic values of all checkpoints and the delays between consecutive event detections. After transmitting the extracted performance parameters to the BLE unit, the algorithm is ready for a new detection phase.

4 Applications

The system has already been applied to several sports disciplines (track and field, volleyball, trampoline), and algorithms for automatic parameter extraction have been developed for vertical jumps and sprints.

For reactive vertical jumps ("drop jumps"), the system was used to detect ground contacts and determine stance duration (t_S) as well as flight time (t_F) from the vertical accelerometer signal. In a validation study we showed that the system detected 94% of the events correctly, and thereby revealed a mean absolute error of 3.4 ± 3.0 ms (t_S) and 4.9 ± 3.9 ms (t_F) compared to a force plate (AMTI BP 600400, 1 kHz) as reference measurement system. Bland–Altman plots (BAP) for multiple observations per individual [18] revealed 95%- limits of agreement (LoA) in the ranges of 9.8 to −8.1 ms (t_S) and 15.0 to −11.4 ms (t_F) [17].

For the analysis of the sprint, t_S during the phase of maximal velocity was extracted from the acceleration along the longitudinal axis of the shank and the angular velocity around the sagittal axis through the shank. For the validation of the sprint application, 12 track and field athletes (10 male, 2 female) performed maximal sprints of 15 m after a 30 m acceleration phase. A light barrier system (OptojumpNext, Microgate, Bolzano, Italy/OJ) served as the reference system. Data acquisition rate for both systems was 1 kHz. During a total of 50 sprints, participants completed 380 steps in the space of the OJ system. Overall, 364 out of 380 steps were detected correctly, which corresponds with a detection rate of 95.7%. For six athletes (50%), all steps were detected correctly. BAP of all 364 steps showed a mean absolute error of 4.3 ± 3.2 ms, LoA range from −11.8 ms to 6.8 ms [19].

After the system had been proven to provide reliable and accurate measurements of stance durations during jumping and sprinting, it was then applied in two field-based diagnosis scenarios. In long sprinting (400 m), changes of the temporal structure of performance parameters (t_S and step frequencies/SF) depending on fatigue and level of expertise were analyzed. 10 male athletes divided into two groups according to their performance level completed two 400 m runs under competitive conditions. Kinematic data were captured continuously over the whole run. By this, characteristic changes in long sprinting performance could be identified between subjects as well as within subjects and allocated to fatigue, expertise or combination of both. More experienced athletes exhibited better values in performance parameters (smaller stance durations; larger step frequencies) and were able to attain smaller decreases of those parameters in case of fatigue. Because fatigue is a main influencing factor for the quality of training and performance, our system now offers the possibility to develop suitable methods for the evaluation of continuous captured long sprint data [20].

In the second scenario, temporal parameters in hurdle sprinting (t_S pre and post hurdle clearing and time for hurdle clearing/t_C) were analyzed at different levels of performance and correlated with overall performance. 14 hurdlers (7 female, 7 male) completed 60 m runs under competitive conditions. The male and female athletes were again divided into two groups according to their performance level. Exemplarily we present here only the results of the female sample. Significant correlations were found between the personal record time for 60 m hurdles and all performance parameters: t_S pre r = .786; t_S post r = .847 and t_C r = .964. All parameters differed significantly for both groups ($p < .05$). More experienced athletes showed better results in all performance parameters than less experienced athletes. Additionally, the standard deviations of all parameters revealed lower values in favor of the more experienced runners. Thus, we concluded that the parameters selected are closely related to overall hurdling performance and also distinguish well between performance levels. Thus, they might be applied e.g. for performance analysis in elite sports as well as for talent development. Further, our findings were in line with previous studies which demonstrated that high expertise was not only characterized by superior performance during a single trial or event, but also by a high stability in repeated performances.

In two additional pilot studies, the IMU system was applied to collect raw data (acceleration and gyroscope) for OFF-SP analysis. The volleyball spike consists also of a vertical jumping movement, and we were interested if flight time (t_F) jump height (JH) during jump shots can be determined with a satisfying accuracy in a sports game situation. Therefore, 23 volleyball players spiked the volleyball from a typical attacking position on the field with sensors attached to both shank. Overall, a total of 106 jumps were analyzed, again with the OJ as reference measurement. Data of both sensor locations were plotted and synchronized with the OJ data. Figure 3 indicates exemplarily vertical acceleration data including instances of take-off before jumping (1) and landing after the jump (2).

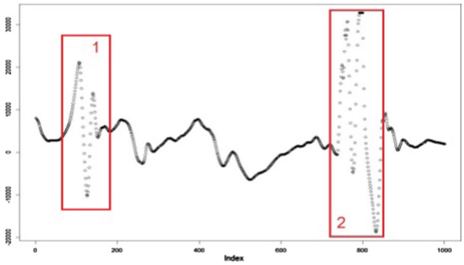

Fig. 3. Vertical acceleration signal including time windows around take-off (1) and landing (2).

The raw data was analyzed to identify consistent signal characteristics, such as local minima or maxima, slopes, thresholds et cetera which might be suitable to build an algorithm for parameter extraction. Several classification criteria were proofed for their accuracy. A simple minimum detection (for take-off) and threshold exceedance (landing) for example reveals 81 overestimations, 21 underestimations and four identical measures of t_F compared to OJ. The differences were in a range of −8 ms up to 24 ms with a mean absolute difference of 6.5 ms which corresponds to 0.9% of real t_F. JH was derived by the following equation ($g = 9.81\ m/s^2$):

$$JH = \frac{g * t_F^2}{8} \quad (1)$$

and leads to an overestimation of less than 5 cm for the largest difference of 24 ms. Subsequent results proofed that an automatic detection of t_F might also be possible with the sensor attached to the lower back as mean deviations were less than 16 ms (2.4 cm). The placement of the sensor at the lower back would be more suitable for the analysis during competitive conditions and will be in focus of further research.

Appropriate gaze strategies during the flight of complex acrobatic maneuvers enable the athlete to control his position, body orientation and motion. The ability to utilize visual cues deteriorates with increasing head angular velocity (e.g. in a double sommersault with multiple spins) and becomes impossible at angular velocities greater than 350 degrees/s. However, little research has been conducted to investigate rotational properties of the head and body during performance [21]. This lack is mainly caused by missing suitable analysis systems for such a highly dynamical movement. Using a motion capturing system, Sanders (1994) showed peak angular velocities of the head ranging from 450 degrees/s to 900 degrees/s and variable values among subjects. Attaching an IMU sensor to the athlete's body offers the opportunity to directly measure such parameters. In another pilot study, we fixed the sensor at the athletes' head (Fig. 4) collected more than 500 datasets during trampolining (including various sommersaults and spins) within a short time. The analysis of these data offered differentiated insights into the complex movement of acrobatic trampoline maneuvers with the aim of performance enhancement. Knowledge about phases of head fixation, angular velocities above a certain threshold and consequently phases without the possibility of using visual feedback might be used to improve means of training. For example, our results indicated that the degree of head angular velocity largely depended on the jump elements (number of rotation and spins) and the individual performance level. Therefore, specific training strategies should be applied for different trampoline skills and must be adapted to individual preconditions.

Fig. 4. Fixation of the sensor at the head of a trampoline athlete by wearing a special cap.

5 Discussion

The applications realized to date indicate that the IMU device provides reliable and accurate measurements of temporal parameters and in combination with the BLE transmission offer promising solutions for real-time performance monitoring. Accuracies of temporal parameters for jumps and sprints are comparable with results of previous studies. Picerno et al. [22], as example, applied IMUs to calculate flight time and jump height in counter movement jumps and reported a high correlation (r = .87) between the IMU and optometrical system (Vicon™). For Drop Jumps, a correlation of r = .98 was reported between reactive strength indexes calculated from a force plate and IMU data [23]. In sprinting, we even determined stance duration with a higher accuracy compared to previous studies. Bergamini et al. [24] achieved LoA in the range of ±25 ms whereas our system produced remarkable lower limits (9.8 to −8.1 ms). However, it must be taken into account, that the IMU in [24] was trunk-mounted and sampled at only 200 Hz. The mean absolute difference between our system and OJ (4.3 ms) is consistent with findings of Purcell et al. [25] whose results were obtained by a shank-mounted accelerometer sampled at 250 Hz.

Applying the system for determining fatigue during long sprints demonstrates that the system is not bound to many of the restrictions which one typically faces in field analysis in sports (e.g. measurement range or duration). In such scenarios, helpful and most relevant information on performance parameters and their alteration depending on fatigue or else can be derived. The device further supports online monitoring for a group of athletes during training and competition. Data from multiple athletes can be monitored on mobile devices that are driven by the Android operating system. We demonstrated exemplarily in volleyball that the IMU reveals jumping heights that are highly correlated to the reference system (ICC = .995). The mean difference of approximately 1 cm are also comparable to results of [22]. We consider that this accuracy is suitable for the use of the system in volleyball team training if real-time feedback is recommended. The trampoline study provides a further example for the application in acrobatic sports that illustrates the wide area of potential applications in sports, in particular as the sensor can be attached to various areas, if a suitable fixation is possible. To extend the application range, we plan to modernize the sensor node towards a smaller and more ergonomic design.

Based on the findings of the applications, further analyses are necessary to achieve a deeper understanding how to integrate the system into training settings as a feedback tool that enhances the quality of training and optimizes sports performance. As a consequence thereof, more complex and individually adapted algorithms may provide improvements of the parameter detection and accuracy as well as deeper insights in performance characteristics. However, on-board computing power is limited, and therefore the cost of additional processing power and time must also be considered. To be capable for more complex algorithms in the future, we currently work on extending the current time frame for computations. By using Direct Memory Access (DMA) we can shift the sensor data acquisition task away from the CPU to gain more time resources for computations. As a further step **t**o enhance the precision of the detection algorithms, we also plan to switch to another MCU that supports floating point number format.

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Emotion Recognition Using Physiological Signals: Laboratory vs. Wearable Sensors

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Abstract. Emotion recognition is an important research topic. Physiological signals seem to be an appropriate way for emotion recognition and specific sensors are required to collect these data. Therefore, laboratory sensors are commonly used while the number of wearable devices including similar physiological sensors is growing up. Many studies have been completed to evaluate the signal quality obtained by these sensors but without focusing on their emotion recognition capabilities. In the current study, Machine Learning models were trained to compare the Biopac MP150 (laboratory sensor) and Empatica E4 (wearable sensor) in terms of emotion recognition accuracy. Results show similar accuracy between data collected using laboratory and wearable sensors. These results support the reliability of emotion recognition outside laboratory.

Keywords: Wearable sensors · Laboratory sensors · Emotion recognition · Machine learning · Physiological signals

1 Introduction

Emotion recognition is currently a hot topic in the field of affective computing [1]. In prior studies, several modalities have been explored to recognize the emotional states such as facial expression [2], speech [3], etc. However, the physiological signals related to autonomic nervous system appear as an appropriate way to assess objectively emotions [4]. Two types of sensors may be used for gathering physiological signals: laboratory and wearable sensors. Laboratory sensors seem effective [5] but, in some cases, they are not deployable outside controlled situations. Also, wearable sensors provide useful and non-obstructive way to obtain physiological signals [6, 7]. Moreover, the wearable sensors gathering physiological data become cheaper and widely available. The accuracy of these sensors has been explored in several studies and shows that the physiological signals gathered by laboratory sensors and wearable sensors seem quite similar. McCarthy and collaborators [6] indicate that the photoplethysmography (PPG) signals obtained from the Empatica E4 are sufficiently precise for the cardiac activity assessment. Other research [e.g., 7] validate wearable sensors as reliable and relevant for the physiological signals analysis. However, to the best of our knowledge, the emotion recognition accuracy obtained by different types of sensors [8]

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was compared in only few studies. In the current study, laboratory and wearable sensors were used to gather physiological data with the aim to recognize emotional states using Machine Learning method (Support Vector Machine – SVM).

2 Method

2.1 Participants

We recruited 19 French volunteers via social networks: 12 women and 7 men whose average age was 33.89 years ± 8.62 (see Table 1 for details). The minimum age is 23.49 years and maximum age is 52.46 years. Participants received €15 at the end of the experiment for their participation.

Table 1. Descriptive statistics of participants

	N	Mean age	SD age
Men	7	31.99	3.76
Women	12	35.00	10.51
Total	19	33.89	8.62

In the sample, all subjects were francophone. Participants had normal or corrected to normal vision. Moreover, participants had not taken any somatic drug(s), which may have an impact on physiological responses (e.g., corticosteroids), on the passing day.

To gather the physiological data, participants have been instrumented of two sensors: the Biopac MP150 (laboratory sensor) and Empatica E4 wristband (wearable sensor). Both sensors recorded cardiac and electrodermal (EDA) activities. In order to synchronize the two sensors during the data acquisition, a program was specifically developed in Python and C.

2.2 Material

For emotion induction, 45 color pictures extracted from the International Affective Picture System (IAPS) [9] have been displayed on a computer screen (1920 × 1080 pixels). The valence and arousal associated to each picture were balanced. Thereby, each picture was categorized under three levels of valence (positive, neutral and negative) and three levels of arousal (high, medium and low) based on the theoretical values provided by the IAPS Technical Manual [9]. Finally, nine balanced categories were created (e.g., positive valence and low arousal) and five pictures of each category were presented to participants (the selected pictures ID are presented in Appendix 1) (Fig. 1).

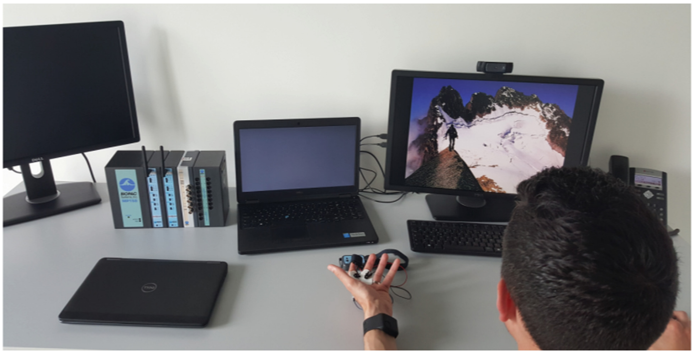

Fig. 1. Experiment setup

2.3 Physiological and Subjective Data

Subjective and physiological data have been collected during the experiment. Concerning the subjective data, two scales have been used. First, the Beck Depression Inventory II (BDI-II) [10] (21 items) was used before the experiment in order to exclude participants with depression issues. During the experiment, the Self-Assessment-Manikin (SAM) [11] was used to measure the emotional responses after each picture. Participant had to position himself on five different pictograms and four intermediate values (scoring from 1 to 9). As prior studies have shown that a 2-dimensional model of emotions (including valence and arousal) is preferable to a 3-dimensional model (including valence, arousal and dominance [12, 13]), only the evaluation of valence (positive/negative aspects of emotions) and arousal (emotional intensity) were considered.

Concerning the physiological data, EDA and cardiac activities have been recorded using two different sensors: the Biopac BioNomadix MP150 and Empatica E4 Wristband. Nine specific features have been extracted from these signals (HR, AVNN, SDNN, rMSSD, pNN50, LF, HF, RD and AVSCL). These features correspond to the most used features according to the literature review of Kreibig [4].

2.4 Machine Learning

Machine Learning algorithms were used to consider the nonlinear between subjective and physiological data. Machine learning models were trained in order to compare laboratory and wearable sensors in terms of emotion recognition accuracy. Support Vector Machine (SVM), supervised learning algorithms [14], were selected to classify data. After training, these models can recognize specific patterns related to specific outputs [15]. Technically, for the algorithms trainings, two types of data were used: physiological data as input and emotional states as output. After training, the models should be able to recognize the emotional states related to the physiological data.

To ensure genericity of the model, two main methods were used. First, the dataset was divided into training dataset (80%) and testing dataset (20%) (i.e., only the training dataset is used during the training). Second, cross-validation method was used during the training to improve the stability of results.

2.5 Procedure

At the beginning of the experiment, participants were informed of the experiment theme and signed a consent form. Then, participants completed a short general questionnaire (gender, date of birth, etc.). After, BDI-II was proposed to measure the clinical depression level (participants with a score ≥ 19 are excluded from the analyses). Afterwards, participants were instrumented with both sensors: the Empatica E4 wristband and Biopac MP150. In order to train participants to the subjective scale, a session with three pictures was also proposed (these data were excluded from the final analyses). Before each picture presentation, a black fixation cross on a white screen was displayed during 3 to 5 s (i.e., duration is randomly defined in order to limit expectation effect). The 45 pictures were presented randomly to participants while controlling the images sequence (i.e., two pictures from the same subcategory could not be displayed successively). Finally, after each picture presentation, participants had to evaluate their emotional state within 15 s using the Self-Assessment-Manikin (SAM) [11] through two dimensions: valence (positive/negative aspects of emotions) and arousal (emotional intensity).

3 Results

3.1 Descriptive Statistics

Among the subjective data collected, 2.3% of responses were missing (i.e., 20 missing subjective evaluations on the 871 collected). The average valence was $3.86 \pm .36$ where the score of 1 represents a very negative valence and 9 a very positive valence. The average arousal was 3.11 ± 1.55 where the score of 1 represents a very low arousal and 9 a very high arousal. The correlations were estimated between the features obtained from the Empatica E4 and Biopac MP150 data (see Table 2 for details). The correlations are high for the cardiac activity features (from .50 to .99). However, the correlation between AVSCL obtained by both sensors is low (.13)[1].

For illustration, the Heart Rate features extracted from both sensors are presented in Fig. 2.

[1] The weak correlation on EDA seems to be due to a problem of data recording for one participant. Deleting these data lead to a correlation of r = .45 between the AVSCL features gathered by both sensors.

Table 2. Correlations between the physiological features gathered by the Empatica E4 and Biopac MP150

	Biopac MP150									
Empatica E4		HR	AVNN	SDNN	rMSSD	pNN50	LF	HF	RF	AVSCL
	HR	.99								
	AVNN		.99							
	SDNN			.75						
	rMSSD				.69					
	pNN50					.61				
	LF						.57			
	HF							.58		
	RF								.50	
	AVSCL									.13

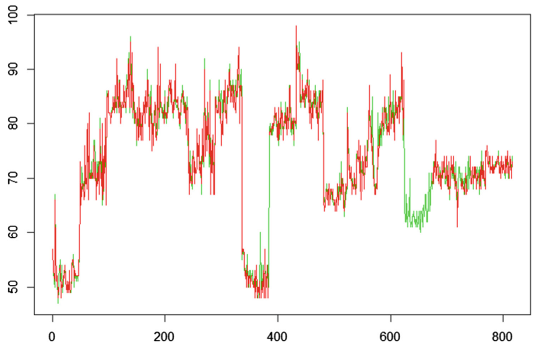

Fig. 2. HR signal gathered using the Empatica E4 (red line) and Biopac MP150 (green line). X-axis corresponding to the full dataset. Y-axis corresponding to the Heart Rate.

Table 3. Results for emotion recognition

		Valence	Arousal
Empatica E4	Training	.657 (SD = .05)	.700 (SD = .02)
	Testing	.659	.704
Biopac MP150	Training	.655 (SD = .03)	.698 (SD = .05)
	Testing	.656	.697

In the “training” lines, two pieces of information are provided: the mean recognition rate through training sessions (cross-validation method) and number in brackets corresponding to standard deviation through training. The “testing” lines correspond to the recognition rate on the testing dataset.

3.2 Emotion Recognition System

Machine Learning algorithms (SVM) were used in order to consider the nonlinear relationships between these two types of data. The Machine Learning models were trained to recognize emotional states as binary variables. A training by sensor (i.e., Biopac M150 and Empatica E4) was carried out. For each sensor, two models were trained: one for valence and one for arousal. The Table 3 presents the main results. In summary, for both sensors, an accuracy of 66% for valence level and 70% for arousal level were found based on person-independent models.

According to these results, the accuracy of emotion recognition appears similar between the wearable sensor Empatica E4 and laboratory sensor Biopac MP150 in this experimental context.

4 Discussion and Conclusion

The aim of the current study was to compare the Empatica E4 and Biopac MP150 sensors in terms of emotion recognition capabilities. Thus, nine features were extracted from the physiological signals gathered by these sensors. The Machine Learning models were trained to recognize emotional states from these features. According to the results, the accuracy of emotion recognition appears similar with respectively an accuracy around 70% for arousal and 66% for valence.

In the current study, emotion recognition was based on extracted features. Consequently a strongly influence of these features on accuracy can be supposed. Nine features were used, a relatively weak number compared to some prior research [16]. Thus, extracting more features may lead to discover significant differences between sensors.

Overall, a stronger emotion induction may improve the accuracy of emotion recognition. Indeed, only few phasic responses have been detected (beyond the natural physiological responses) even though this feature reveals emotional activation. A stronger induction should influence physiological signals and may lead to difference between sensors. Thus, it could be interesting to conduct new studies to ensure of the similar recognition capabilities between sensors.

In future works, it could be relevant to compare emotion recognition from these sensors in a less controlled environment with the potential presence of motions.

In conclusion, in this study, wearable sensors appear as accurate as laboratory sensors for emotion recognition. The E4 device seems to be relevant for emotion recognition in daily life as a non-intrusive, easy to use and accurate wearable sensor.

Acknowledgments. We would like to thank all those who participated in any way in this research. This work was supported by the French government through the ANR Investment referenced ANR-10-AIRT-07.

Appendix 1

See Table 4.

Table 4. Picture ID by category of valence and arousal

Arousal	Positive valence	Neutral valence	Negative valence
High arousal	8492; 4659; 4695; 5629; 8501	1120; 5950; 8475; 1932; 8341	6300; 3301; 6263; 6520; 3500
Medium arousal	2075; 2160; 7330; 7470; 7580	8065; 7497; 2220; 1945; 5535	3550.1; 2345.1; 2800; 9140; 2751
Low arousal	5764; 5811; 1910; 5870; 2370	2101; 7038; 7185; 7490; 7491	9395; 2490; 9001; 2722; 2039

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Development of Support Systems for Capturing and Reducing the Hand-Arm-Stress

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Abstract. The human is permanently confronted with different stress factors, for example during an assembly process. In this case an extreme body postures with a high force transmission can be injurious the health. Additionally a high stress on the hand can cause pain and lead to the so-called rhizarthrose. The stress factors can be captured and reduced by using support systems. This work concentrates on the development of support systems for capturing and reducing the stress on the hand-arm-joints. The developing starts with a research on sensors and support systems which have already been applied for the upper body and for manual work. Subsequently first systems are being developed systematically and demonstrated on a process example. The results show the objective capture and reduction of the hand-arm-stress.

Keywords: Prototype · ArtRose · ErgoJack · Physical work · Manual work · Screening method · Acceleration sensors · Angle measurement · Rhizarthrose

1 Introduction

1.1 Methods and Therapy

People are constantly in contact with products and thereby loaded differently. In particular, high power transmissions, short rest periods as well as incorrect postures influence the health [1]. In this case, typical diseases may occur due to high stress. To determine physical stress, screening methods are used in most cases. These screening methods are based on the allocation of points for certain stress situations. The LMM (Key Indicator Method) of [2] and RULA (Rapid Upper Limb Assessment) of [3] provide a comprehensive picture of the stress situation of the upper body. On the basis of the subjective assessment, such methods require long-term experience as well as a long investigation period. In addition, only a few scenarios can be observed by videos, which can lead to a false assessment of the physical stress. These inexact estimations are associated with high costs [4].

In the worst case, diseases in the wrist for example arthrosis can be caused by an incorrect estimation. An arthrosis on the wrist leads to a painful restriction of the mobility of the wrist. An anomaly of the compressive stress in the wrist is being held responsible for the high joint wear and the joint pain. An arthrosis at the thumb saddle is called as rhizarthrose. Figure 1 shows a deformed joint site. This is an indication of

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the functional loading of the thumb beam during the gripping-process [5]. The pain sensation can only be reduced by frequent rest periods or by reducing the hand stress. Frequently, the symptoms can only be alleviated by minimally invasive joint cleansing or by the severing of painful nerve fibers. In a last step, there remains in some cases only a partial stiffening of the carpal bones - or the supply of individual finger joints by arthroplasty or prosthetic. In the case of joint cleansing, a needle is inserted into the joint capsule. If the injection is deeply injected into the thumb saddle joint, the palmar-extending tendon of the flexor carpi radialis can be injured [6].

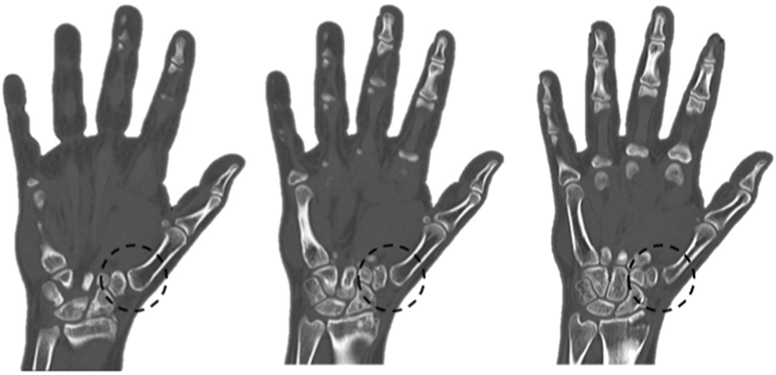


Fig. 1. Computed-tomography of a rhizarthrosis.

A novel therapy involves a stabilization by kinesio-taping. In addition to the massage effects, that stimulate the flow of blood and lymph, the elastic adhesive tape supports joint functions. The influence of the tapes on the tensions corrects muscular imbalances so that a balance between the muscle groups can arise again. The stimulation of the proprioceptors in the joints ensures a better sense of movement. By stimulating the receptors, pain in the joint is relieved [7]. To determine the hand stress, sensor gloves can be used which detect an active movement of the patient. These can additionally be equipped with an assessment function to document and analyze the progress of the therapy. In the work of JSI-Glove some methods for objective assessment of hand stress are described [8].

1.2 Support Systems

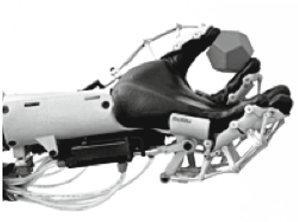
To capture the posture with support systems in consideration of LMM or RULA, it must include specific acceleration sensors for measure. With the sensors, it is possible to detect characteristic data sets on the user. Acceleration sensors are most frequently used in the field of activity detection. They react quickly to changes in activity and provide meaningful data on the movement patterns of users [9]. Acceleration sensors can be used 2 or 3 dimensionally. Two 2D sensors arranged at a 90° angle extend the measurement dimension to the third spatial direction [10]. Figure 2 shows different shirts or trousers variants with integrated acceleration sensors [11]. These were built in different sizes. The focus of the work was the detection of movement and not the objective determination of physical stress.

Fig. 2. Examples of sensor clothes [11].

An alternative sensor concept to acceleration sensors are magnetometers. [12] presents this principle briefly and then evaluates it. The activity characteristics can also be derived from supplementary information sources. For example, a GPS logger can be used to record the user's position and speed histories [9]. In the field of motion analysis, a further sensor concept was also presented. It utilizes the nearly linear resistance dependency of electrically conductive fibers from their mechanical strain. These innovative lines of conductors are integrated into customary textiles and provide information on the physical activity and the movements of their users by evaluating the individual resistances of individual measuring strips. However, the system must be calibrated based on the individual anatomy of each user [13].

To reduce the hand-stress during gripping and to reduce the load in the thumb saddle joint in the case of a rhizarthrosis, some support systems do exist. The support systems for gripping are often based on gloves or hand orthoses, which allow the use of electrically actuated. Table 1 shows an overview of some support systems for the hand. The focus of active gloves lies in the reinforcement of the gripping. In addition, the user is to be protected against overloading and fatigue. In the medical field, active gloves are used for rehabilitation of patients with functional disorders. Movement and hand movements can be re-trained by means of a movement therapy of the hand motor. In the technical realization of active gripping, they used often actuators. These include electric motors for driving traction cables (tendon drive), pneumatic actuators or electric motors for direct driving the joints.

Table 1. Examples of support systems.

Support Systems	Actuator functionality
	Idrogenet Gloreha Professional Flexible rods via pneumatic for tension and pressure moves for flexion and extension. (by www.gloreha, 06.03.2017)
	Festo Exo Hand Pneumatic actuators on a joint accomplish the alignment of each individual finger to close the hand. Thumb with multiple actuators. (by www.festo.com, 06.03.2017)
	RoboGlove Electric motor pulls ropes to close the hand. Opening of the hand is done manually after the actuator has been switched off. (by www.nasa.gov, 06.03.2017)

2 Prototype

This chapter focuses on the development of support systems for capturing and reducing the stress on the hand-arm-joints. On the one hand there is developed a system as a sensor jacket (ErgoJack) to capture the posture and on the other hand there is developed a system as an active hand orthoses (ArtRose) to reduce the pain caused by rhizarthrose.

2.1 ErgoJack

Figure 3 show the first Prototype of ErgoJack. The acceleration sensors were limited to three sensors according to [15] for one half of the body. The sensors were positioned on the lower and upper arm as well as on the upper chest musculature in order to give a statement about the trunk and arm movements according to the LMM or RULA method. ADXL 345 was used as acceleration sensors. The sensors transfer all three axis positions to a microcontroller (Arduino Micro) during the measurement. The display of the JSI-Gloves is available for further processing and display of the data [8]. For the display via the PC a receiving system was implemented by PLX-DAQ (Parallax Data Acquisition Tool). ErgoJack can receive process and display data wirelessly on the Computer, if the receiving system is connected to the PC.

Fig. 3. Prototype: Ergojack.

2.2 ArtRose

For the developing of ArtRose, the focus was on the support of the thumb while taking the computer mouse, as well as the relaxation or improvement of the blood flow at the joint end of the thumb. The developed prototype consists of an actuator and vibration component (see Fig. 4).

The actuator component is a pulling solenoid which has been inserted into a plastic housing made of PLA. The housing has a groove for a hook and loop connection. This allows the actuator to be attached to the thumb. The vibration component, together with a toggle switch, is located in a plastic housing. This is attached to the wrist with a Velcro fastener. The vibration motor is located at the position of the thumb-saddle joint. Both components can be switched on using the toggle switch. When switching on, the thumb is pulled for example, to a computer mouse. At the same time, a vibration is transmitted to the saddle joint. With the Velcro, both components can be carried by any hand sizes. The entire system is supplied with a 9 V block battery.

3 Application

The focus of the application for ErgoJack is a comparison between the body posture and the measurement. A subsequent evaluation, for example according to LMM or RULA method, is a programming work that can be implemented as with the JSI-Gloves

Fig. 4. Prototype: ArtRose.

by [8]. Before a measurement could be carried out, measuring sensors were recorded by all sensors and compared to actual body angles. From the detection of the signals per body measurement a basis was developed in order to be able to interpret body postures from signal information. Figure 5 shows measurements of four different postures.

The application was examined on how ArtRose affects the pain sensation. This is done with the same task with and without the support system. The task is a CAD modeling with CATIA V5. For this purpose, several CAD blocks with drill holes were generated within 10 min. In conclusion, the pain sensation is assessed by one. In Fig. 6 the experimental setup is shown. The following test conditions were chosen:

1. The same mouse is used.
2. The model is created using the same CAD approach.
3. The CAD blocks with holes always have the same dimensions.
4. The thumb of the right hand is in the same position.
5. Forearm lies flat on the table and stands 90° to the upper arm.
6. No relaxation pauses.

4 Discussion

The results of ErgoJack show that the capturing of posture is faster and more accurately than with a classical screening method. Moreover, herewith a misjudgment of stress will be prevented. In contrast to the systems from the state of the art, ErgoJack can be worn easily and without hindrance throughout the day. Every year, companies spend a lot of money on work-related complaints [15]. With ErgoJack, a system is presented which, enables a permanent analysis of posture. Through this system, for example, an assembly process can be examined objectively in relation to ergonomic conditions. It offers the possibility to compare different process flows with each other in order to show improvements. In the future, physical stresses can be interpolated from the hand to the shoulder in combination with the already developed sensor glove (JSI-Glove) by [8]. Additionally, it is also possible to adapt individual users, for example by an age

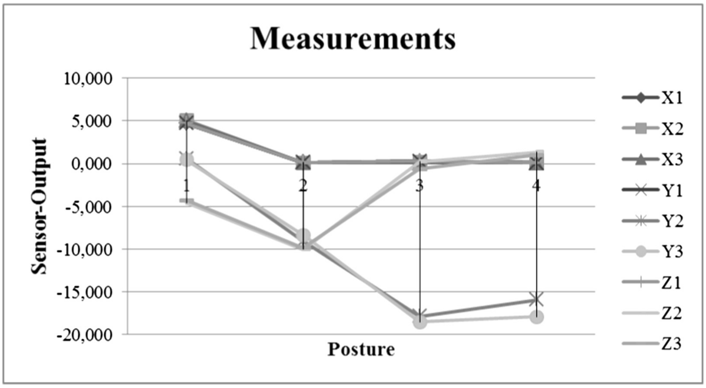


Fig. 5. Sensor signals X-Y-Z of 4 postures: no. 1: the arm is bent at 90°. No. 2: the arm is extended forward. No. 3: the arm is extended towards the ground. No. 4: the upper body is bent forward by 45°, while the arm is extended towards the ground.

Fig. 6. Application: ArtRose.

and gender factors. It should be possible to carry out an angle measurement of the head, for example, by means of sensors on the cap. It is also designed to adapt the system adaptively to any jacket or clothing.

The results of ArtRose show that the use of solenoids reduces the pain on the thumb joints. It can therefore be assumed that longitudinal wear can also be avoided. Thus, a longer manual work can be performed, particularly in areas of high physical stress such as industrial manufacturing, assembly and logistics. In those areas there is a great need

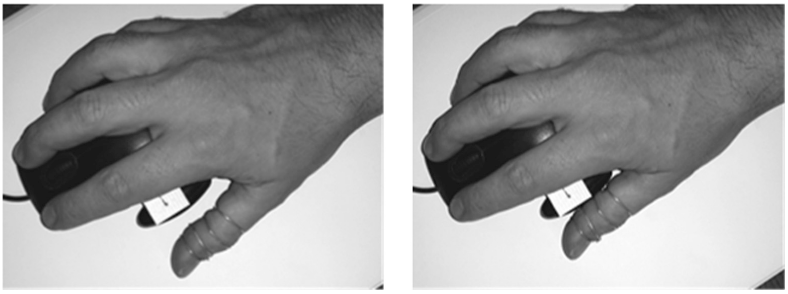


Fig. 7. Prototyp: ArthRose (conventional).

for adaptive assistance systems [16]. In the mouse experiment it was found that the work was affected by the geometry and mass of the system. These disadvantages can be avoided, for example, with an FGL actuator. These thin wires can be reminiscent of their old shape, and could carry a high force when energized. In principle, this can be an FGL tissue (matrix). With ArtRose, automatic gripping support will be carried out in the future. The systems today only carry out a static gripping support depending on the force measurement by the sensors. An automatic execution of gripping by detecting the finger movement is not supported. In the future, the system will not only support the stabilizing, in the same time also intelligently reinforce them with training measures, as well as stimulate the blood circulation through targeted vibrations. Furthermore the system shall give a signal against overuse. The prior art has shown that there are hitherto no systems that use targeted vibrations to activate blood flow. In later work, the frequency as well as the amplitude and position of the vibration should be found depending on the blood stream or nerve, in order to reduce the pain more specifically. As a conventional solution ArtRose has been converted with a permanent magnet without a vibration motor. The use with a mouse is shown in Fig. 7. For this purpose, a permanent magnet was pressed into a printed housing. The housing can be flexibly glued to any object or product. The thumbs are applied by means of a metallic thumb cover when using the product. Thus, the stress on the thumb saddle joint can be reduced.

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A Wearable Device Supporting Multiple Touch- and Gesture-Based Languages for the Deaf-Blind

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Abstract. Over 1.5 million people in the world who are completely deaf-blind use touch-based alphabets to communicate with others and to interact with the world. However, they rely on an assistant who plays the role of an interpreter in translating the world for them. Unfortunately, despite the research work realized in the last decade, on the market there are no assistive devices for providing people who suffer from severe multi-sensory impairments with technology for social inclusion. In this paper, we introduce dbGLOVE, a wearable device for supporting deaf-blind people in being completely independent in communicating with others and in interacting with the world. Our system was co-designed with users to be a natural interface and to accommodate for different already-existing touch- and gesture-based languages, such as Malossi and deaf-blind manual, in order to offer a unique device for connecting different communities with an affordable solution.

Keywords: Deaf-blindness · dbGLOVE · Malossi · Deaf-blind manual · Wearable devices

1 Introduction

People who are blind or deaf rely on sensory replacement to compensate for their People who are deaf-blind have a severe degree of combined visual and auditory impairments resulting in limited communication, access to information, and mobility. According to estimates, 1.5 million people are completely deaf-blind, worldwide. Moreover, different levels of blindness and deafness affect over 150 million people.

Deaf-blind individuals primarily use touch to communicate with others and to interact with the world. Touch cues can be utilized in basic (functional) communication. Also, advanced tactile signing techniques and tactile alphabets, such as, the deaf-blind manual, Lorm, or Malossi, are the preferred communication system in the communities of people who are deaf-blind: the hand becomes a typewriter for writing and reading messages using a specific tactile code.

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In the last decade, several devices successfully explored the possibility of incorporating touch-based languages into wearable technology in the form of gloves to help people who are deaf-blind interact with the world [1]. However, lack of attention to ergonomics leads either to demonstrators which cannot be manufactured or to prototypes having poor acceptability. As a result, there are no commercial devices which are market-viable products that can be utilized effectively by end users, and, thus, individuals who are deaf-blind still lack opportunities for being completely independent in communicating with others, interacting with the world, working, and being fully included in the society.

In this paper, we introduce dbGLOVE, a wearable interface for touch- and gesture-based interaction which is specifically designed for providing people suffering from multi-sensory conditions with support for bidirectional communication. dbGLOVE is designed to refine the work discussed in [2] to incorporate several already existing touch-based languages, so that people who are deaf-blind are not required to learn a new communication system, which is among the most complicated tasks for them.

We discuss the ergonomics of the device and its hardware architecture, consisting of a flexible pad which incorporates a total of 42 sensors and actuators (18 capacitive sensors, 5 flex sensors, 16 vibration actuators, and a 9-degrees-of-freedom Inertial Measurement Unit consisting of accelerometer, gyroscope, and magnetometer). Heterogeneous sensors accommodate for the different touch and motion cues utilized in functional communication and in tactile signing and alphabets, such as the deaf-blind manual, Malossi, or Lorm. As a result, the proposed device can be utilized by the people with multi-sensory impairments to input text and messages via touch. These, in turn, can be displayed on a screen so that the sighted can visualize them, they can be translated into speech with a Text-To-Speech (TTS) system, or they can be transmitted over the Internet to people who are co-located or remotely located. In addition to providing users with an input interface to PCs and smartphones, dbGLOVE incorporates actuators which enable simulating touch cues in the form of vibrations over the palm of the hand, so that the deaf-blind can use it as an output device, to receive feedback and to read messages.

Moreover, we describe the implementation of two tactile communication systems, that is, the deaf-blind manual and the Malossi alphabet, which are well adopted in the United Kingdom and in Italy, respectively. Involving users and experts in a participatory, co-design process led to their optimal adaptation on dbGLOVE.

Finally, we detail the experimental results of a preliminary study involving healthy individuals who received the device for the first time. The experiment focuses on both input and output features, to evaluate the viability of dbGLOVE as a bi-directional communication device. The majority of participants (72%) were able to use the device efficiently (80% performance), without any prior knowledge of any the languages. Consequently, from our findings, we can conclude that dbGLOVE can be utilized as a viable interaction tool for enabling communication in people with sensory and multi-sensory impairments, though further investigation involving deaf-blind individuals will be realized as part of our future work.

2 Related Work

In case of multisensory impairments, tactile alphabets are utilized as an alternative communication system. They rely on the concept of sensory substitution to replace the communication channels which are compromised (e.g., vision or hearing) with touch. Several touch- and gesture-based alphabets have been developed and they consist of different components, as described in [1], in the form of gesture, pressure, and touch cues. Specifically, the Malossi, Lorm, and deaf-blind are three alphabets that use the surface of the hand to represent letters using different types of tactile signing. In the Malossi alphabet, shown in Fig. 1, phalanxes are utilized to sign letters in the form of different pressure cues: different areas of the (left) hand can be pressed or pinched in sequence to write words on the palm of the deaf-blind individual as in a typewriter.

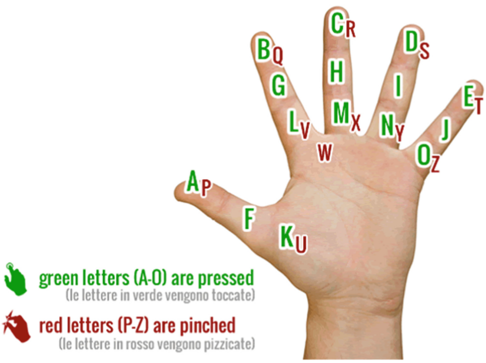

Fig. 1. The Malossi alphabet: letters from A to O are pressed, letters from P to Z are pinched.

The Malossi alphabet has a simple structure which is more suitable for implementation with respect to other languages, such as, Lorm, which were incorporated in wearable glove-like devices [3], recently. Moreover, it provides with a single interaction surface, that is, the palm of the hand, with several advantages with respect to or other communication systems relying on different areas, as described in [4, 5]. Furthermore, tactile languages based on pressure inherently support mobility [1], because they utilize a limited surface of the body and simple stimuli. This characteristic is very different from gesture-based alphabets, which would require complex robotic systems for producing output [7]. Furthermore, the layout defined by the language is very convenient, because the letters are located in areas having similar physiological structure [6], though they have different sensitivity and stimulation intensity. Also, the overall layout of the language is similar to other alphabets, such as the deaf-blind manual [7], which results in the opportunity of serving multiple communities and language niches with a single interface.

3 System Design and Architecture

In this Section, we describe the hardware and software architecture of the proposed system. It consists of a device structured in two components: the central unit and a replaceable pad. The former is responsible for acquiring input from the user (i.e., movement of the hand, touch cues over the surface of the pad, and the flexion/extension of the fingers), processing signals, and communicating with an external device (e.g., PC or smartphone) equipped with drivers and applications (Fig. 2).

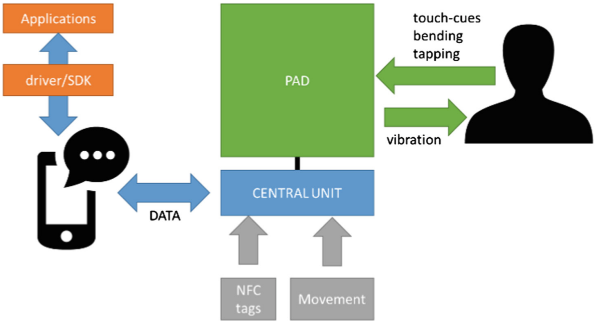

Fig. 2. Block-diagram of the architecture of the device.

3.1 Hardware Device

The hardware component of the system consists in a device that can be worn on the left or right hand. Several research papers presented interactive devices in the form of fabric gloves incorporating electronics. However, this introduces intensive mechanical stress over the components, in addition to increasing the complexity in manufacturing the device. Conversely, dbGLOVE utilizes a single surface consisting of a hand-shaped pad in which electronic components are incorporated in a polyurethane cast to ensure resistance to moisture. The shape of the device has been designed to map a statistical hand accommodating for 95% of the adult male population. However, different sizes can be realized to support children. Within the outer cast, there is a printed circuit board (PCB) realized with a mix of rigid and flexible material to ensure durability and resistance, to enable flexing and extending fingers, and to increase the ergonomic feeling of the device. The surface of the pad includes 18 one-wire capacitive sensors based on the architecture of the commercial MPR121 controller available from Freescale [8]. 15 sensors are conveniently placed over the phalanxes, to accommodate for the layout defined by the Malossi alphabet; 3 additional sensors are located on the top of the palm, to provide users with additional functions (e.g., menu, next, previous). A tactile texture modeled over the surface of the pad displays the corresponding representation of the letter in Braille, in order to facilitate users who are Braille-savvy and to increase Braille-literacy of people who know touch-based alphabets, only.

Moreover, the polyurethane coating increases impedance and, thus, acts as a shield for spurious signals which are known to be an issue for capacitive sensors.

Moreover, dbGLOVE includes 5 commercial flex sensors [9] which detect flexion/extension of the five fingers to support recognition of sign languages. This implementation is very different from other solutions: we placed flex sensors over the palm to reduce mechanical stress on the components and to avoid bending problems which affect the signal, as discussed in [1]. Flex sensors are incorporated within two protective layers which enable sliding within the cast, in order to reduce known issues related to mechanical stress on soldering pads on the proximal area of the sensors [1].

Finally, the back of the pad, which is in contact with the surface of the palm, includes 16 vibrotactile actuators in the form of precision button-style motors [10]. 15 motors are located over the phalanxes, in locations which correspond to capacitive sensors. One actuator is located over the palm to provide the user with feedback about menu functions. Two motor drivers accommodate for simultaneous vibration of up to two actuators. They are utilized for reproducing tactile sensations over the hand of the users by means of skin displacement at different intensity [5]. In particular, pulse wave modulation (PWM) is utilized to define diverse pressure cues (Fig. 3).

Fig. 3. Front and rear views of the pad of the device.

The pad is connected by means of an I2C bus to the central unit. By doing this, the pad can be easily replaced in case of damage, or for hygienic reasons. The central unit includes an Inertial Measurement Unit having 9 degrees of freedom (accelerometer, gyroscope, and magnetometer), the microcontroller, and a rechargeable LiPo battery which supports up to 10 h of continuous operation, in addition to status LEDs and power button. The device connects via Bluetooth Low Energy or USB with PCs and smartphones, in order to reduce pairing issues and ensure maximum durability. The firmware of the device includes signal processing algorithms and security protocols.

3.2 Software System

The software system was designed with the aim of providing users with the maximum degree of versatility with respect to connectivity and usage. To this end, the software component of the system consists of a main application which includes the driver, the system for configuring the settings of the device, and a UDP server for exposing data on the local network, as shown in Fig. 4. This architecture supports multiple applications based on a standard UDP client which receive pre-processed data from the device. Libraries available as Software Development Kits enable developing applications easily and leveraging signal processing functions which are part of the core application.

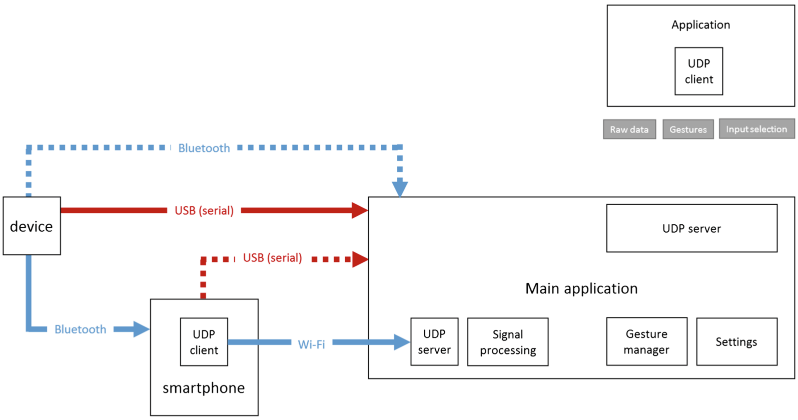

Fig. 4. Block-diagram overview of the software architecture of dbGLOVE.

4 Experimental Study

In this Section, we describe an experimental study in which we evaluated the efficacy of dbGLOVE as a bi-directional communication tool. To this end, we divided the study in two experimental tasks focusing on the output and on the input features of the device. We primarily considered the former, as producing output which can effectively be recognized by users is one of the main issues in the development of glove-like devices for the sensory and multisensory impaired [1]. Also, we specifically considered capacitive input, and we did not take into consideration flex sensors, because the purpose of this study was evaluating the simplest form of tactile alphabets, that is, touch-based languages consisting of pressure cues, such as, the Malossi alphabet and the deaf-blind manual.

A piece of stimulation software was realized ad hoc to implement the tasks of the experimental protocol. Figure 5 shows the interface of the application. It includes a panel for monitoring the data transmitted from the device, a shape showing the status of the sensors, and a control panel for activating motors at different intensities.

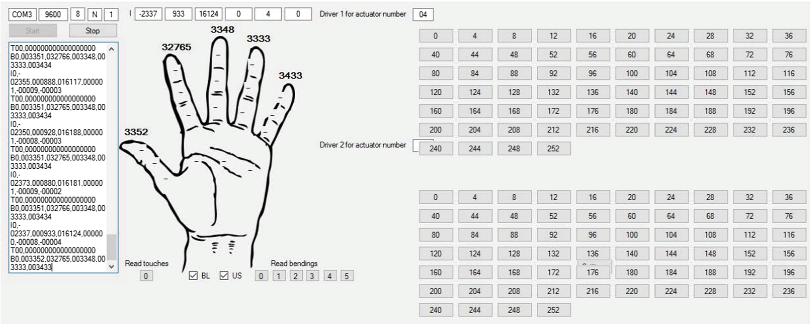

Fig. 5. Screenshot of the software utilized in the experimental study.

A total of 88 individuals were recruited for the experimental studies. We utilized two different groups of users for task 1 and 2, because our objective was to evaluate the input and output features separately. Participants had normal vision and hearing, and no prior knowledge of any tactile languages. Also, they had normal sense of touch, which was evaluated with on a simple assessment based on sensitivity to pressure. The majority of them were not familiar with deaf-blindness. We did not recruit any people with multisensory impairments because our objective was to preliminarily evaluate the effectiveness of the device, before involving individuals who are more delicate and prone to frustration.

The experiment was realized in noisy environments to reproduce the condition of real-life scenarios, though they were allowed to comfortably seat in front of a desk with the equipment. Subjects were provided with short briefing about deaf-blindness, and they were instructed about the tasks before starting the experiment. They had 5 min to get familiar with the device and explore it, before the beginning of the task.

In task 1, participants were delivered tactile stimulations at different intensities over the palm of the hand, and they were asked to identify the area in which the stimulation occurred. Specifically, trials involved 3 sets of stimulations each consisting of 5 pressure cues at different intensities, and on different sensitive areas. Both intensity and location were chosen randomly, ensuring that each trial included different intensities and areas, in order to deliver at least one stimulus for each sensitive area. Vibrations were delivered at intensities ranging from 1 to 251, representing no stimulus and maximum intensity, respectively: we defined 6 different intensity levels (i.e., 1, 51, 101, 151, and 251) to standardize the protocol. In each trial, motors were activated according to a specific pattern: intensity was increased by 50 in each stimulation, in the first trial; it was completely random in the second trial; in the third trial, intensity was descending. This was to identify the minimum and maximum sensitivity thresholds, and to evaluate individuals' touch sensitivity. 70 volunteers participated to the study. Individuals ranged from 16 to 65 in age (average 28 ± 12). A total of 1071 responses were recorded.

In task 2, participants were provided with an informative leaflet displaying the Malossi alphabet for 10 min before the beginning of the test. Then, they were presented with random letters on the display, and they had to touch the area of the device representing the letter. The objective of the test was to evaluate the effectiveness of the device in recognizing input from the user, in terms of sensitivity of the actuators, and thresholds for avoiding spurious signals. 18 individuals participated to the study. Their average age was 25 ± 7. In each trial, users were presented with 27 letters displayed at random. A total of 468 responses were recorded.

5 Results and Discussion

In the first task, we focused on evaluating the effectiveness of the device in representing output. Specifically our objective was three-fold: (1) obtaining the range (minimum and maximum) in terms of intensity for vibration to be recognized correctly; (2) studying the efficacy of dbGLOVE as an output device; and (3) identifying critical areas of the hand in terms of recognition of the stimulation.

763 correct answers were obtained out of 1071 responses, showing an accuracy of 71.24% in recognizing the area in which vibration occurred. However, as shown in Fig. 6, performance is strictly related to the location of phalanxes. Specifically, proximal and distal phalanxes show the highest similarity and very good performance ranging from 70.5% to 92.6%. Conversely, medial phalanxes have the worst results, showing an average accuracy of 49.28%. However, this is due to the lack of adherence of the pad to the phalanx, which can be compensated by introducing holders to be attached to medial phalanxes. Figure 6 shows high performance on lower intensity values because participants were able to correctly identify that either no vibration occurred, or it had very low intensity.

As regards to preferred intensity, values ranging from 100 to 250 produce the best results, though stronger pressure cues lead some decrease in performance due to the dispersion of stimuli over a larger surface, as shown in Fig. 7, which represents the distribution of individuals who identified vibration in areas which are close to the actual phalanx being stimulated. As a result, frequencies from 100 to 200 accommodate for individuals' different sensitivity, and maintain good accuracy levels.

By increasing adherence of the pad to the palm of the hand and, specifically, to medial phalanxes, we obtained +10% increase in performance, leading to 81.68% overall accuracy in recognizing output, in users who received vibrotactile stimulation

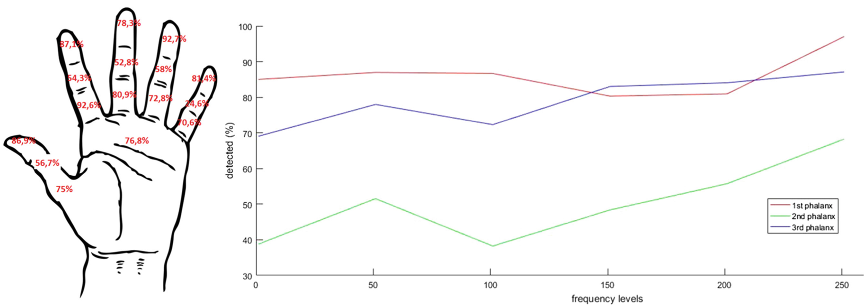

Fig. 6. Performance in recognizing output: data about individual areas and about intensity.

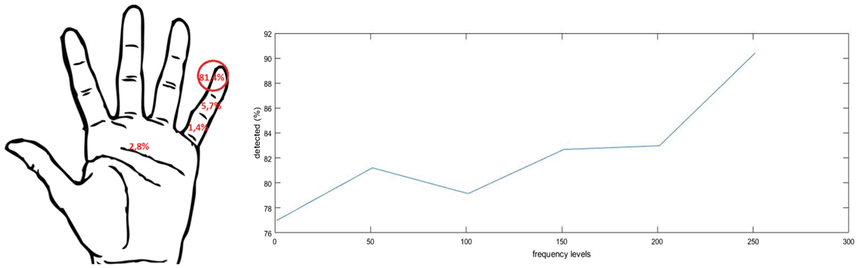

Fig. 7. Performance in recognizing output: higher intensities and dispersion effect.

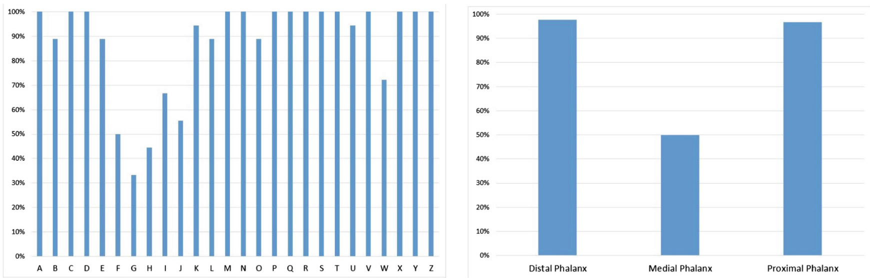

Fig. 8. Performance in task 2: difference in phalanxes.

for the first time. Indeed, by introducing some training, users will be able to get more familiar with the device and consequently, improve their performance.

In regard to task 2, which focused on the input features. Specifically, the objective of the study was two-fold, that is, (1) to evaluate the accuracy in detecting input, and the time spent by users to understand the communication system. We obtained 408 correct answers out of 468 responses, showing an accuracy of 87.17%. Figure 8 shows the accuracy for each letter: as in the previous task, the proximal and distal phalanxes have the best performance, with 97% and 98% accuracy, respectively. Conversely, the medial phalanx shows accuracy level of about 50%. This issue which will be investigated in our future work, could be caused by several factors, from sensitivity of the device to the nature itself of letters located on medial phalanxes.

6 Conclusion

In this paper, we introduced dbGLOVE, a wearable device for enabling blind and deaf-blind individuals to communicate with others and interact with the world by means of a natural interface that reproduces already-existing touch- and gesture-based alphabets adopted by different communities of people suffering from multisensory conditions.

We detailed the architecture of the system and specifically, the hardware and the software components, and we presented the results of an experimental study focused on the evaluation of the effectiveness of the device as a bi-directional interface for recognizing input and providing users with tactile output based on pressure cues over the surface of the palm of the hand.

Results from our study show that all the subjects were able to realize the experimental tasks. Moreover, by appropriately adjusting the ergonomics of the device, performance in correctly recognizing tactile stimulation is 81%, whereas the effectiveness of the input system is 87%. These results were achieved in individuals without any previous knowledge about the device and the communication system. Also, results were obtained in noisy environments to reproduce real-life scenarios.

Future work will include experiments involving individuals who actually have some degree of multisensory impairment to the visual and auditory channels, and who are proficient with touch- and gesture-based alphabets. Also, investigation will focus on the time required for learning the language, as touch-based systems are among the first forms of communication which are utilized for teaching languages to children who are deaf-blind born or to people who become deaf-blind. Finally, future work will include studies on the inter-dependency between languages, that is, learning Braille from Malossi and vice versa.

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A Step in the Right Direction – Understanding Privacy Concerns and Perceived Sensitivity of Fitness Trackers

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Abstract. Keeping an active lifestyle has been important and recommended for decades. The arrival of the Internet of Things (IoT) offers opportunities to simplify the tracking and logging of data supporting that lifestyle. So-called activity or fitness trackers have become smaller and more affordable over the past few years. However, their use is not as widespread as could be. This explorative study with n = 82 participants investigates privacy concerns and sensitivity regarding data gathered with wearables. It was found that long-term storage location and possible recipients of the collected data do play important roles. However, the consensus was that the participants would prefer to keep said data to themselves. Furthermore, user factors such as age, gender, and privacy behavior could not be identified as having an effect on sharing said data.

Keywords: Persuasive technology · Privacy · User modelling · Quantified self

1 Introduction

The spread of online services, be it the internet, mobile apps, or smart devices, has enabled a lot of positive and empowering opportunities. By now, almost everyone can search the internet, book vacations, or reach friends anytime and anywhere. Unsurprisingly, this also includes the opportunity to keep better track of one's own life. It has become easy and almost effortless to monitor step count, calorie intake, and even the exact path one has walked during the day.

While the smartphone is more than sufficient to track this, newer technologies have been developed that include other sensors to collect additional data. Not only active followers of the quantified-self movement but also merely curious persons can and do buy so-called activity trackers that add somewhat health-related data into the mix, such as heart-rate or calorie expenditure.

Taking care of one's health is important to many as it should be. The World Health Organization (WHO) has recommended that every adult should engage in at least 150 min of moderate physical activity per week to maintain their health [1]. Therefore, it comes as no surprise that the fitness sector is booming. People are encouraged to eat healthier and do more exercise, not only to prevent muscle and posture problems, but also to decrease the likelihood of gaining weight and to actively reduce stress (cf. [2]).

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The readily available commercial activity trackers and fitness apps that not only keep track of what one has done but that also encourage or remind their users to do more—for example, take at least 250 steps each hour (for example, on Fitbit devices)—are one way to support a more active and healthy lifestyle.

However, as with all data collection, there are also concerns. These do not limit themselves to the mere accuracy of the aggregated data (e.g., [3–5]). With news of hacker attacks on well-known companies, big data, and personalized advertisement, there is also a growing concern about privacy and the protection of one's data.

2 Related Work

Previous research concerning so-called fitness or activity trackers have oftentimes focused on their reliability and data accuracy (e.g., [6–8]). Meyer et al. [9] have studied acceptance in accordance with the devices' usability by including factors such as appearance, wearability, and device interaction. Preusse et al. [10] focused in their acceptance of wearables study on older adults.

Usability and acceptance might go hand in hand with another oftentimes researched topic, namely the abandonment of use. Clawson et al. [11] have studied the reselling of used wearables to determine reasons for no longer using or wishing to use these devices.

This complements another, and no less interesting, focus of research which is the (initial) motivation of use. This approach is to be considered from two different directions. For one, there is the reason behind the use. Is the user merely interested in his or her statistics, an ambitioned life-logger, or needs the input to hold or increase one's personal goals, such as weight, daily steps, etc.? For another, the motivation might come from the device itself (cf. [12]). Newer generations of activity trackers do not only log data, they give their wearer feedback on their movement or lack thereof. For instance, many Fitbit devices remind their users to make a minimum of 250 steps each hour if they have not done so by ten minutes to the full hour. Thereby, the devices encourage sedentary people to get up and stretch their legs, actively changing their posture but not "bothering" people who have reached this step count already.

When dealing with online data or information disclosure, the topic of privacy is never far (cf. [13, 14]). Even though its definition is somewhat vague [15], always depending on the specific context, one more or less holistic description of privacy could be the right to allow or deny "access to the self" [16, p. 8]. Due to the advancement of technology and, not the least, the prevalence of the internet, this, of course, does include access to information gathered by electronic devices. With the ubiquity of online devices and the current era being described as the information age, it is unsurprising that one pivotal point of the more recent suggestions for defining privacy includes information privacy, meaning the disclosure of personal information to a third party (e.g., [17, 18]). A detailed view into information privacy research is given in [19].

Within the context of privacy research, there are two phenomena that appear quite often and have been well documented. For one, there is the "Privacy Paradox" which describes people's wish to not disclose information while at the same time being rather free and open with the information they do disclose, especially online (e.g., [20]).

This discrepancy between attitude and actual behavior has been the focus of many studies (e.g., [20–23]). The most probable explanation is what is described in the literature as "Privacy Calculus." In this attempt to make sense of seemingly illogical behavior, it is stated that in each and every circumstance and situation, the individual tries to weigh the perceived risks that come with the disclosure of information against the benefits reaped from the same [24]. For a comprehensive summary, see, e.g., [19]. According to the privacy calculus, if the timely rewards for information disclosure (e.g., monetary or social benefits) outweigh the possible drawbacks or perceived risks, be it in the near or farther future, (e.g., newsletters, spam emails, etc.), then an individual is more likely to give that information [19].

The perception of privacy and wish to keep information to oneself is even more prominent in the context of biometric data [25]. Even though activity trackers are not usually considered medical devices – in fact, it states just that on the package of, for example, Fitbit devices – the data that these gadgets may collect are at least health-related. Privacy in this context has already been researched in a few studies (e.g., [25–27]). Mostly, however, these studies focus on how to better protect data transfers or encrypt the data. The perception of users has, so far, been largely neglected, although Motti and Caine [28] analyzed qualitative data from websites dealing with privacy concerns and wearables. Bellekens et al. [29] conducted a study on situational awareness concerning privacy, security, and wearable devices and found that most users are misinformed or perceive their security incorrectly. Their survey remained rather generic though, without too much details on health information or biometric data. However, it is exactly this perception of privacy and willingness to disclose biometric data that is the focal point of the present study.

3 Research Design

In order to get a better view into the topic of privacy in connection with activity tracker data, first, a focus group was conducted. Addressed were the issues of privacy and data protection. Furthermore, the disclosure of the recorded tracker data was discussed. Based on this qualitative insight and an extensive literature research, an online questionnaire was developed. It consisted of several different sections to be introduced now:

Explanatory Variables: The first section included demographic data such as *age*, *gender*, and *education*. This was supplemented with the following sections.

Self-efficacy in interacting with technology: The technology affinity of the participants was surveyed with 8 items based on [30] as self-efficacy when dealing with electronic devices or technology is an important aspect of activity tracking in the digital age. Self-efficacy has been identified to shape acceptance, use, and performance in interacting with various kinds of interactive technology [31, 32].

Frequency of sharing personal information on Social Media: Due to the question of sharing potentially sensitive data, another short section determining the use of social media and what content is shared was added as well.

Self-efficacy sports: With wearable devices best knowns as activity trackers and therefore mostly associated with sports and fitness, the next section of the questionnaire examined the affinity for physical. To include participants who might be unable to exercise, regularly or at all, the next section surveyed reasons for physical inactivity such as injuries or chronic illnesses.

Privacy behavior: This section included 12 items translated into German from Palacios et al. [33] to determine participants' general behavior concerning privacy, mostly but not exclusively regarding online services.

Dependent Variables: The main part of the questionnaire starts with a general survey of usability aspects of activity trackers. Here, items included the fit, price-value, handling, and also design, not only of the hardware but the accompanying software needed to interact with the tracker as well. After this, participants were asked to indicate the importance of keeping track of different types of data. Furthermore, the following variables were queried:

Perceived sensitivity: The participants' perceived sensitivity of 14 different trackable data types is assessed. These data types were: steps, pulse, route captured via GPS, calories, blood pressure, flights of stairs, standing hours, sleep analysis, body mass index (BMI), blood sugar, oxygen saturation, UV radiation, body temperature, and body weight. The detailed assessment of their perceived sensitivity can be seen in Fig. 1.

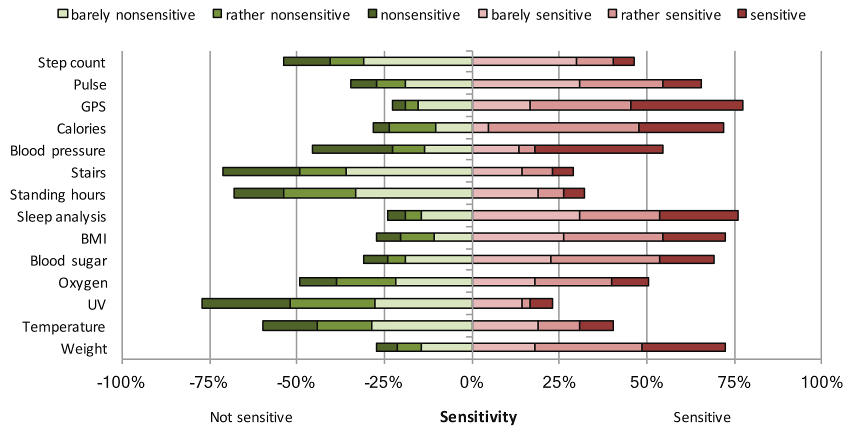

Fig. 1. Perceived sensitivity of different measures recordable by a wearable fitness tracker.

In subsequent sections, the *perceived criticality* of gathering these types of data was surveyed for two different contexts: long-term storage of the captured data and *sharing the data with others*. For the context long-term storage, the participants were asked how critical they deem the long-term storage on the device itself and on servers belonging to the manufacturer of their device. Sharing the data surveyed the perceived criticality of disclosing the tracker data to friends and an *online community* (mainly) comprised of strangers is surveyed.

Statistical Procedures: All answers to the items were captured on 6-point Likert scales ranging from not important/critical at all to very important/critical. For the statistical analyses the scales were aggregated into average means. For example, the perceived sensitivity score is calculated as the arithmetic mean across the perceived sensitivity evaluations of the 14 assessed data types. The results are analyzed with parametrical and non-parametrical methods, using bivariate correlations (Pearson's r or Spearman's ρ), single and repeated multi- and univariate analyses of variance (M/ANOVA). The type I error rate (level of significance) is set to $\alpha = .05$ (findings $.05 < p < .1$ are reported as marginally significant). Pillai's value is considered for the multivariate tests and effect sizes are reported as η^2. Arithmetic means are reported with standard deviations (denoted ±). Furthermore, the scales used were tested for their internal reliability by calculating Cronbach's α (see Table 1).

Table 1. Reliability of scales and sources.

Scale	Items	n	Cronbach's α
Self-efficacy in interacting with technology (SET) [30]	8	81	α = .920
Frequency of sharing personal information on social media (FSMP)	5	81	α = .857
Self-efficacy in sports (SES)	8	81	α = .907
Privacy behavior [33]	12	81	α = .781

4 Sample

A total of 131 data sets was collected in Germany during summer in 2016. Due to incomplete answers, only 82 sets are used in this analysis. This sample includes 36 men (43.9%) and 46 women (56.1%) in the age range from 16 to 55 years (M = 31.4 ± 8.9). In the sample, age and gender were weakly correlated ($\rho = -.228$, $p = .040 < .05$), indicating a slightly biased sampling that captured more younger male and more older female subjects (see Table 2). Furthermore, within the sample 36 people possessed a wearable activity tracker (21 men and 15 women), whereas 46 (15 men and 31 women) did not use such a device.

Table 2. Characteristics of the sample (** p < .01, * p < .05, + p < .1). SET: Self-efficacy when interacting with technology, SES: Self-efficacy Sport, FSMP: Frequency of Social Media Posts, PB: Privacy Behavior.

	Age	Gender	Health	SET	SES	FSMP	PB
Age	—					−.275*	
Gender	−.228*	—		−.396**	−.193⁺		
Health			—		.511**	−.214⁺	
SET				—	−.195⁺		.211⁺
SES					—		
FSMP						—	
PB							—

The participants' age and their reported frequency of social media posts (FSMP) is negatively associated ($\rho = -.275$, $p = .013 < .05$). Thus, older people are less willing to share personal information on social networks. Also, gender is linked to self-efficacy in interacting with technology (SET) ($\rho = -.396$, $p < .001$) with women reporting lower technical self-efficacy than men. In addition, gender and self-efficacy in sports (SES) correlate marginally significantly ($\rho = -.193$, $p = .085 > .05$), meaning the women in this sample consider themselves slightly less athletic than the men.

The perceived health of the participants is strongly related to their sport self-efficacy ($\rho = .511$, $p < .001$). The negative correlation between sport self-efficacy and the frequency of social media posts is marginally significant ($\rho = -.214$, $p = .054 > .05$). Furthermore, the sample showed marginally significant correlations between technical self-efficacy and sport self-efficacy ($\rho = -.195$, $p = .083 > .05$), respectively privacy behavior ($\rho = .211$, $p = .060 > .05$).

5 Results

This section is structured as follows. First, we present results concerning the *perceived sensitivity* of different types of trackable data. Once the general evaluation of different data types is established, the *perceived criticality* is reported. This will start with the results for the perceived criticality of storing data on the own tracker and a server belonging to the manufacturer. Lastly, the critical evaluation of disclosing said data either to friends or publicly to potential strangers is reported.

5.1 Perceived Sensitivity of Data

On average, the reported sensitivity of the trackable data was near the center of the scale (54.4% ± 20.8%). However, the participants do ascribe varying levels of sensitivity to the different data types (see Fig. 1). For example, GPS data, weight, and sleep analysis are seen as rather sensitive, with the majority of answers falling onto the right side of the graph. Other data types, such as UV radiation, the number of climbed flights of stairs, or the hours spent standing are regarded as not sensitive.

Statistical analyses show that the perceived sensitivity is not related to the other user diversity factors considered explanatory variables in this study (see Table 2). To understand the structure of this perceived sensitivity, a two-step cluster analysis on the 14 perceived sensitivity items was performed. This analysis identified two distinct clusters of participants that will be used as factors in the subsequent evaluations:

The first group is composed of people with significantly higher sensitivity (referred to as *sensitive*) and consists of 37 (45.1%) participants (13 males, 24 females). The second group includes participants with significantly lower sensitivity (non-sensitive) and consists of 42 (51.2%) participants (21 males, 21 females).

Accordingly, the participants from the high sensitivity group reported a significantly higher sensitivity as to trackable data (70.5 ± 13.4%) than the participants from the low sensitivity group (39.4 ± 13.7%) ($F_{1,77} = 103.683$, $p < .001$, $\eta^2 = .574$). However, there are no relationships between the sensitivity clusters and the participants' gender ($\rho = -.150$, $p = .188 > .05$) and respectively their age ($\rho = .150$, $p = .184 > .05$) and privacy behavior ($\rho = -.069$, $p = .547 > .05$).

Regardless of the perceived sensitivity, the participants are interested in the data their daily life creates, as can be seen in Fig. 2. The subjects of this study would like to keep track of their steps, their heart rate, and also their GPS data. BMI, blood sugar levels, UV data, and body temperature, on the other hand, are of lesser importance to the participants.

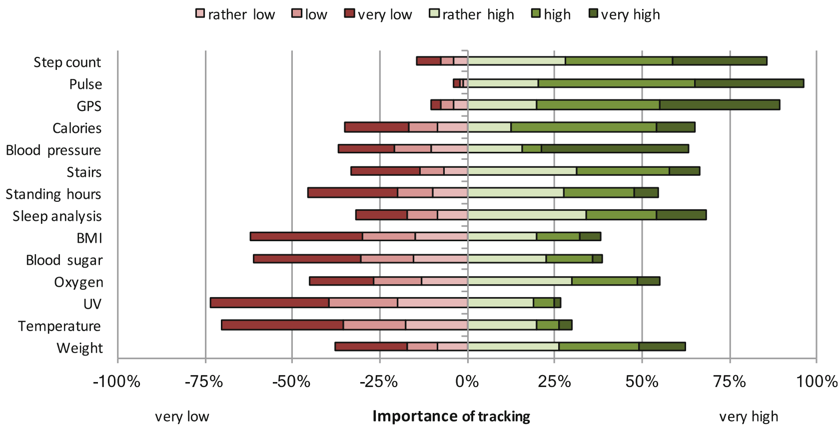

Fig. 2. Importance of tracking.

5.2 Perceived Criticality

In general, storing the measured data on the device itself or on servers belonging to the manufacturer is regarded as neither particularly critical nor uncritical and the mean falls near the center of the scale (54.4 ± 20.8%, 56.9 ± 15.2%). Sharing the recorded data with friends is rated as rather uncritical and falls below the center of the scale (36.7 ± 23.6%). However, sharing the data publicly is regarded as rather critical (60.4 ± 24.3%).

Next, we analyzed whether the desired data tracked on a wearable are shaped by the participants' sensitivity perception. However, an analysis of variance (ANOVA) with the sensitivity cluster as independent variable and the perceived sensitivity as dependent variable revealed no significant differences between both groups ($F_{1,77} = .350$, $p = .558 > .05$).

A repeated measures ANOVA with the sensitivity cluster as independent variable, *perceived criticality* of storing the measured data as dependent variable, and whether the data is stored on the device or on company servers (*storage location*) as within-subject variable identified a strong and significant omnibus effect of storage location ($V = .439$, $F_{1,75} = 58.799$, $\eta^2 = .439$, $p < .001$). There was also a strong and significant difference between both sensitivity clusters ($F_{1,75} = 17.954$, $p < .001$, $\eta^2 = .934$). However, no interaction between *storage location* × *sensitivity group* ($V = .008$, $F_{1,75} = .584$, $p = .447 > .05$) could be found.

The analysis shows that for the factor storage location long term storage of the measured data on the device itself is considered as less critical (36.9 ± 22.6%) than storing the data on a company's servers (59.8 ± 22.1%). Concerning perceived criticality, the sensitive participants evaluated data storage more critical (57.2 ± 23.4%) than the non-sensitive participants (39.4 ± 21.3%), see Fig. 3.

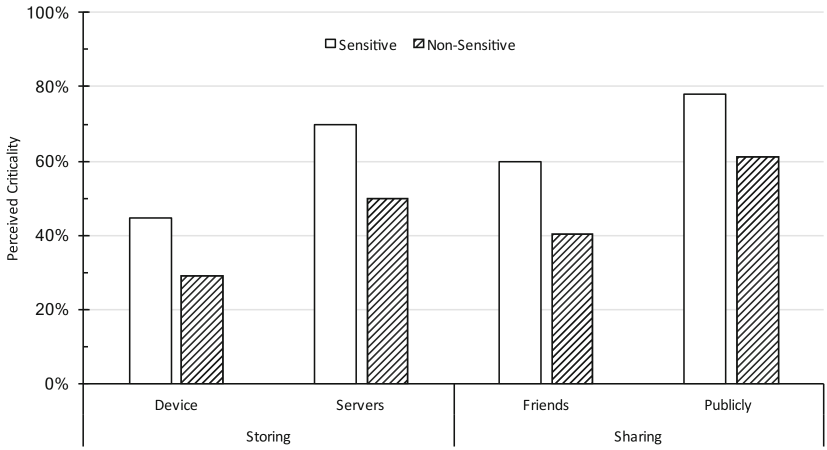

Fig. 3. Perceived criticality of long term storage of data on the device or on servers and of sharing the captured data with friends or publicly by sensitivity cluster.

Furthermore, a second repeated measures ANOVA with the sensitivity cluster as independent variable, the *perceived criticality* of sharing the data as dependent variable, and the audience (i.e., friends vs. publicly) as within-subject variable was calculated. A significant and strong overall effect of the within-subject factor audience ($V = .441$, $F_{1,71} = 55.949$, $p < .001$, $\eta^2 = .441$) and a significant main effect of the between-subject factor *sensitivity cluster* ($F_{1,71} = 15.358$, $p < .001$, $\eta^2 = .944$) could be found. However, there was no interaction between *sensitivity cluster* × *audience* ($V = .004$, $F_{1,71} = 251$, $p = .618 > .05$).

Sharing activity tracker data with friends is considered as less critical (50.1 ± 22.1%) than sharing the data publicly (69.5 ± 22.5%), see Fig. 3. As above, the sensitive group considers sharing in general (friends and publicly combined) as more critical (68.9 ± 19.6%) than participants from the non-sensitive group (50.7 ± 25.0%).

Table 3 lists the results of a correlation analysis concerning perceived sensitivity of data recorded by an activity tracker: The factor *perceived sensitivity* correlates positively with the *perceived criticality* of long-term storage of the measured data on the device itself ($\rho = .313^{**}$, $p < .05$) and on company servers ($\rho = .445^{**}$, $p < .001$). Likewise, the overall sensitivity also correlates positively with the *perceived criticality* of sharing the data with friends ($\rho = .394^{**}$, $p < .001$) as well as publicly in online forums ($\rho = .320^{*}$, $p < .05$).

Table 3. Correlations between the explanatory variables and the perceived criticality of long-term storage and data sharing (** p < .01, * p < .05, + p < .1). SET: Self-efficacy when interacting with technology, SES: Self-efficacy Sport, FSMP: Frequency of Social Media Posts, PB: Privacy Behavior, SENS: Sensitivity Clusters.

	Perceived Sensitivity	Storing		Sharing	
		Device	Servers	Friends	Publicly
Age					
Gender		.366**	.232*		
Health					
SET					
SES					
FSMP					−.195^{+}
PB				.303*	.190^{+}
SENS	.863**	.313*	.445**	.394**	.320*

6 Discussion and Limitations

The present study showed that the participants were interested in knowing data typically recorded by an activity tracker. However, it could also be revealed that said data should, for the most part, be only made accessible to one self. The notion of storing one's lifelogging data on a company's server is not favorable. Even participants who rate the sensitivity of said data as not as high are rather of two minds concerning this storage option.

Although motivation to physical exercise might come in the form of encouragement or compliments for achieving milestones, the present study showed that sharing data from a wearable activity tracker is not favored either, especially, when the audience or recipients of said data might be strangers in online forums.

However, for one thing, the sample is rather small. For another, it is also relatively young. Older users should be studied as well and in depth concerning interest in, perception of activity trackers, and data collection/privacy [5, 10]. Furthermore, the sample exhibits age/gender correlations implying a non-homogenous distribution.

This should also be rectified in future studies to evaluate possible influences of user factors such as age, gender, sport affinity, privacy disposition, and the likes. For example, the perceived criticality of long-term storage of the captured data is solely determined by the participants' gender and this relationship between gender and perceived criticality is rather small. Likewise, the perceived criticality of sharing the tracker data with friends or publicly is related to the reported privacy behavior of the participants: Those who are careful in respect to their own privacy while using the internet, who use ad blockers, check and manage their browser's cookies, etc. also perceive sharing the tracked data with friends or publicly as rather critical.

We hypothesized that this perceived criticality of storing and sharing health and fitness data is consistently governed by privacy behavior and frequency of social media postings as people who are very concerned for their privacy and post little are less likely to want to share their activity data with companies (by storing them on their servers) or friends or strangers (by posting on forums or social media platforms). However, the data from our study does not support this. In fact, only isolated relationships between the investigated factors of user diversity/explanatory variables and the perceived criticality could be identified.

Nevertheless, we found that the perceived sensitivity of the measurable health and fitness data is consistently related to all considered perceived criticality aspects. More importantly, an explanatory cluster analysis found that the participants can be separated into two distinct groups based on their perceived sensitivity of the assessed data types: The first group regards the trackable measurements as rather sensitive, whereas the second sees them as less sensitive. Further studies need to closely evaluate whether these two distinct clusters also emerge for larger and more heterogeneous samples. Also, we need to evaluate if the perceived sensitivity of sensor data can be established as a novel and reliable construct to assess a person's privacy disposition towards the tracking, storing, and sharing of sensor data. Therefore, both the privacy paradox and the privacy calculus should be further included in future studies as the present sample did not yield conclusive data to explain the evaluation of different types of data trackable by wearable devices.

7 Outlook

With the spread of the Internet of Things and ever more gadgets available to link to it, there needs to be more research into usability and motivation of use. Especially regarding activity trackers, there is yet a lot missing in the understanding of the motivational factor it could provide to increase physical activity. As the majority of participants of the present study were recruited via fitness forums, they are already predisposed to an active lifestyle. Therefore, the motivational aspect of an activity tracker could not be examined here and would require further studies.

With the sedentary workload increasing, a lack of movement is harmful on many levels. It heightens the risk for skeletomuscular problems, facilitates the elongated use of wrong posture, and also enhances the risk of gaining weight due to missing energy expenditure. As activity trackers are obtainable for decreasing amounts of money, there should be more research to find out why they are not used more frequently. Is it the lack of interest in physical activity or rather the risks or concerns about the use of the collected data that inhibits potential users. While the presented study is a first step to offer answers, it is by no means sufficient. With the lack of a big enough sample, there needs to be more research as to why people reject the use of activity trackers and what motivates the use. Is it only life-loggers and active athletes that profit from the wearable or can other user groups benefit with few or no restrictions as well.

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Development of Customized Orthotics Based on Lower-Leg Anthropometric Data and Task

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Abstract. The paper presents the development of a customizable lower-leg orthotic device. It consists of a single degree of freedom multi-loop linkage designed to facilitate task-specific lower extremity training for rehabilitation purposes. The device guides the knee, ankle and foot of the user along a walking trajectory obtained from motion capture of a healthy human subject. We hypothesize that a device that closely mimics natural human walking motion will be able to provide more desirable design solutions in terms of comfort, stability and safety. Multibody dynamic simulation software OpenSim is used to characterize and assess the trajectory produced by the proposed device. The dynamic simulation predicts the effects of walking with the device and allows the study of the interaction of the orthotic device with the human body during the conceptual and detailed design phases.

Keywords: Anthropometric design · Orthotic · Simulation study · Mechanical design · Walking

1 Introduction

Exploiting the dynamics of human walking and leg morphology in order to create lighter and more efficient assistive devices has been a major area of research for the last several decades. While the terms orthosis and exoskeleton are sometimes used interchangeably to refer to assistive devices, Dollar and Herr [1] used the term orthosis to refer to an anthropomorphic wearable device that is used to increase the ambulatory ability of a person suffering from leg pathology by working in concert with the operator's movements. Exoskeletons, on the other hand, were defined as devices that augment the performance of an able-bodied wearer.

Human gait is a result of synchronized and periodic motion of the legs. The structure of the leg plays a major part in determining the resultant motion. In the sagittal plane, a kinematic chain with two rotational joints as shown in Fig. 1 can approximate the structure of the human lower-leg. This simplified kinematic structure is at the heart of the mechanical design of many exoskeleton or orthotic devices to provide assistive action.

Several orthotic designs have been proposed and prototypes built over the last several years. Of these, orthotic devices that rely on kinematic programming to obtain

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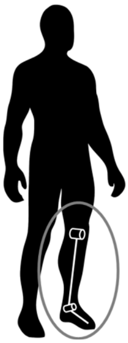

Fig. 1. A simplified kinematic approximation of the lower-leg in the sagittal plane featuring two links connected by two revolute joints.

the desired motion include the Powered Gait Orthosis (PGO), which is a one DOF system for each leg having a mechanized hip and knee design, along with a cam - modulated linkage for knee function generation with variable time ratio [2]. On the other hand, the passive leg orthosis developed at the University of Delaware uses a combination of springs and linkages in order to geometrically locate the center of mass of the leg - orthosis system, and then, balance out the effect of gravity [3]. Both these devices were designed to assist the locomotion of the user over level ground.

When designing orthotics, a major concern is wearability. Wearability is defined as the interaction between the human body and the wearable object [4]. In case of orthotics, the definition extends to include the effects of the human body in motion, or Dynamic Wearability. Major concerns include matching and obtaining close alignment between the structure of the exoskeleton to the wearer, affectation of the biomechanics of locomotion due to added mass and inertia of the device itself as well as the additional kinematic constraints inadvertently imposed on the wearer [1]. Portability and safety are two other major factors that need to be considered. Portable orthotic devices can be used as a part of the wearers everyday life without the need for constant medical supervision that would limit the application of orthoses to clinical settings.

With these requirements in mind, we propose the design of a lower-leg orthotic device that is based on anthropomorphic measurements of the user's limbs and is built specifically to mimic their natural physiological task performance. In order to replicate human walking motion as closely as possible, the device synchronizes the motion of the knee and the ankle as a whole instead of having separate mechanisms at each of the joints. In addition, special attention is devoted to the issue of augmenting the support provided to the biological limb with a backbone chain. Additionally, dynamic simulation tools are utilized to position the static and moving elements of the mechanism appropriately in spaces around the body so as to minimize the effect on the resulting motion.

2 Design of a Wearable Lower Leg Six Bar Mechanism

Our goal is to design mechanical orthotic device, based on anthropometric data from a human lower extremity that can mimic as closely as possible humans' natural walking gait trajectory, as well as can be easily paired with the human limb, avoiding collision between the linkage and the wearer's limb. Data required to describe a person's natural gait can be collected using various types of motion capture technologies available commercially. These can range from complete motion capture systems like Qualisys [5] or Vicon [6] to more affordable options like Kinect sensor kits [7]. The linkage topology selected depends on the complexity of the physiological task to be supported. Many commercially available mechanism synthesis packages (e.g. MechGen [8], MotionGen [9]), make the exploration and selection of a number of different linkage topologies easily achievable. Once the dimensional synthesis of the mechanism is carried out, task- and limb-specific assessment criteria are employed to identify the most suitable design candidate. This design candidate is then modified and the biological limb is augmented with the anthropometric backbone chain. Based on the dynamic simulation of the device in conjunction with a user, additional design adjustments are made to ensure the device is stable and does not interfere with the fluid motion of the human body. The customized device so obtained can then be prototyped and manufactured. This process is illustrated in Fig. 2.

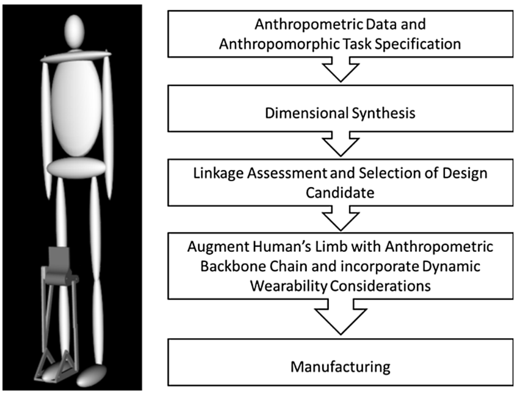

Fig. 2. The process for development of customized orthotic devices for the lower-leg.

The design approach starts by obtaining experimental data of a healthy human subject walking on a treadmill at a speed of 1 km/h and recording the motion using high speed video cameras. The target kinematics of natural walking motion are obtained by attaching infrared markers to the lower body of the subject (as illustrated in Fig. 3(a)). The recorded data conveys frame-by-frame information about the positions of the rigid segments of the lower body, namely the trunk, thighs, shank and feet. In the sagittal plane, the trajectory traced by the foot resembles the well-known 'teardrop' shape. While the gait data obtained may vary across different trials, yet the qualitative nature of the data remains similar.

This average trajectory of the Toe marker is observed with respect to a global fixed frame set on the ground. However, in order to look at the motion of the lower leg in isolation, the thigh segments has to be held stationary as shown in Fig. 3(b). It shows the positions of the infrared markers attached to the body transformed relative to a new fixed frame attached to the thigh, as well as the new trajectory traced by the foot relative to the thigh fixed frame.

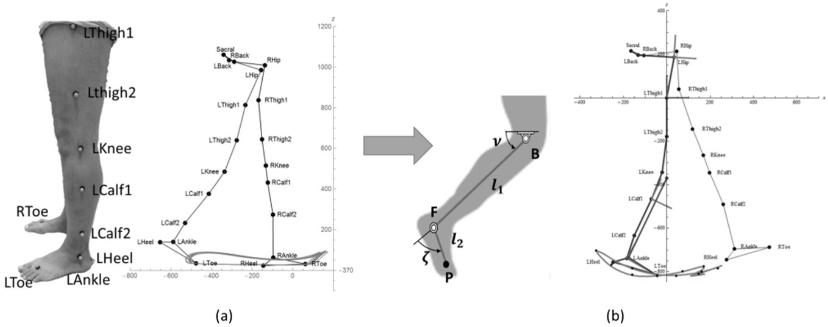

Fig. 3. Data collection using motion capture system followed by fixing the thigh frame to obtain 2R kinematic backbone chain for design of orthotic device.

Plecnik and McCarthy [10] developed a formulation for the design of a lower leg mechanism based on Stephenson II six-bar function generators for 11 accuracy points. Tsuge et al. [11] further extended this work to present the design of an optimized Stephenson III six-bar linkage for following ankle trajectory. Robson and Soh [12] presented the idea of using the human's actual limb to replace the backbone chain of a linkage in the design of wearable devices. Plecnik and McCarthy [13] further showed a methodology to synthesize a Stephenson II six-bar function generator that incorporates an already specified backbone chain to yield smooth movement throughout the desired task. The resulting linkage design is a scaled kinematic inversion of the function generator as shown in Fig. 4.

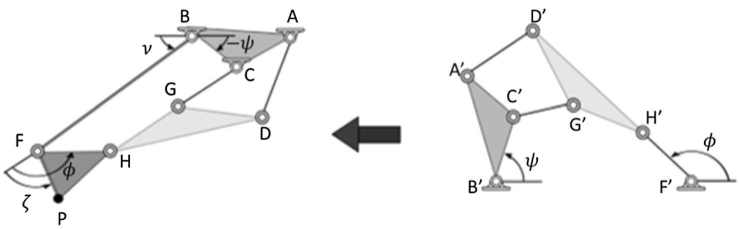

Fig. 4. A Stephenson III path generator obtained by coordinating the RR joints of the kinematic chain BFP with a Stephenson II function generator (adapted from [13]).

The synthesis equations detailed in these works [11, 13] were solved in 2 h 14 min and 21 s on a node using UC Irvine high performance computing cluster. Parallel processing was used with 64 CPUs at a speed of 2.2 GHz for each core. 332 design candidates were obtained from the synthesis process.

3 Assessment of Design Candidates

Of the 332 linkage designs obtained, none of the solutions satisfies all the eleven specified task positions. However, nine of the solutions were able to pass through ten of the specified eleven positions. Only six of these linkages (five going through ten positions, and one going through nine positions) are found to be free of order defect, i.e. they go through the specified task positions in the order specified as shown in Fig. 5.

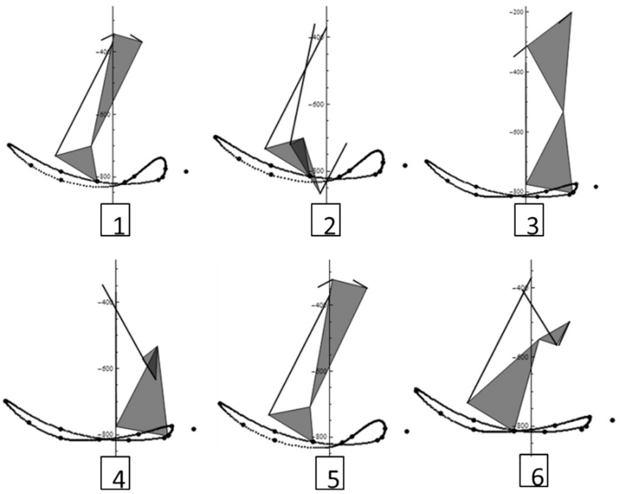

Fig. 5. The six design candidates free of order defect.

The design candidate for the development of the lower leg orthotic should not only go smoothly through the specified task positions in the specified order, but should interface well with the limb of the user and not impede their natural movement according to the principles of wearability. Gemperle et al. [4] identify the most unobtrusive locations on the human body for placement of wearable devices. These locations, shown in Fig. 6(a), consist of the shins and the tops of the feet on the lower leg. In accordance to this, we identify areas around the lower leg where it is unsuitable to locate the linkage or parts of it (see Fig. 6(b)).

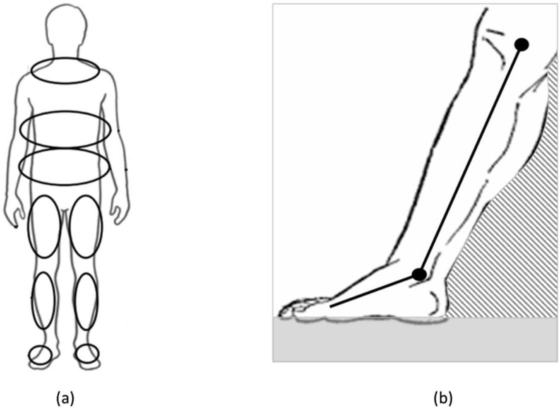

Fig. 6. (a) The general areas found to be the most unobtrusive for wearable objects include shin, and top of the foot on the lower leg (adapted from [4]). (b) Conversely, the shaded regions around the lower leg are undesirable for locating the linkage based wearable device.

The shaded area locates the region below the second link of the kinematic backbone chain that mimics the foot. The presence of any component of the linkage in this region is undesirable as it will cause collisions with the ground and impede natural walking motion. On the other hand, the presence of the mechanism in the crosshatched region behind the calf could increase the chances of collision with the upper leg segment during flexion of the knee affect the gait and cause injuries to the user. Based on these criteria, Linkage solution 2 is eliminated from the list of suitable designs.

Next, the linkage designs are evaluated on compactness of the human leg - orthotic system using the following formula:

$$\min S = r_1 + r_2 + A_1 + A_2 \tag{1}$$

where,
r_1 is the distance of the fixed pivot A from the fixed pivot B at the knee,
r_2 is the distance of the fixed pivot C from the fixed pivot B at the knee,
A_1 is the area of the ternary link DGH
A_2 is the area of the ternary link HFP.

The most preferred linkage was the one with the lowest S score and it is found to be linkage solution number 1 in Fig. 5.

4 Evaluation of Mechanism for Orthotic Design Using OpenSim

To evaluate the operation of the linkage solution 1 as a walking device, a dynamic simulation is created in the open-source multi-body simulation package OpenSim [14] environment as shown in Fig. 7. The six-bar mechanism is attached to the thigh in such a manner that fixed pivot B of the linkage is collocated with the human knee.

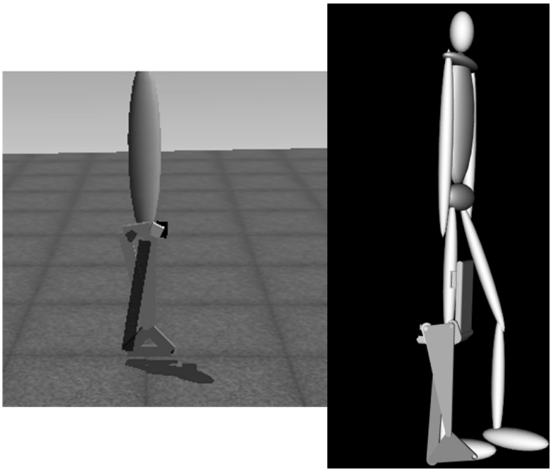

Fig. 7. A 3D dynamic model of the six-bar mechanism attached to the human body along with characteristic forces in OpenSim environment.

Simulation results are presented in terms of the computed joint angles at the knee and the ankle of the supported limb as well as its toe trajectory in Fig. 8. These results can be considered as performance characteristics for evaluating a practical feasible operation of the proposed orthotic device.

The simulation results indicate knee and ankle angles obtained with the proposed orthotic device lie within ±10° of the experimentally obtained values. The toe trajectory is also found to be sufficiently close to the experimental trajectory to guarantee natural motion of the supported leg.

The simulation results also indicate that augmenting the human limb by collocating the kinematic chain as a ‘backbone’ for the orthotic device helps to provide greater support, balance and stability to the device as well as the user. It is relocated to the radial part of the affected leg, co-locating with the rotational axes of the human’s limb joints to mimic the desired physiological walking trajectory. The chosen design leads to increased safety for the user and a weight balance on both sides of the leg.

Finally, a reduced scale of the orthotic device was 3-D printed to test the system and see how all the parts fit together (see Fig. 9).

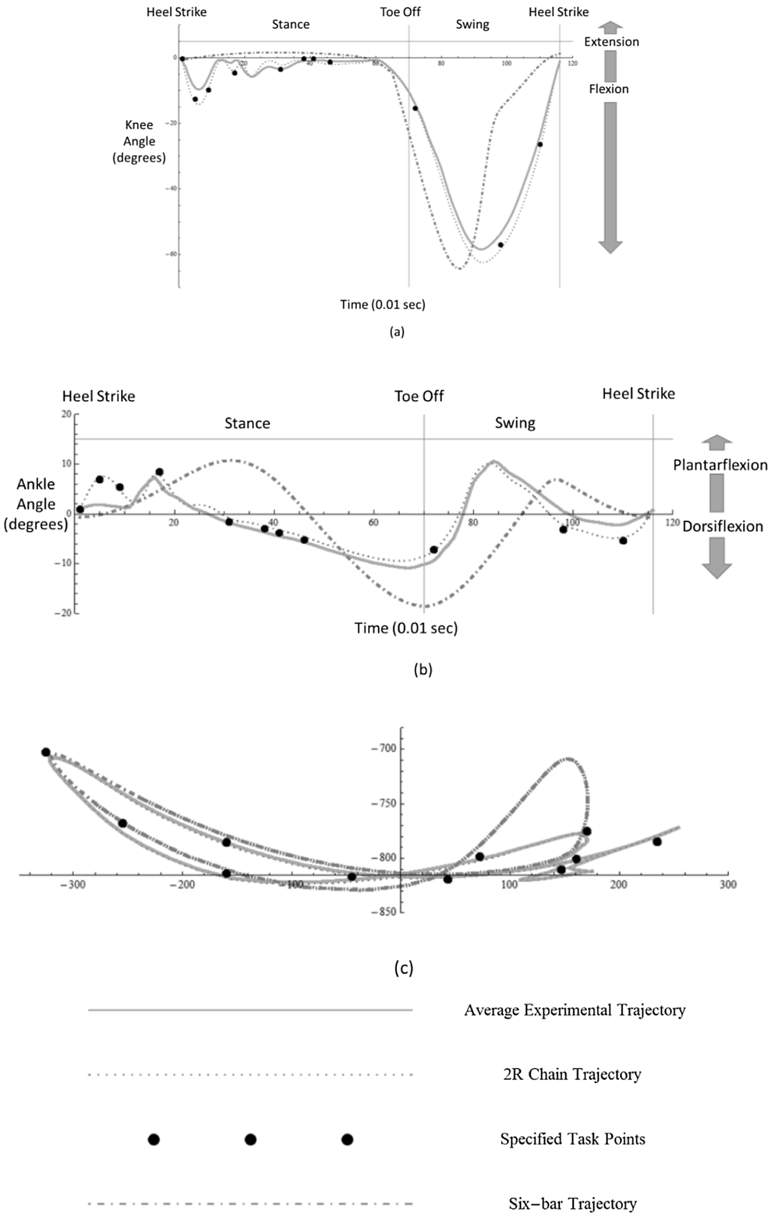

Fig. 8. Comparison of (a) knee angle, (b) ankle angle and (c) toe trajectory of natural human walking obtained experimentally with simulated device trajectory using OpenSim environment.

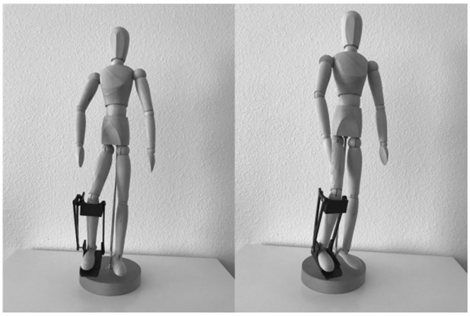

Fig. 9. Reduced scale 3D printed model of the orthotic device.

5 Summary

A mechanical design of a six-bar linkage for lower leg orthotic is presented through a dynamic simulation of its characteristic motion. The concept of dynamic wearability is used to assess synthesized design candidates. Finally open-source software package OpenSim is used to evaluate the output trajectories in the presence of characteristic ground contacts and human like input motion. This environment is also used to assess the placement of the mechanism in spaces around the human body and to suggest modifications. Test results from the preliminary prototype have validated the proposed design of the orthotic. Comparison between human natural walking trajectory and the combined human-device trajectory in OpenSim, as well as experimentally with a full scale prototype will be addressed in our future research.

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An Intelligent Pen to Assess Anxiety Levels Through Pressure Sensors and Fuzzy Logic

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Abstract. Anxiety is a physiological state of activation, which is commonly measured using direct or indirect methods. In psychology, the tools used to obtain information about the state of anxiety in a subject are commonly, self-reports, which represent how the person perceives his or her own physiological and cognitive state of anxiety. Additionally, anxiety has been tested on graphics tests, which evaluate the characteristics of strokes, such as the pressure exerted by the pen or the oscillation of the line. These characteristics are measured in an indirect and, in certain way, subjective manner; thus it is necessary to develop objective tools that throw specific and directly measurable data. For these reasons in this paper, we present an intelligent pen that has the objective of providing a presumptive diagnosis of anxiety levels that presents a person (especially students of middle and higher education). The pen uses an electronic device to measure two pressure levels (at pen tip and pen body) and an inference system based on fuzzy logic. This prototype has been tested with 9 volunteers in an experiment consisting in two stages: a first under simulated stress condition, and a second under normal writing.

Keywords: Hearing loss · Sign language · Deaf persons · Video summary · Children with disabilities · Learning objects

1 Introduction

According to a publication of Spring American College Health Association Survey, in United States of America around 50% of students that have been admitted to a university present emotional stress situations during the next 12 months. In the same way, the different responsibilities and activities of universitary life produce exhaustion and weariness in more than 80% students, bringing with them mental illnesses that can affect the behavioral health [1].

In this line, the comorbidity is defined as the presence of one or more additional diseases or disorders co-occurring with a primary disease. The comorbidity between

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headache (migraine), anxiety and depression is very common, predominating many of the times one over the other, although it can be considered that the migraine can be an alteration of type chronic headache. In this line, if we only focus on the anxiety and depression, we can notice that these diseases have a strong comorbid relationship [2].

Even having some inconsistent results, several studies claim that anxiety disorders (including panic disorder), are related with ideas and attempts of suicide. Therefore, it is very important conducting an early diagnosis of these types of disorders as well as evaluating the suicide risk of persons that suffer from anxiety [3].

In a research about anxiety prevention, a sample of 106 students from the Faculty of Education of the Universidad Complutense de Madrid, who answered a State - Trait Anxiety Questionnaire (STAI), were studied. The results showed a high rate of anxiety in the students, leading to psychological and mental alterations, causing low academic performance as well as loss of self-esteem to establish interpersonal relationships. Appropriate interest in the mental health of university students is not always taken into account, even less with the idea that university youth constitute a relatively healthy segment of the population [4].

On the other hand, according to the Pan American Health Organization and the World Health Organization, in Ecuador, among 2008 and 2010, the top five causes associated with mental health were [5]:

- The depression has increased from 108 to 113 cases per 100,000 inhabitants.
- Anxiety likewise increased from 66 to 99.
- Epilepsy 47.8 to 63.2
- Mental retardation from 25.2 to 37.

In light of the foregoing, it is fundamental to have technological tools that can help carrying an early detection of anxiety in universities, middle education institutions or workplaces. For these reasons, in this paper we propose an intelligent pen able to provide a presumptive diagnosis of anxiety level present in a person that writes some text. This pen can be easily incorporated to any evaluation or diagnostic process that is carried out during the teaching-learning process.

The rest of the paper is organized as follows. In Sect. 2 we present a brief overview of contributions related with mental health care and anxiety diagnosis/treatment. The general designs of the pen as well as the informatics system are depicted in Sect. 3. Section 4 describes the pilot experiment that we have conducted with 9 volunteers with the aim of validating the first stage of our proposal. Finally, Sect. 5 presents some ideas for discussion and future work.

2 A Brief Overview of Contributions to Support the Diagnosis and Treatment of Anxiety

The negative psychological and behavioral symptoms detected belatedly constitute an important problem for the care of people with mental disorders and their caregivers. This situation can cause the deterioration of patient's quality of life, therefore it is necessary an early diagnosis and monitoring through some technological aid such as portable autonomous multisensory intervention device (PAMID). PAMID not only supports monitoring patient's physiological conditions, but also allows performing an automatic multisensory intervention with the aim of reducing the negative behavior of persons with cognitive deterioration (anxiety, agitation or aggressiveness). PAMID relies on microelectronics and measures several parameters such as heart rate, body temperature and dermal impedance that is related to sweat [6].

In the robotics area for mental health care, Kulic and Croft have determined that reaction that a person presents to the movements of a robot manipulator during the interaction of the same, helps detecting anxiety. To this aim, the robot produces movements in real time using the patient's physiological signals. These movements have the aim of generating emotions in the patient and produce a response in him/her. The physiological responses are classified using fuzzy logic [7].

Moreover, the Electronic Health Records (EHR) of university students were used by Zhang et al. with the aim of determining the risk of suffering anxiety or depression. To this aim, the authors have used the M-SEQ algorithm that works in two stages: first discovers a set of diagnosis codes that are discriminative of anxiety/depression, and then extracts each diagnosis pair from each patient's health record to represent the temporal orders of diagnoses [1].

In other line, Miranda, Calderón and Favela propose to use wearable technologies as an alternative for monitoring Blink Rate (SBR) and Heart Rate (HR) in the Social Anxiety Disorder (SAD) treatments. To this aim, the authors have conducted an experiment that involved 8 subjects in two groups: Mild SAD and No SAD. The experiment consisted on an induced anxiety situation where each participant gave a 10 min speech in front of 2 teachers. The results of this research show higher average heart rates after induced anxiety spans on the mild SAD group (no evidence of increased SBR as an anxiety indicator) [8].

3 General System Architecture

As can be seen in Fig. 1, the intelligent pen relies on several electronics and informatics elements that interact between them. Some of the most relevant components are described below:

- During the diagnosis stage, both the **teacher** and the **student** interact with the **interface building block layer**. Each student uses the **intelligent pen** to write any kind of text and while this happens, the teacher can see the pressure levels of the different sensors placed in the pen as well as the presumptive anxiety level inferred by the expert system (**computer**).
- In the services layer, the system provides several services to the users:
  - **Web monitoring system**: provides a web interface to monitoring remotely the interaction between users and intelligent pen. This interface shows graphics that change dynamically as pen detects pressure changes.
  - **Report generation**: creates different kinds of reports containing the presumptive diagnosis and a register of pressure levels over the time. Likewise, these reports contain other variables such as the time of use, maximum and minimum pressure values, etc.

- **Graphics of real time**: provides an interface to observe how the pressure of all sensors varies as users interact with pen.
- **Transmission services**: allow sending and receiving data between the intelligent pen and computer. To this aim, this element uses Bluetooth protocol and web services.

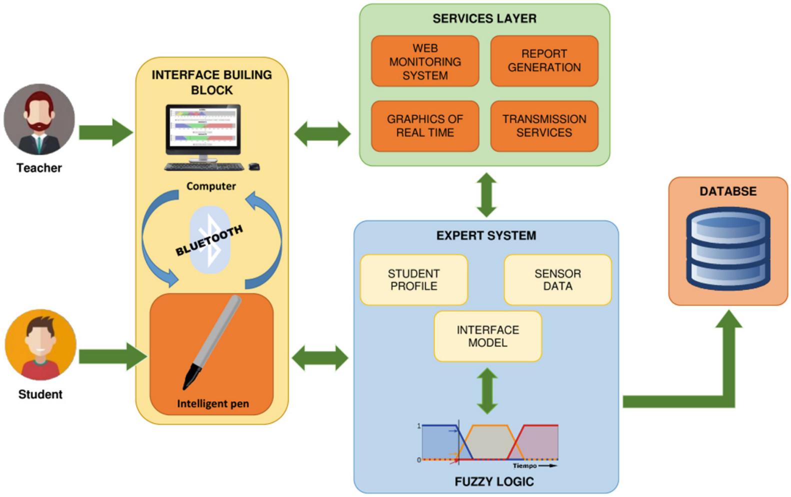

Fig. 1. The general system architecture and the 3 layers and components that constitute it.

- The presumptive diagnosis is inferred by the expert system, which relies on the following elements:
  - **Student profile**: contains demographic and academic data of the student. With this information, the expert system can adjust some elements of the fuzzy logic module.
  - **Interface model:** this element relies on a fuzzy logic inference system. In this module are contained all the rules and the model parameters such as defuzzification method, activation function, fuzzy model (Mamdani, Sugeno, etc.), among others.
  - **Sensor data:** is a dynamic data structure that contains the pressure values of sensors placed in the pen. The information of this element as well as the student profile and his/her presumptive diagnosis are stored in a **database**.

In Fig. 2 it is possible to see the first assembled version of our intelligent pen (left side) as well as the 3D model used to model the prototype.

In the Fig. 3 we can see the electronic structure of the intelligent pen. The sensor placed on the pen body is force sensitive resistor (MF01), the sensor place in the pen tip is a linear potentiometer, and the Arduino One is the responsible of collecting data and sending to the computer.

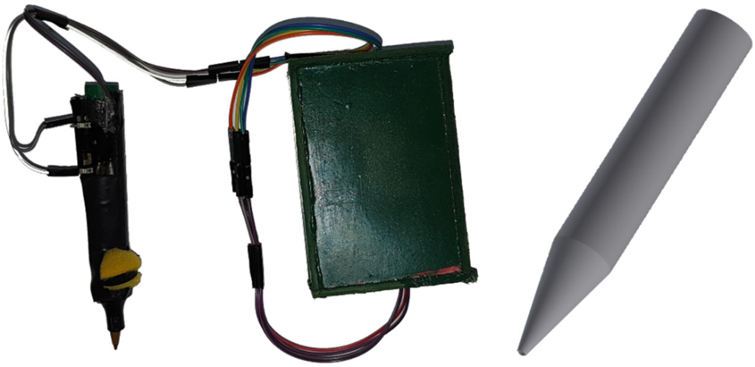

Fig. 2. The first version of intelligent pen prototype (left side) and its 3D model (right side).

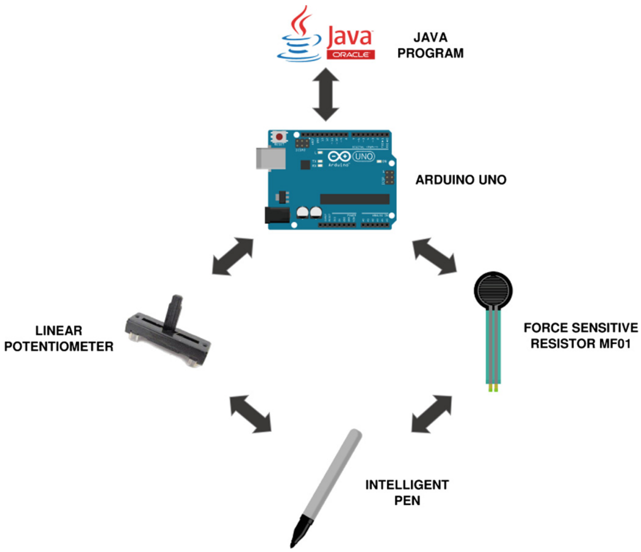

Fig. 3. The different electronic components on which relies the intelligent pen.

On the other hand, it is important to mention that fuzzy logic model uses three variables to infer the anxiety diagnosis (Fig. 4):

- *Var input 1*: this variable measures the pressure level of the sensor A, that is placed on the pen body (in the area where user holds the pen for writing). The sensor used to measure the pressure is the MF01 model and represents three pressure levels: low, medium and high.
- *Var input 2*: this variable measures the pressure level of the sensor B, that is placed on the pen tip. This sensor relies on a linear resistance and represents three pressure levels: low, medium and high.

- *Var output*: represents the presumptive anxiety diagnosis and has three levels (very low, low, medium, high and very high). In order to defuzzify the level of anxiety, our fuzzy model uses the Center of Gravity method (Eq. 1):

$$anxiety = \frac{\int_a^b \mu(x)f(x)dx}{\int_a^b \mu(x)dx} \quad (1)$$

Where:

- **μ(x)** represents the membership degree of value **x** to diffuse set
- **f(x)** represents the membership function for the given interval [*a*,*b*]
- **a** and **b** define the interval in which is defined each function.

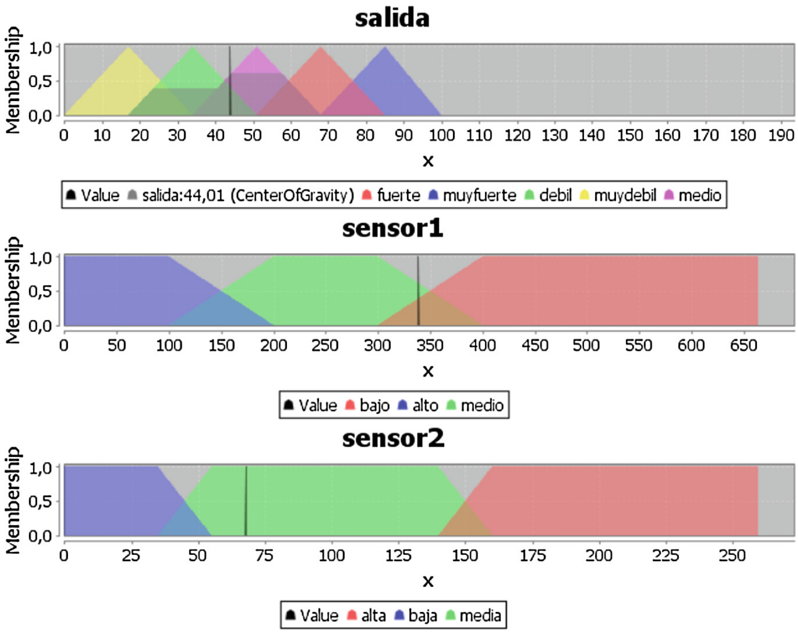

Fig. 4. The three variables used by the fuzzy logic model to infer the anxiety level. At the top of the figure, we can see the output variable (anxiety level), the middle represents the pressure in the body pen (sensor A) and the bottom the pressure in the pen tip (the sensor B).

4 Pilot Experiment and Preliminary Results

With the aim of validating the intelligent pen and the inference system, we have conducted a pilot experiment with 9 volunteers at the Universidad Politécnica Salesiana. The main characteristics of the group of volunteer are the following:

- Average participant age: 22 years
- Number of women: 4
- Number of man: 5
- Occupation: university students (systems engineer career).

The pilot experiment consisted in two stages: in the first one, we asked participants to write a paragraph of 73 words containing a short story about their life, whereas in the second stage we have asked participants to play an Ecuadorian game named “Stop the hand”. In this game, the judge gives a consonant, and the participants must to write certain words that start with this word (a color, a person name and last name, an animal, a city name, a country name, a fruit name, and a thing name). After a certain time (5 or 7 s), the judge says “Stop the hand” and no one can continue writing. The winner is the person that writes more words. For the experiment, each participant has used the pen during the two stages.

In the Fig. 5 we can see the pressure levels that have been registered by the intelligent pen. As it can be seen, the pressure level in sensor A (that is placed on the pen body) shows a mean of 577.3 and standard deviation of 105.4 for normal writing, whereas the mean is 623.8 and standard deviation is 56.17 for writing under stress situation. These results confirm that participants tend to make more pressure in the body of the pen in that situation where they feel more anxiety.

In the other hand, the pressure level in sensor B (that is placed on the pen tip) shows a mean of 24.08 and standard deviation of 6.93 for normal writing, whereas the mean is 23.36 and standard deviation is 5.46 for writing under stress situation. Although these results show that under stress situation the pressure level is lower than under normal writing, the standard deviation is lower, which means that the most of persons feel some anxiety level (given that press the pen harder).

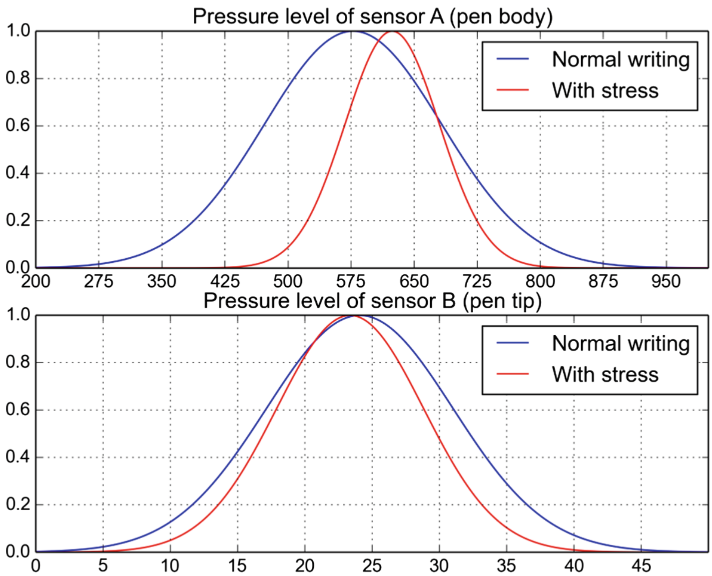

Fig. 5. Levels of pressure of each sensor placed on the intelligent pen.

5 Conclusions and Future Work

In this paper we have presented an intelligent pen that is able to support the presumptive diagnosis of anxiety. In this first phase, we have tested the pressure level detection under stress situations. The strategic location of the sensor in the body of the pen allows the pressure to be detected more easily, and allow registering data with greater facility.

In the same way, although the mean pressure in the pen tip under normal writing is lower than mean pressure under stress situation, the standard deviation confirms that the most of users press the pen strongly under stress situations.

The issues of ergonomics and comfort are very important to take into account, since in this way the people who are tested are not necessarily informed about it, but on the contrary, it should be done in a more natural way to eliminate bias.

Our intelligent pen can be used in any educational level as a tool to determine whether students are under stress situations. With this information is possible to apply preventive strategies that could help improving the students' performance. Likewise, the pen can be used too in business field to creating better work environments.

As lines of future work, we propose the following ones:

- To design and make a pen in which is considered ergonomics, with aim of guarantying a better grip as well as the user comfort.
- To design a communication module that relies on Bluetooth protocol (with aim of not using cables).

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Real-Time Eye-Interaction System Developed with Eye Tracking Glasses and Motion Capture

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Abstract. In the industrial environment such as aircraft cockpits and train driver's cab we wished to real-timely acquire the eye-tracking position and made it synchronous with all controlled digital screens with which the machine could dynamically response to the user' s current situation awareness (SA). Wearable eye-tracking glasses could only provide the relative position to the captured video, using which we gathered the data of the eye movement data (2DOF). While the motion capture device could only provide the position and orientation data, using which we accessed the displacement and angular displacement of the head (6DOF). We combined such two devices together into a novel real-time eye-interaction system to synchronize the user's visual point on the screens. A spatial transform algorithm was proposed to calculate the visual point on the multiple digital screens. With the algorithm and the human factors analysis the machine could strengthen its dynamic service abilities.

Keywords: Eye-interaction system · Eye tracking glasses · Motion capture

1 Introduction

Nowadays the eye-tracking equipment have many types. The core function of the eye-tracking system is to judge eye rotation and make it synchronization with the image of the time. These systems are generally divided into 2 types.

One is the contact type which is usually driven by the electro-oculography (EOG) signal which need to be gathered with the wearable electrode slice in the eye. The EOG signal is rapidly conduction which also has nothing to do with the light or the operating environment. Many researchers used the EOG signal as the input interface to computer [1–3]. The developed system was real-timely well-used. But the detection ranges of the interface only included less countable directions which is the big weakness of these type.

The other type of the eye-tracking system is non-contact equipment which is the most popular and wide used on account of the non-invasion. These systems usually used an infrared sensor or several web cameras to recognize the facial features or the pupil rotation. These non-contact eye movement systems mainly include desktop application

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for the digital screen and wearable application for the moving scene based on the gathered video captured by the micro camera on the glasses or a hat. The desktop application is used with a bar-like equipment for instance Tobii eye tracking system and SMI desktop eye tracking system which have a build-in infrared sensor. Rózanowski and Murawski went through further research which made the sensor more reliable in the harsh environment and also improved the infrared recognition algorithm [4, 5]. Besides the camera video recognition solution was also studied. Hao and Lei got the head and eye rotation data by recognizing facial features [6]. Because the eyes are very near from the front camera of the phone it is easy to recognize the pupil features. Lee and Min got the eye tracking path with the pupil data [7]. More further, Panev and Manolova used the camera and 3D depth sensor to find out the head and eye rotation [8]. In the desktop application mentioned above the infrared and the cameras must be pre-fixed in front of the eye for the algorithm which lead to a narrow field of view, just on the screen. But it can be real-timely interacted as a human-machine interface which could help the disabled even play the game [9]. In the wearable application the eye-tracking system can be used in wide field of view and the data is more accurate because the sensors are just designed on the glasses near the eyes. Also there are also several novel ways to gather the data. Using the specially designed mark points on the glasses and fixed capture cameras Lin et al. got the head gesture data and made it an eye-controlled human–machine interface [10]. In his research the movement of the eye was not considered which made the system only responsible with the head move. While the commercial wearable equipment is well designed like SMI eye-tracking glasses. But all the wearable equipment shows what you are staring at based on the moving video captured on glasses not based on a fixed screen. Such wearable equipment could only be used in the post analysis which is completely on the opposite of the desktop application.

In order to real-timely evaluate the user's SA and tune the human-machine display interface in a train or plane cab, we need to develop a new real-time eye-interaction system. The real-time of the desk application and the wide usability of the wearable application must be integrated together based on the current eye-tracking system. In this method, we could make the machine real-timely get which part you are staring at now and which part you are not noticed for a long time. This research gives the machine a real-time interface and make it possible that the machine can real-timely change the display strategy.

As the concept of awareness situation was defined by Endsley in 1995 [11], the researchers have proposed some method to assess it. In particular, Endsley came up with the situation awareness global assessment technique (SAGAT) which was an objective measure of SA [12]. With our real-time interface the machine could automatically answer the queries to replace the ones needed in the SAGAT during freezes in a simulation. When SA is decreasing to the waring edge, the display of the machine could change their interface to highlight the overlooked information based on the Itti's attention map [13]. According to the SEEV model [14], the machine will improve the non-noticed part's saliency until the user see it.

We wish this unique wearable equipment could be an input interface of the machine to enhance the machine's perception of the user's situation aware and strengthen the machine's dynamic service abilities.

2 System Description

As mentioned above, the core function of the eye-tracking system is to define the head and eye rotation. With the eye tracking glasses, we could get the eye movement and with the motion capture, we could get the movement of the head. Combined with these two devices data with the software SDK, our designed eye-interaction system could get the head line (head gesture) and visual line (considering the eye movement). Meanwhile the system used physical parameters of the screen and device such as the length, height and field of view to calculate the visual point on the digital screen. The algorithm runes processes from the root node of body (the waist joint), the eye point, the head line, the visual line, finally to the visual point on the digital display screen (Fig. 1 shows the algorithm processes 1–5). Every screen need to be calibrated with 3 points to be defined its plane position in the space before used. Our eye-interface system is real-time and wide field of view which could be used as a novel human-machine interface.

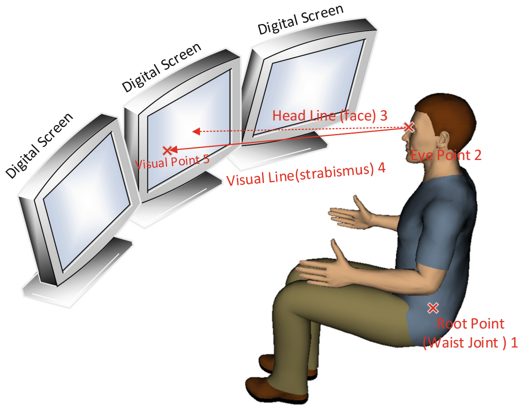

Fig. 1. The spatial relationships between the key control points and the lines. Calculation sequence is from the root point, the eye point, the head line, the visual line, finally to the visual point.

2.1 Root Point and Coordinate Definition

Usually the user of this system is not moving who is standing mostly sitting on the chair such as drivers, pilots and system controller. So the screens location is an invariable data relatively to the user during the use period. In order to construct the algorithm, we set the waist joint of the user as the root point of the coordinate which is not moving during use. Based on the root point we set up the right-hand coordinate system in which the X axis is positive in the forward direction while the Y axis is positive in the left direction and the Z axis is positive in the upward direction (Fig. 2 shows the coordinate).

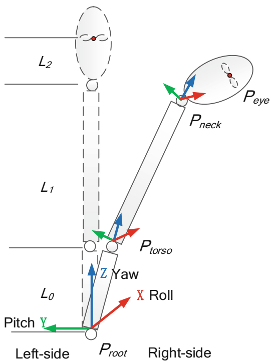

Fig. 2. The define of the key parts of the human segments, coordinate and rotation angles.

2.2 Eye Point and Head Line Calculation

In order to calculate the visual line of the user which need the eye point (the root point of the visual line) and the direction vector of the line. Wearable eye-tracking glasses and motion capture device are the common devices in human analysis. Using the motion caption APIs, we could real-timely get the postures of the key joints. Combined with the joint segment parameters the eye point position relatively to the root point could be calculated.

The size data of the human segments must be pre-given in the process. It contains 3 length size parts between the joints or key points, marking L_0, L_1, L_2. Unusually the motion capture device could provide the postures, marking *Roll(α)*, *Pitch(β)*, *Yaw(γ)*. Specially the rotation data which is gathering from the motion capture device must be defined whether it is a Euler angle in a dynamic coordinate system. It is a big different about the angles definition whether the coordinate rotates every time. Based on the test result the FAB system which is used in this research as the motion capture device provides the Euler angles which are in the dynamic coordinate system by the transform sequence (Z-Y-X Yaw-Pitch-Roll). The rotation angels are positive defined by the right-hand rotation rule.

Based on 3D transform method in the advanced mechanism we could build the rotation transform in the system as matrix-1.

$$
\begin{aligned}
R[x_0, y_0, z_0]^T &= [x_1, y_1, z_1]^T \\
R &= R_Z(\gamma) R_Y(\beta) R_X(\alpha)
\end{aligned}
\tag{1}
$$

Furthermore, we could get the eye point position ($P_{eye\text{-}root}$) by addition of the key control points' position and the head posture rotation matrix ($R_{eye\text{-}root}$) by multiple product of the rotation matrix (Eq. 2).

$$\begin{aligned} P_{eye-root} &= P_{eye-neck}(\gamma_{head}, \beta_{head}, \alpha_{head}, L_2) + P_{neck-torso}(\gamma_{torso}, \beta_{torso}, \alpha_{torso}, L_1) \\ &\quad + P_{torso-root}(\gamma_{root}, \beta_{root}, \alpha_{root}, L_0) \\ &= [x_{eye-root}, y_{eye-root}, z_{eye-root}]^T \\ R_{eye-root} &= R_{eye-neck}(\gamma_{head}, \beta_{head}, \alpha_{head}) R_{neck-torso}(\gamma_{torso}, \beta_{torso}, \alpha_{torso}) R_{torso-root}(\gamma_{root}, \beta_{root}, \alpha_{root}) \end{aligned} \tag{2}$$

Some researchers used the infrared sensors or the cameras to get the head gesture [5–8]. But such indirect accessing method need to recognize the feature of the user which may cause the error of the use because of the difference between the users also leading to the narrow usable viewing field. Nowadays, the motion capture device is tiny, wearable and wireless which provides the direct data of the head gesture. So it is a better choice than the other sensors.

2.3 Visual Line Calculation

In order to confirm the visual line, we need not only the head posture but also the eye movement. So the wearable eye tracking glasses are the best chosen device for the eye movement data. With the help of the glasses' API we could get the relative visual point in the moving video captured from a micro camera on the glasses (Fig. 3).

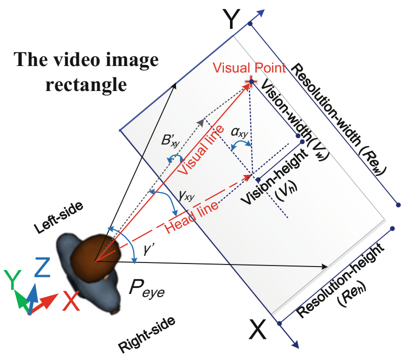

Fig. 3. The spatial relationships between the head line and the visual line. The visual line is obtained by two rotation transformations ($R_Z(\gamma), R_X(\alpha)$).

Based on the proportional relationship between the video resolution and the relative visual point we could get the elevation angle α_{xy}. Using the pre-test data or the glasses' argument list, the video view angle γ' can be defined. Then we could get the polar angle γ_{xy} by the scale calculation. Thus the direction vector of the visual line (Eq. 3) can be defined and the parameter equation of the visual line (Eq. 4) can be calculated from the eye point. After such work the position and gesture of the eyeball have been recorded with 6-DOF data by definition of the visual line.

$$R_{vision} = R_X(\alpha_{xy} = \frac{V_h}{V_w})R_Y(0)R_Z(\gamma_{xy} = \frac{V_w}{Re_w}\gamma')R_{eye-root}[1,0,0]^T$$
$$= [m_{vision}, n_{vision}, p_{vision}]^T \quad (3)$$

$$\begin{cases} x = \lambda m_{vision} + x_{eye-root} \\ y = \lambda n_{vision} + y_{eye-root} \\ z = \lambda p_{vision} + z_{eye-root} \end{cases} \quad (4)$$

In addition, as shown in the paragraph the β'_{xy} is the exact elevation angle which is not used. It is not easy to be measured because of the difficulty of the distance measurement between the eyes and the screen. Some researchers used the 3D depth sensor to get the data [8]. But this solution will decrease the user's usable viewing field also bring the new device to the environment. Others used the physical relationship to calculate the distance [10]. This method need the user not to break the distance by moving the head during the test.

In our research we held the ideas that it was no more device to be involved in except the motion capture device and the eye tracking glasses which made us could not reach the distance data. But we could still succeed in calculating the screen distance with the math method on the next step.

2.4 Screen Plane Calculation

The digital screen is a space plane which is unknown to the base coordinate of the human. There is a commonsense that we need 3 points to define a space plane. In order to locate the screen plane, the designed system will guide the user to focus on the 3 calibrated points on the vertex of the screen rectangle during the calibration process while the 3 visual lines will be recorded in the system as lines equations set (Eq. 5) (Fig. 4).

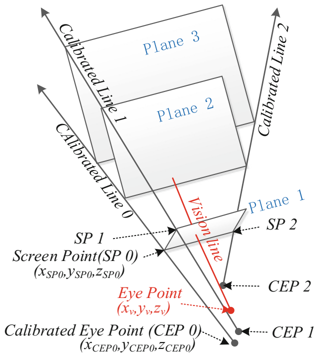

Fig. 4. The key points on the screen SP_0, SP_1, SP_2 are on the 3 calibrated visual lines which were recorded on the guidance of the system when starting. The screen rectangles on the plane 1–3 are the possible solution.

$$\text{CLine*0,1,2:}\{\underline{\lambda_*}|m_{CL^*}, n_{CL^*}, p_{CL^*}, x_{CEP^*}, y_{CEP^*}, z_{CEP^*}\} \quad (5)$$

As mentioned above, we haven't any distance sensor in the system which makes us cannot define the points which the user saw on the screen that is we cannot get the λ_0, λ_1, λ_2 (in the Eq. 5) which leads to various possible planes shown in the Fig. 4. It pushed us to find a new way to achieve the plane equation.

We must import some physical parameters of the screen which are the width and the height of the digital screen to help to confirm the correct plane. Meanwhile, the Line ($\overrightarrow{SP_0SP_1}$) is perpendicular to Line ($\overrightarrow{SP_0SP_2}$). Through these 3 restrictions we could build the equation set (Eq. 6).

$$\begin{cases} \text{Width: } \left|\overrightarrow{SP_0SP_2}\right| = Screen_{width} \\ \text{Height: } \left|\overrightarrow{SP_0SP_1}\right| = Screen_{height} \\ \text{Perpendicularity: } \overrightarrow{SP_0SP_1} \bullet \overrightarrow{SP_0SP_2} = 0 \end{cases}$$
$$\Rightarrow \begin{cases} f_1(\underline{\lambda_0}, \underline{\lambda_1}, \underline{\lambda_2}) = Screen_{width} \\ f_2(\underline{\lambda_0}, \underline{\lambda_1}, \underline{\lambda_2}) = Screen_{height} \\ f_3(\underline{\lambda_0}, \underline{\lambda_1}, \underline{\lambda_2}) = 0 \end{cases} \quad (6)$$

In the equation set we can find there are 3 unknown variables (λ_0, λ_1, λ_2) and 3 equations. With geometrical relationship analysis there is only one solution of the equations. It is a little difficulty that we find solution by manual steps. But fortunately with the help of the computer we could use the existing math software library to find the solution of the equation set. Once we find the λ_0, λ_1, λ_2, we get the 3 key points SP_0, SP_1, SP_2 on the screen and the plane equation (Eq. 7).

$$\begin{aligned} &\text{Normal vector: } \overrightarrow{SP_0SP_1} \times \overrightarrow{SP_0SP_2} = (A, B, C) \\ &\text{Plane: } \mathrm{P}(x_{SP0}, y_{SP0}, z_{SP0} | A, B, C) = 0 \end{aligned} \quad (7)$$

As the algorithm described, the plane equation is based on the root point and the base coordinate. As long as the user don't move the waist position, the head and eyes can move in a wide viewing field during the use which is an improvement than the current equipment.

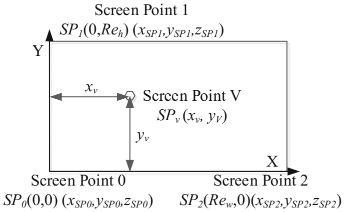

Fig. 5. The screen coordinate is based on the SP_0 point. The SP_1 and SP_2 are the vertices of the screen monitor. Screen point V is the virtual point which the user is starting at.

2.5 Visual Point Calculation

On the premise of getting the screen plane equation, we could calculate the intersection between visual line and the plane which is a point position in the three-dimensional space data ($\underline{x}$, $\underline{y}$, $\underline{z}$) in equation (Eq. 8). As long as we get the parameter $\underline{\underline{\lambda}}$ we get the visual point in space based on the root point.

$$\begin{cases} \text{Plane: } \mathrm{P}(x_{SP0}, y_{SP0}, z_{SP0} | A, B, C) = 0 \\ \text{Visual Line: } \mathrm{L}(\underline{\underline{\lambda}} | m_{vision}, n_{vision}, p_{vision}, x_{eye-root}, y_{eye-root}, z_{eye-root}) = 0 \end{cases} \tag{8}$$

However, we need print the point on the digital screen. That is, we need transform the point from the three-dimensional space based on the root of the human to the 2-dimensional plane based on the screen basic point. Choosing the starting point of the screen image resolution as the base control point we could build a new 2-dimensional coordinate (shows in Fig. 5).

By counting the cross product of the vector and some geometric methods, we could get the physical position of the screen point V (the visual point) which is described by the parameters (unit of length). Then based on the proportional relationship between the physical length and height data of the screen and the resolution of the screen, we could find the exact virtual point (x_v, y_v) (unit of resolution) on the screen and mark it with the software in real time. Pantograph equation shows in (Eq. 9).

$$\begin{cases} x_v = \dfrac{\left|\overrightarrow{MP_0MP_v} \times \overrightarrow{MP_0MP_1}\right|}{\left|\overrightarrow{MP_0MP_1}\right|\left|\overrightarrow{MP_0MP_2}\right|} \times Re_w \\ y_v = \dfrac{\left|\overrightarrow{MP_0MP_v} \times \overrightarrow{MP_0MP_2}\right|}{\left|\overrightarrow{MP_0MP_2}\right|\left|\overrightarrow{MP_0MP_1}\right|} \times Re_h \end{cases} \tag{9}$$

2.6 Data Synchronization

A wide viewing field eye-interaction system require synchronizing all the controlled digital screens. A data synchronization module was developed to estimate whether the computational visual point was on one of the screens. It is a center design which processes all data and records the eye-tracking path.

In order to indicate the visual point, the system will send commands to the sub-module in the screen and mark the point on the interface. Also with the enough restricts or importing in advance the system could synchronize that point on the control desk. For example, the button or the indicator on the driver's desk could light up in specific color to indicate you are staring at it.

3 Application

SA is a word for the human which includes 3 levels (perception, comprehension and projection) [11]. The system is designed to real-timely get the visual point which the user is staring at. With the help of the designed eye-interaction system we could calculate the user's perception. The information was divided into different important levels(*IL*). The sum of all the information importance score is 100. Once one information is changed in the display interface, the score will reduce the corresponding value (*ILc*). Once the user notices the information the score will recover the corresponding value(*ILn*). We set the starting score 100 as the best SA perception (SA_P-). And the current SA perception could be defined in Eq. 10. When the SA_P is under the warning level (60 scores). The system will highlight the information which have lost focus for a long time and whose important level is high.

$$SA_P^{N+1} = SA_P^N - \sum\nolimits_i ILc_i^{N+1} + \sum\nolimits_i ILn_i^{N+1} \big| \, SA_P^0 = 100 \tag{10}$$

The attention map could be calculated by the Itti's model [13] when the user is starting at a point on the screen. We could cumulate saliency-based visual attention rate with the elapsed time in Eq. 11. The $\bar{S}$ is the average number of the attention saliency rate during a task with the time t_e. The information area of interest is A_0 to A_i. The IL_A is the importance level of the area. The function $\delta(A, t)$ is the attention saliency intensity of the area A at the time t. Considering the SEEV model [14] the user will take less effort to see the salient area which means the less $\bar{S}$ is the better.

$$\bar{S} = \frac{1}{t_e} \sum\nolimits_{A=0}^{A_i} IL_A \int_{t=0}^{t_e} \delta(A, t) dt \tag{11}$$

With the dynamic saliency readjustment based on the SA_P and $\bar{S}$, the machine will enhance the perception of the human and offer the better service.

4 Further Work

The algorithm is an exact solution of the virtual point in mathematics. The core difficulty of the algorithm is to find the root of the ternary quadratic equation set in (Eq. 6). Through the complex spatial analysis, we could know it is only one reasonable solution. But there is also an unreasonable solution in the negative direction of the axis. Also we could only use the computer math tools to find a numerical solution, which leads to some uncertain solving process.

Furthermore, as we known applying the computer math library to solving the root is a kind of numerical calculation. So the numerical stability of equation must be considered. Also it will take time to real-timely solve the root which brings the delay to the system. If it had some way to reach the exact solution of the equation set with a mathematical expression, the problem will be solved satisfactorily.

In addition, the algorithm includes a lot of steps which may bring the error added up. The error analysis is a lot of work. Maybe it is possible to simplify the algorithm by assuming the calibrated eye points are in the same position (CEP_0, CEP_1, CEP_2) (shows in Fig. 4). With such work the Eq. 6 will be simplified and easily be solved.

For further simplification, we can assume the eye point also in the same position which will simply the Eq. 8. It will be a great save of calculated amount of the algorithm. But the error must be calculated to show whether it is in an acceptable range with such simplified calculation model.

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Wearable Technologies: Accessibility, Wearability and Applications

Accuracy and Efficiency Validation of a Helmet Mounted Vibrotactile Feedback System for Aerodynamic Head Position During Cycling

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Abstract. A pilot is presented to evaluate a helmet mounted vibrotactile feedback system (VFS) for managing head position during cycling by feedback to a subject when its head deviates from a preset aerodynamic position. The VFS measurements are validated with a Vicon motion capturing system. The effect of the VFS is compared with verbal instructions only. In 89.66% (P = 0.15) of all measurements, the VFS value is in accordance with the Vicon system. In 83.33% of the cases, the sensor correctly leads the subject to the predefined position after perturbation of the position. Changing the margin of error of VFS has little influence on the improvement of attaining the predefined position. The sensor accuracy and efficiency of retaining or resumption the predefined reference position indicates that it can be usable for time trialists, triathletes and track cyclists in attaining their aerodynamic head position.

Keywords: Vibrotactile feedback · Posture management · Cycling competition

1 Introduction

More and more professional cycling athletes aim to optimize their cycling equipment and posture, in addition to their conditional performance, as every second may lead to success or failure. During high speed cycling (>30 km/h), aerodynamic drag becomes the main force cyclists need to overcome [1]. So, most gain in profit can be obtained by optimizing aerodynamics under the retention of biomechanical efficiency. The optimal aerodynamic position can be measured, for example in a wind-tunnel [2–4]. Body fit systems for time trial cycling aim at guiding a cyclist towards that optimal aerodynamic cycling position. These body fit systems mainly focus at showing cyclists how to

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minimize their frontal area as an indicator for aerodynamic drag, but only work offline and focus on monitoring, where feedback is provided after a practice session by a coach. During cycling, the athlete does not have guidance.

In this research, a vibrotactile feedback system (VFS) that allows monitoring and steering head position during cycling in real time is evaluated for accuracy and efficiency. The system provides cyclists with acoustic and vibrotactile feedback when they deviate from a pre-set optimal cycling position, such that they are guided towards that position, in which no feedback is given. The VFS is a commercially available inclination sensor from Lazer Sport NV. The VFS provides the first such solution on real time posture steering, and has the purpose to retain the ideal head position on a bike. The VFS is attached to the helmet and can be calibrated towards a desired head position. The VFS alerts the subjects when they deviate too far from the optimal position, mostly occurring when fatigue sets in. This innovation might be especially beneficial for time trialists, triathletes and track cyclists, where air resistance has the most considerable impact on performance [5].

2 Materials and Methods

Participants. Atotal of nine test subjects are assessed. Healthy subjects without any professional cycling experience are included as their potential learning curve is still to be initiated. The subjects are recruited in the researcher's network. The participants are four men and five women. Eight of the test subjects are in the age interval of 21–24 years and the other one has an age of 42.

Ethical Approval. Ethical approval was obtained from the ethics committee of the Antwerp University Hospital and the University of Antwerp (reference number: B300201629562). Informed consent was obtained for all subjects.

Test Helmet. The same helmet (Lazer Wasp) was used for all subjects. The helmet has an aerodynamic design that reflects actual conditions of use. The size of the helmet can be adjusted by making the straps smaller or bigger to ensure a perfect fit for every test subject. Four infrared markers were fixed on top of the helmet, using double sided tape, as displayed in Fig. 1. Two markers (C and D) are used for calculating the reference inclination vector, the other two markers (A and B) only have a control function.

Vibrotactile Feedback System (VFS). The VFS is a commercially available inclination sensor from Lazer Sport NV [6]. Test subjects wear the test helmet equipped with the VFS to register data on head tilt and to provide feedback accordingly. The sensor measures the angle between the user's current position and the horizontal line (0°), which is represented as a value between −180° and 180°. A predefined reference angle can be set manually by holding a calibration button. Both vibrotactile and acoustic feedback are provided when deviating from that ideal angle (Fig. 2).

A bandwidth from 1° to 45° can be set to give the subject a margin of error around the ideal head angle position. In this experiment, head correcting performance for three different bandwidths 4°, 8° and 12° were assessed. The inclination angle of the helmet, and therefore also of the head, is measured in a 3D work plane with an accuracy

Fig. 1. Placement of markers on the Lazer Wasp helmet. Four infrared markers are scattered throughout the length of the helmet in one line. Markers are indexed A to D from front to back.

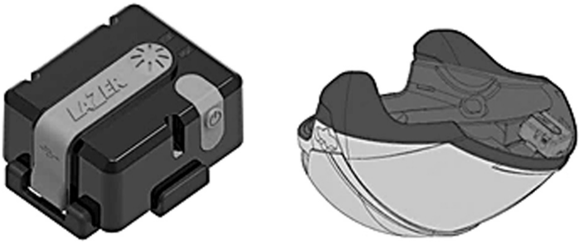

Fig. 2. Left: VFS device. The light-coloured buttons can be used to activate the sensor and to calibrate to a desired reference position. right: VFS fastened on a helmet. This is possible at one position, in two directions by the straps on the bottom of the sensor [6].

interval of ±2°, according to the manufacturer's specifications. The feedback intensity increases with increasing deviation from the ideal position. In addition to the inclination angle, the sensor also registers an X, Y and Z coordinate, however not used as feedback input control. The sample rate of the sensor is 12.5 Hz.

Testing Procedures. The accuracy and applicability of the VFS are tested in the M^2OCEAN movement analysis laboratory at the Antwerp University Hospital. During the experiments, infrared markers attached to the helmet (as in Fig. 1) are registered by the motion capture system Vicon with an accuracy of at least 1°. Eight infrared Vicon T10 cameras record all movements of the infrared markers on the helmet. A video camera films the entire experiment in the visual spectrum, to facilitate the interpretation of the results and make more accurate analyses.

Subjects are riding on a race bike stationary positioned on rollers, wearing the test helm. The saddle height is adjusted so that the person can take a comfortable position [7]. A limited resistance is imposed to simulate real physical effort. Placing a block under the front wheel, the bike reaches the horizontal position to correct the height of the back wheel due to the rear wheel rollers.

The VFS is set at a conveniently attainable angle that remains constant throughout the entire experiment. Subjects initially attain the predefined posture actuated by the

VFS. Then they are instructed to remove from that predefined position, after which they resume their position, whether or not steered by the VFS.

Each experiment exists of three consecutive such phases where the posture is altered during cycling. Every test step in each phase is repeated three times.

In the first phase, the subject only moves his or her head while instructed to fixate the upper body. In the second phase, the subject only moves the trunk while instructed to hold the relative position of the head constant. In the third phase, the subject freely moves both head and trunk. In each phase, the subjects were asked to alter their head and trunk position accordingly and return subsequently to the reference position, receiving either or no feedback from the VFS. Under no feedback condition, subjects were instructed only once to attain their initial position. They did not receive any other feedback on their initial position All subjects did four trials, namely for bandwidths of 4, 8 and 12° and the same experiment without feedback from the VFS to determine the ability to maintain a predefined posture. The sequence of the conducted trials with and without feedback was randomized in every test subject.

Analysis and Statistics. The inclination angle of the VFS was stored and exported for processing. The VFS error was examined by comparing its value to the angle derived from the markers on the helmet, tracked with Vicon. The data from Vicon and VFS were synchronized. For each subject, the reference position was retrieved manually from the measured data, as the value in which the angle derived from Vicon is substantially constant, displayed in the shaded part Fig. 3. Firstly, the deviation from the mean value of the VFS is calculated in this reference area as a systematic error.

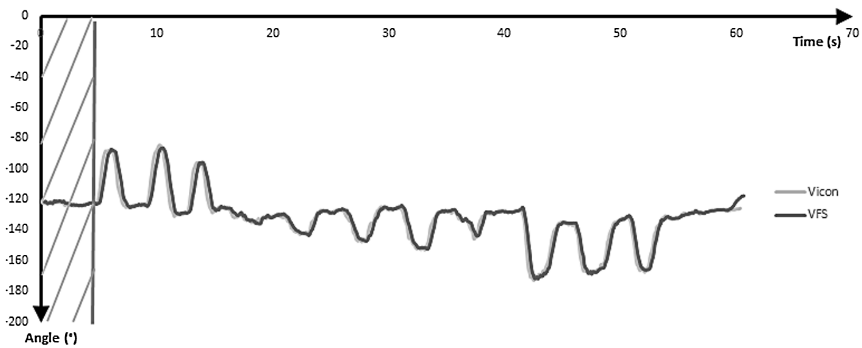

Fig. 3. Graph plot example of the no feedback experiment of subject 6. Inclination angle is observed in function of time. Both VFS and Vicon values are plotted on the same graph. Firstly, the subject takes the predefined position (shaded part to vertical line). After this, three repeats of three moving parts (head, trunk, head + trunk) are visible, where the subject in between each case returns to the reference position.

Secondly, both VFS and Vicon graphs are plotted on each other corrected by this systematic error. It was noted that the VFS gives a noisy signal. For comparisons, the signal was averaged over nine measuring points (0.64 s) to obtain a smoothed graph of head angle as function of time (as in Fig. 3). Vicon and VFS values were then compared with Blant-Altman (B&A) plot analysis and the intra-class correlation coefficient model 2.1 (ICC). ICC was calculated for example subject 6. This method was used as an indicator because this measurement only depends on the VFS and not on the subjects themselves. Possible errors in VFS measurements were investigated by using the B&A plot analysis, which gives an indication of the relation and clinical differences between VFS and the gold standard Vicon. Confidence intervals for 95% limits of agreement for the differences were calculated to determine systematic differences or possible errors of the VFS [8]. SPSS version 24.0 Chicago was used for statistical analysis. Using a paired samples T-test, mean differences as well as standard deviations, confidence intervals and significance levels are known.

In Fig. 3, the three repetitions of every test are visible. In between two alterations, the subject always returns to the reference position. In this way, inclination vectors of the test subject's posture before and after altering the posture were compared. As the VFS provides feedback that helps maintaining the predefined posture, the posture after perturbation will be within the margin of error compared to the one before. During these reference periods, the average inclination angle is calculated to eliminate deviations and to control the efficiency of remaining the position within the bandwidth of allowable error. The minimum and maximum value of all average reference angles were subtracted for every subject.

Lastly, the influence of the vibrotactile and acoustic feedback compared to a single instruction was investigated. Minimum and maximum values in the latter reference period were to the feedback measurements (4°, 8° and 12°). Results from all nine subjects were analyzed in a One-Way ANOVA test and studied in detail using Tukey Post-Hoc tests.

Subjects were asked to complete a questionnaire after the experiments to evaluate the applicability of the VFS. Subjects were inquired on usability in real life applications and perception and disturbance of the vibration and acoustic signals on a 6 point Likert scale (0 to 5).

3 Results

By plotting VFS and Vicon inclination angles in function of time, outliers are excluded. For subject 1 and 9, the experiment without feedback were incomplete and omitted.

To check the accuracy of the Vicon measurements, the sensor is held two times in a fixed position and standard deviation of this experiment is evaluated. The average standard deviation of this two repeats is 0.34°, which is smaller than the allowed deviation of the system of 0.5° and confirm the use of the Vicon mocap as gold standard.

After this, inaccuracies of VFS measurements are determined. The average deviations from the mean value of the VFS for all experiments is 2.86°, SD = 1.35°.

The VFS sensor is further evaluated for accuracy, efficiency and gain of feedback.

Accuracy. A B&A plot between Vicon and VFS is displayed in Fig. 4, i.e. difference of VFS and Vicon values in function of the average values of Vicon and VFS. Values are calculated for subject 6, but similar results are expected for any other subject. The

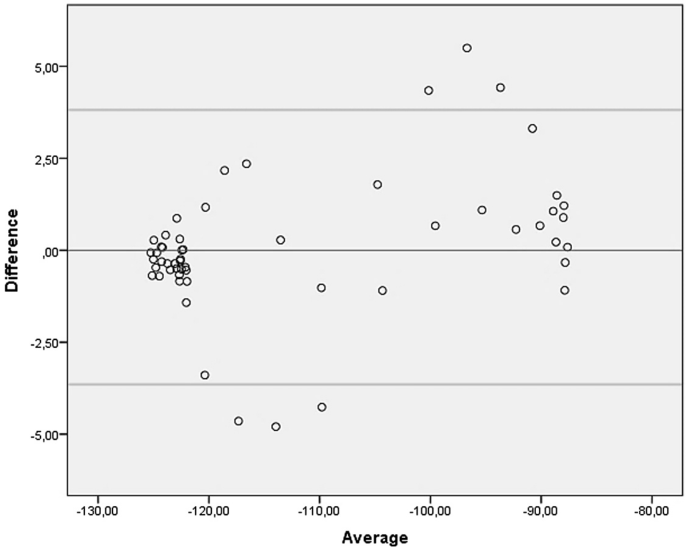

Fig. 4. B&A plot analysis of VFS and Vicon measurements retrieved from the first peak in Fig. 3. The plot shows differences between VFS and Vicon (Y-axis) in function of fluctuations displayed on the X-axis (average of VFS and Vicon).

average on the x-axis is calculated as (Vicon + VFS)/2 from Fig. 3 for the first peak value. The difference on the y-axis is Vicon−VFS for the same area. The middle dark line shows the mean difference, while the lighter outer lines represent the 95% limits of agreement (mean value ± 2SD). The highest agreements are found at values where the VFV is stable (around 120°). The ICC of the example of subject 6 is 0.99 ($P \leq 0.001$).

The accuracy analysis is accomplished with the paired samples test for the shaded reference position (Fig. 3) in the beginning of experiments as well as for whole experiments. In 96.55% of cases at the beginning of experiments, the VFS is accurate compared to the reference system Vicon (acuracy of 1°). For the whole experiment, the VFS is accurate compared to the Vicon reference in 89.66% of cases.

Efficiency. Table 1 summarizes maximal differences of the average values in the reference position time slots, for the different types of feedback. This table shows the average difference for all subjects as well as the related standard deviation.

Table 1. Efficiency VFS. Average differences and standard deviations for all forms of feedback are showed. Values are averages of the nine subjects.

Bandwidth	Average difference ± SD (°)
12°	12.94 ± 6.05
8°	8.60 ± 4.65
4°	8.16 ± 4.68
No feedback	10.60 ± 3.24

For 12° feedback, 100% of the test subjects stay in between the extreme boundaries, for 8° feedback one subject exceeds the margin of error and for 4° feedback 66.67% attain the reference position correctly. On average, the VFS steers the subject in 83.33% of experiments to the correct position.

Reactions to Feedback. As expected from Table 1, there is no significant difference in feedback from the VFS compared to the no feedback experiments ($P = 0.77$). Also in between feedback groups 4°, 8° and 12° there is no significant difference in margins of error. A person does not attain sooner the reference position with lower bandwidth (although receives feedback sooner), and does not attain the position significant more accurately for lower bandwidths. In the protocol, subjects attained perturbed and reference positions only for a few seconds. To pinpoint bandwidths and assess benefits from actual use, longer periods have to be taken into account.

Questionnaire. The questionnaire indicates a few remarks from the subjects. Acoustic feedback is perceived as a buzz, while it is meant to be received as beeps. Furthermore, Vibrations are not felt during the effort, but subjects perceived the vibrations as an auditory signal. Generally, the subjects thought that they retained their position very well. Subjects confirmed that the sensor works for head position as intended. By altering trunk position the sensor does not give desirable feedback.

All subjects said the VFS is useful and will help better retain or resume a position. Half of the test subjects thought that they also can retain their reference position without receiving feedback. Three people out of the nine subjects found the vibrations absolutely not perceivable, especially the intensity is noticed as quite low, while the vibration frequency is considered as acceptable. Also, three subjects perceived the vibrotactile cues as annoying, compared to only one person for the acoustic feedback. The acoustic feedback is generally considered as better to interpret. However, three subjects declared that the used intensity and amplitude is not ideal. Only four subjects considered the combination acoustic-vibrotactile feedback as an added value.

4 Discussion

Both B&A analysis and ICC indicate the accuracy relation between Vicon and VFS. Looking at the 95% limits of agreement around the mean difference (Fig. 4), most outliers perform for peak values on the right side of the plot. The similarity between both values is less accurate in this area.

For critical analysis of the sensor accuracy, P-values larger than 0.05 are considered as significant. Results with an absolute average in difference between VFS and Vicon lower than 1° are clinically not significant, due to the accuracy of ±1° of the Vicon system. When the P-value is lower than 0.05 and the mean absolute difference is higher than 1, measurements are considered as inaccurate [9]. The VFS is always accurate for the reference position at the beginning. When looking at the whole experiment, four out of nine subjects delivered P-values lower than 0.05, but all 95% confidence intervals are within absolute value of 1°, so these four cases can be considered as clinically irrelevant. The sensor is less accurate for fluctuations in the movements than for static movements, but still stays accurate. In general, the sensor can be considered as reliable in measuring head angles.

For 12° feedback, all subjects attain their reference position. For 8° feedback, the subjects comes out of the feedback margin in few cases, but generally this bandwidth is wide enough. Only for 4° feedback, the subject comes more out of the error range, namely in 33.3% of the cases. Looking at the average deviation of 2.86°, SD = 1.35 and the confidence intervals for 95% limits of agreement of B&A, some VFS measuring points will go out of the 4° boundary. Thus, for the 4° feedback setting the sensor will sometimes give feedback for adjustment to the subject while this is not required, i.e. the subject is located within the boundaries. This can be confusing for the subject and results in more errors and more out of bandwidth measurements [10]. For future applications, bandwidths of 5° are most recommended on the basis of average deviation ratios.

A striking outcome is that there is no better retaining of the reference position by the VFS compared to experiments without feedback. This may be due to the short experiment times where subjects pay attention to their posture and the fact that in no feedback mode, subjects are instructed to retain that position, whereas with the VTF system, subjects are guided, without taking account of their reference position. During outdoor racing, subjects will not be aware of their posture and especially pay attention to the race itself [11]. In this case the VFS will be more helpful, which should be tested in a different study design.

From the questionnaire, improvements for better perception of feedback signals are recommended. Vibrotactile and acoustic cues are not always perceived properly by all subjects. Feedback intensity could be changed for better detection. Signals are indicated as annoying, but this might decrease by habituation, when often using the sensor. The utility of the VFS as a head-correcting device is shown in the experiment and is qualitatively affirmed by the participants.

5 Conclusion

This study validated the VFS in terms of accuracy and efficiency for retaining a predefined head position on a bike. Regarding the results, it can be concluded that the sensor is effective for use in outdoor racing. A margin of allowable error of 5° around the reference angle is recommended, as a bandwidth in which subjects receive no feedback. This bandwidth is function of sensor accuracy and might be smaller as sensor accuracy increases. Similar applications could be investigated to monitor and steer the whole body of cyclists. This, in combination with the VFS, may improve retaining aerodynamic position while cycling and may progress the performance of professional cyclists.

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The Pressure Comfort Sensation of Female's Body Parts Caused by Compression Garment

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Abstract. The garment pressure comfort sensation was studied in the paper. The garment pressure comfort threshold was defined and calculated according to staircase method of psychophysics. In experiment, 10 subjects were employed in sensory tests and pressure measurements. A novel stretchable compressive belt was designed and developed, which was used to control the pressure applied on separate body parts by its extension and intention, and the subjects judgment and pressure monitor were recorded in times. Finally, the comfort thresholds at 13 separate body parts were investigated. This study provided proper comfort pressure range to human body for developing compression wear.

Keywords: Garment pressure sensation · Comfort threshold · Human fators · Clothing ergonomics

1 Introduction

Compression garments are used for operational reasons such as tight-fitting garments or girdles, or medical reasons such as the medical stockings or bandages for treatment venous ulceration, deep vein thrombosis or burns [1]. The term of garment pressure is one of important factors to evaluate the performance of comfort, function, and security of compression garment. Pressure from compression garment onto human body should be in an appropriate range. Insufficient pressure will limit its efficiency and perhaps reduce aesthetic appeal of the garment, while too much pressure will result in feeling of fatigue and reduce heart, lung as well as bowel function for the wearer, thus may lead to serious damage to health [2–4].

One of key technologies of compression garment industry is to build evaluation system on pressure comfort. At present, there are four mainstream evaluation systems were built up from different research groups, i.e., 'objective clothing pressure' [5–7], 'subjective psychological response' [8], 'physiological response' [9, 10] as well as interrelationship between pressure and psychological/physiological responses [11].

The subjective evaluation on garment pressure comfort relies on individual psychological feeling on pressure and pressure values were measured by certain pressure

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measurement system. Makabe et al. carried out a series of sensory tests and pressure measurements while subjects wearing various brassiere samples, which were different in shape, material, pattern, etc. [12]. Ito et al. clarified effects of mean pressure on compressive sensation of women's underwear. They concluded that total compressive sensation and comfort of long or half sleeve underwear were respectively related to its compression on back, chest, abdomen, upper arm and forearm. Several research groups studied relationship between compressive waistband and pressure sensation [13]. Mitsuno et al. analyzed the relationship between waistband-pressure and pressure sensation under various respiratory and posture conditions. A significant pressure difference was found between left and right sides of bodies when subjects moved asymmetrically in relation to median line [14]. Hideko and Saito compared pressure sensation of young and middle-aged subjects when garment pressure generated by a belt was applied to abdominal region. They observed that those who were in middle-aged group felt "loose" in anterior waist and felt "tight" in lateral waist [15]. In the region of anterior waist, fat difference between the two subject groups was markedly large, while the difference was small in the region of lateral waist. Nakamura et al. examined the influence of pressure intensity and width of belt on compressive feeling and sensitivity of abdomen. They found that compressive sensitivity was higher when belt's width was wider and this tendency was especially remarkable when belt width was in the range of 3 to 10 cm [16].

Sensitivity variation from one region to another on human body is another striking aspect of pressure sense. Weinstein tested absolute touch threshold and threshold difference through applying a small rod or hair to skin surface. They found that the pressure sensation was non-uniform regarding to sex, laterality, and body part. Women were more sensitive than men in terms of touch sensitivity, as well as significant laterality differences were existed, some body parts were significantly better on right, others were significantly better on left for these measures [17].

Due to compression garment difference and subject sensation diversity, the credibility of previous research conclusions is not convincing enough and it is very hard to repeat their research result. Therefore, it is still important to build a scientific and precise evaluation system on pressure comfort. In the study, pressure comfort threshold was defined and calculated by introducing staircase method of psychophysics.

Pressure comfort threshold is a feeling boundary between comfortable and uncomfortable. When wearing compression garment, if garment pressure is in appropriate value/range, human body will feel comfortable. Then increase garment pressure gradually to a critical point where feeling changed to uncomfortable. The critical point of pressure value is defined as pressure comfort threshold.

It is preliminary exploration in the application of psychophysics in evaluation on pressure comfort and difference thresholds, in order to lay the foundation for seeking more scientific and precise staircase-method-based evaluation on garment pressure sensation and discrimination. This study will provide proper comfort pressure range to human body for developing compression wear.

2 Experiments

2.1 Subjects

Ten healthy female college students were employed in the pressure sensory test (mean age: 22 ± 2 years, height: 160 ± 7 cm, weight: 56 ± 6 kg). Table 1 shows the subjects' anthropometric parameters. The experimental protocol was informed, and consents were obtained from all subjects prior to undertaking the study.

Table 1. The subjects' anthropometric parameters.

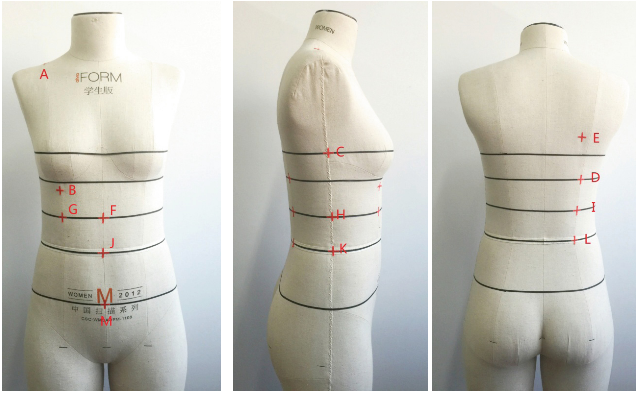
Subject no.	BMI (kg/m^2)	Chest girth (cm)	Waist girth (cm)	Hip girth (cm)
1	21.87	85.0	70.0	99.0
2	23.73	95.7	82.0	100.6
3	27.10	100.0	77.0	100.0
4	20.25	82.1	77.2	95.1
5	22.15	88.1	73.3	100.0
6	18.87	87.4	71.8	93.1
7	20.93	91.0	70.9	93.6
8	21.23	90.6	73.2	97.5
9	20.70	84.0	64.0	91.0
10	19.65	78.0	62.0	86.0
Mean	21.65	88.2	72.1	95.6
S.D	2.35	6.49	6.00	4.75

2.2 Pressure Sensory Test

Compression was examined using Air-pack type contact pressure sensor (AMI TECHNO CO., LTD, Japan) and a multichannel measuring system, Fig. 1 shows the pressure measurement system. The pressure sensor has a circular, flexible probe (pressure measurement range: 0–35000 Pa; precision: ±100 Pa) at one end. The compressive belt was well designed by elastic band and 2 metal rings, which could make the applied pressure gradually increase as its extension. The elastic band is knitted by polyester fiber and spandex, with width of 10 cm, thickness of 1.2 ± 0.1 mm, and its elastic recovery is around 96.1% at extension of 60%.

Fig. 1. The pressure sensory test: (a) pressure measurement system; (b) compressive belt.

Totally 13 different body parts below waistline were tested for pressure comfort threshold, shown in Fig. 2.



Anterior Lateral Posterior

Fig. 2. The pressure sensory part: (A) middle shoulder; (B) underbust; (C) armpit; (D) where underbust line and scapular line cross; (E) scapula; (F) anterior center of empire line; (G) anterior lateral of empire line; (H) lateral empire line; (I) where empire line and scapular line cross; (J) anterior center of waistline; (K) lateral waistline; (L) where waistline and scapular line cross; (M) abdomen.

2.3 Testing Method and Procedures

Subjects were required to complete identical 3-hour standing measurements. For 24 h before attending testing, the subjects were required not to engage in heavy physical labor, or strong exercise, and to ensure they had enough sleep and kept to their regular routine. They were asked to eat food at least 2 h before commencement, and at least 30 min before signing in lab. The measurements were conducted in Clothing Ergonomics Laboratory, with the room temperature of 20 °C ± 3 °C and relative humidity of 65% ± 5%.

Based on the staircase method of psychophysics, the comfort threshold testing sequences were designed. Six alternating ascending and descending determinations were made at each site. For example, the data sheet for subject 4 on underbust part was listed in Table 2. The symbol "+" stands for feeling comfortable while "−" stands for feeling uncomfortable.

Table 2. Pressure comfort threshold test data sheet for subject 4 on underbust (B).

Up sequence		Down sequence		Up sequence		Down sequence		Up sequence		Down sequence	
Pressure (Pa)	Comfort (±)	Pressure (Pa)	Comfort (±)	Pressure (Pa)	Comfort (±)	Pressure (Pa)	Comfort (±)	Pressure (Pa)	Comfort (±)	Pressure (Pa)	Comfort (±)
630	+	1340	−	690	+	1040	−	560	+	970	−
960	+	1200	−	800	+	940	−	720	+	820	−
1160	+	970	−	930	−	810	−	840	−	710	−
1240	−	820	+			720	+			630	+

Firstly, wearing compressive belt, subject was required to feel the changeable of pressure while belt was stretching gradually until cannot bearing it any more, then loosing belt until the subject felt no pressure. Secondly, pressure sensor was fixed on the measurement position, shown in Fig. 3, measurements on shoulder and anterior center of empire line for example. Thirdly, the pressure sequences were started to carry out in orders. Application of different levels of pressure to the body can provide different levels of comfort. The comfort status changed accordingly pressure increasing gradually. When the subject responded of uncomforting, increasing pressure a little bit, then decreasing the pressure gradually, as soon as the status changes to comfort, continue to decrease the pressure a little bit, then increase pressure again. The test sequences were repeated for 6 times, the comfort pressure threshold was obtained by averaging the garment pressure on the status changing at each test sequence, which was calculated by Eq. (1).

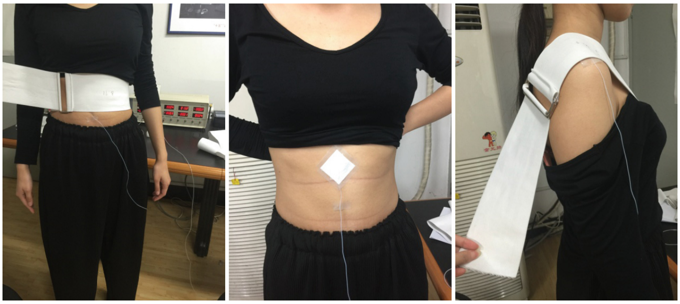


Fig. 3. The measurements on shoulder and anterior center of empire line.

Pressure comfort threshold

$$= \frac{\left(\frac{1160+1240}{2} + \frac{970+820}{2}\right) + \frac{800+930}{2} + \frac{810+720}{2} + \frac{720+840}{2} + \frac{710+630}{2}}{6} = 863\text{Pa} \quad (1)$$

3 Results and Discussions

Calculating pressure comfort threshold for each measurement site, the results were analyzed and discussed in the following section.

3.1 The Distribution of Pressure Comfort Thresholds

The Mean Value in Pressure Comfort Threshold of Subjects. Figure 4 shows the mean pressure comfort thresholds of all subjects at different measurement sites, the pressure sensation varied dramatically at different body parts.

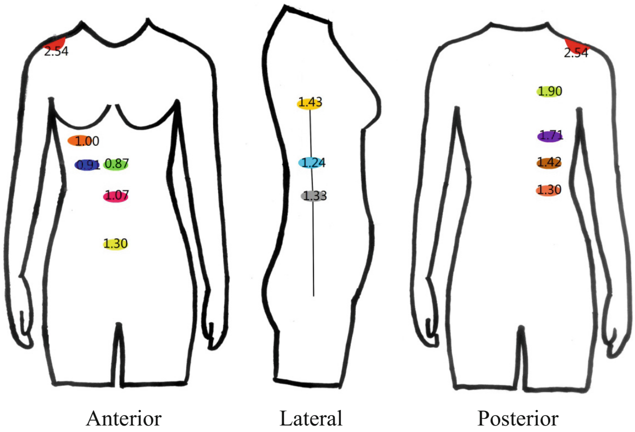


Fig. 4. The distribution of mean pressure comfort thresholds.

It can be seen, first of all, that the maximal comfort threshold is in the middle shoulder (A), 2540 Pa. Scapula and where underbust line and scapular line cross tend to rank next in comfort threshold values, 1900 Pa, 1710 Pa, respectively. Followed by the where empire line and scapular line cross (I), lateral waistline (K), where waistline and scapular line cross (L), abdomen (M), and lateral empire line (H), 1430 Pa, 1420 Pa, 1330 Pa, 1300 Pa, 1300 Pa, and 1240 Pa, respectively. Finally, the minimal values in comfort threshold tend to anterior center of waistline (J), underbust (B), the anterior lateral of empire line (G), and anterior center of empire line (F), 1070 Pa, 1000 Pa, 910 Pa, and 870 Pa, respectively.

3.2 The Variation of Comfort Threshold on Circumference or Vertical Direction

The distribution rules of pressure comfort thresholds on same circumference or vertical directions are summarized, shown in Fig. 5, 6, 7 and 8.

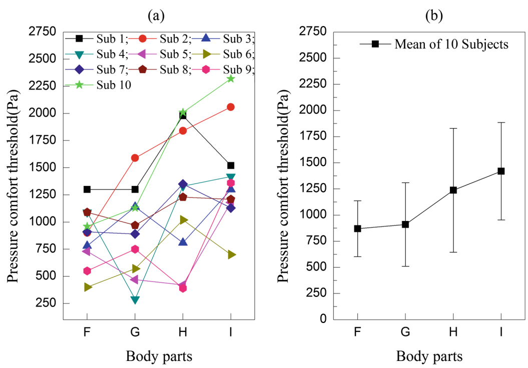


Fig. 5. The comparison of pressure comfort thresholds on empire line.

F, G, H and I, is the part on anterior, anterior lateral, lateral, and posterior lateral empire line, respectively. As shown in Fig. 5, the comfort threshold gradually increases from anterior to posterior.

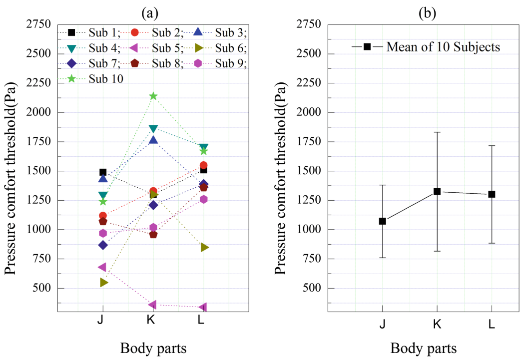


Fig. 6. The comparison of pressure comfort thresholds on waistline.

J, K, and L, is the part on anterior, lateral and posterior lateral waistline, respectively. As shown in Fig. 6, the minimal value in comfort threshold is on anterior part, similar ones are on the lateral and posterior lateral waistline.

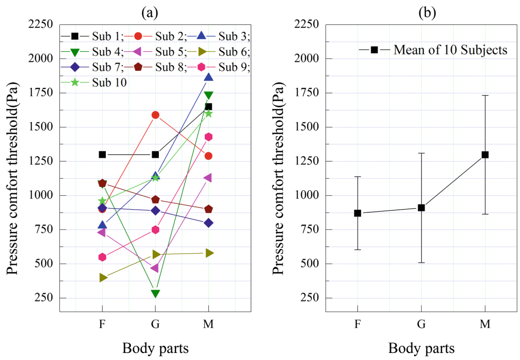


Fig. 7. The comparison of pressure comfort thresholds on anterior center line.

F, J, and M, is the intersection of center line and empire line, waist line, and abdomen, as shown in Fig. 7, the comfort threshold gradually increases from top to bottom.

D, I, and L, is the test part on posterior Princess seam, respectively, E is the scapula part, as shown in Fig. 8, the comfort threshold gradually reduces from the top to bottom.

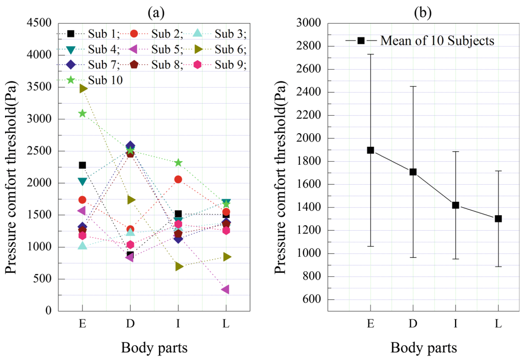


Fig. 8. The comparison of pressure comfort thresholds on back.

According to the above analysis, we can sum up the two rules:

(1) On the same circumference direction, the garment pressure comfort thresholds: back > side seam > front;
(2) On the same vertical direction, pressure comfort thresholds increase with the drop of height on anterior center line, while decrease on princess seaming.

3.3 The Variation in Pressure Comfort Threshold of Individuals

Variations in pressure comfort thresholds among subjects are remarkable. The pressure comfort thresholds of 10 subjects on each test part are depicted in Fig. 9. We can see that the subjects 3 and 10 in the outermost position or the periphery, while subjects 5 and 6, basically in the innermost. The results mean that subjects 3 and 10 have stronger ability to withstand pressure, but the ability to withstand pressure was lower for subjects 5 and 6.

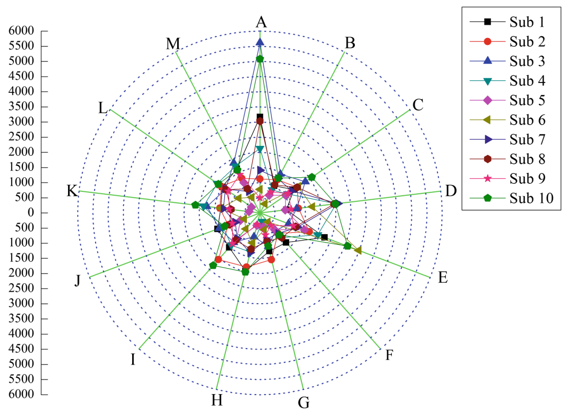


Fig. 9. The pressure comfort thresholds for all subjects on each test part.

Figure 10 shows the comfort threshold and the standard deviation of each test part. The discrete degree on shoulder midpoint (A) is very large, the degrees on test parts of B, C, F, and J are lower, close to its mean value, mean that the pressure comfort threshold difference on the four test parts for the subjects is small.

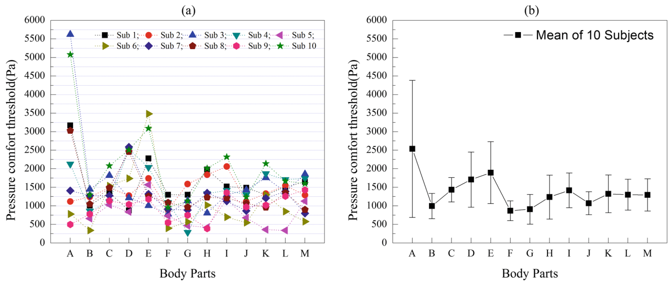


Fig. 10. The variation in pressure comfort threshold of test parts.

4 Conclusions

The garment pressure comfort threshold was defined and calculated according to staircase method of psychophysics. In experiment, 10 subjects were employed in sensory tests and pressure measurements. A novel stretchable compressive belt was developed, which was used to control the pressure applied on separate body parts by its extension and intention, and the subjects judgment and pressure monitor were recorded in times. Finally, the comfort thresholds at 13 separate body parts were investigated. The results were summarized as below:

(1) There are obviously variations in pressure comfort threshold among different body parts, which means that these parts differed greatly in pressure sensation. Higher values appear at the positions of bone-next-to-skin, such as shoulder, and etc., while the lower values appear at the positions of remarkable fat accumulation regions such as lateral waist and abdomen, medium values appear at the parts with muscle layer distribution between skin and bone.
(2) On the same circumference direction, the garment pressure comfort thresholds: back > side seam > front; On the same vertical direction, pressure comfort thresholds increase with the drop of height on anterior center line, while decrease on princess seaming.
(3) Variations in pressure comfort thresholds among subjects and body parts are remarkable. Large discrete exists at mid-shoulder position, other parts are relatively concentrated in a certain range.

It is preliminary exploration in the application of psychophysics in evaluation on pressure comfort threshold, in order to lay the foundation for seeking more scientific and precise staircase-method-based evaluation on garment pressure sensation. This study will provide proper comfort pressure range to human body for developing compression wear.

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Universal Design Based Evaluation Framework for Design of Wearables

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Abstract. In our previous study, we have reviewed the existing criteria from different design domains that seem as relevant for the design and assessment of the wearables. Our next goal is developing a Universal Design-based assessment framework, which should cover all three layers of the Universal Design model: the transcending principle, process-related principles, and human factors principles. The equity principle says that an application of design is universally inclusive for all kinds of different users. We propose starting an evaluation with the assessment of equity, using a revised version of the guidelines of the National Institute of Health for Equality Impact Assessment. The process-related principles include flexibility, error-management, efficiency, and stability and predictability. For these principles, we propose the use of well-established usability evaluation tools with focusing on the principles listed above. For the evaluation of human factors principles, which include ergonomic, perception and cognition principles, we propose the use of the Inclusive Design Toolkit developed by the Engineering Design Centre of the University of Cambridge. A combination of mentioned above three tools can provide a comprehensive and fast evaluation framework for wearables and other types of design artifacts, which do not have interactions with screen-based input/output devices.

Keywords: Wearables · Universal Design · Design framework

1 Introduction

The growing interest in wearable devices can be recognized by the number of new products, startups, and research studies related to this field. New developments in ubiquitous computing, tangible interfaces, Internet of Things, and Big Data together with new demands of the end users challenge researchers, engineers, and entrepreneurs to think about new solutions in the wearable computing.

Designing the wearables is a case of human-computer interaction design. However, there are different peculiarities due to the different nature of the human-computer interface in wearable computing devices. A wearable computer is worn, not carried, and can be regarded as being a part of the user and user controllable [1]. Wearability is defined as the interaction between the human body and the wearable object [2]. A user literally wears the device in form of clothes, watches, jewelry, and other wearable

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artifacts. It is important for designers to consider human factors much more, in comparison to traditional old computer screens or even the younger generations of mobile devices. Also, wearable technology potentially gives people with visual and other sensory disabilities better, less conspicuous, and easier access to information and services [3]. For designing wearables, it is not enough to just apply the usability rules, because the nature of user interfaces for wearables is versatile and different to the traditional, screen-based human-computer interfaces. The human factor design principles should be applied for use in design and evaluation of wearable devices.

Universal Design (UD) is a popular design framework that is used in the different areas of design and development from architecture to product design. *"Universal design attempts to make products, equipment, building interiors and exteriors, transportation systems, urban areas, as well as information technology, accessible to and usable by all without regard to gender, ethnicity, health or disability, or other factors that may be pertinent"* [4]. In our previous studies, we outlined [5] how UD principles can be applied to the different themes for wearables and reviewed [6] several accessibility evaluation tools from other fields, from which criteria for evaluation of the accessibility in wearables during the design process can be borrowed.

However, it is not an easy task to apply the principles themselves to the design artifacts. Though UD principles are well defined, there is still a lack of the applied tools, ready for use in a lab for different purposes. It is necessary to supply the design students with simple and efficient tools based on UD principles, which can be applied in the different stages of design process to the wearable devices. The goal of this research is to supply designers, researchers, and students with a tool or a set of tools, which can be used for the quick assessment of design artifacts for wearable computing.

In the following sections, we present a hierarchical model for UD principles, describe groups of the principles and propose tools that can be used for evaluating each group.

2 Hierarchical Model for UD Principles

The origin of the Universal Design concept was proposed by Mace [7], program director of The Center for Universal Design in Carolina University. His work was influenced by early ideas of UK researcher Goldsmith, reflected in a book Designing for the Disabled [8]. Being focused on issues of accessibility in buildings, Mace outlined distinction of universal design to other types of design for people with special needs. Mace ideas were compiled by a team of researchers in The Center for Universal Design at North Carolina State University into guidelines. Seven principles applicable to environmental accessibility were defined for the first time in a book of Connell et al. *The Universal Design File* [9]. UD was defined in the book as the design of products and environments to be usable to the greatest extent possible by people of all ages and abilities [5].

There are two synonym terms for Universal Design: *Exclusive Design, and Design for All*. While all three terms have different origins, they have similar ideas, concepts, and goals, and can be used as interchangeable ones [10, 11].

Seven UD principles by version of Connell et al. with the corresponding descriptions are listed in Table 1.

Table 1. Principles for universal design and their definitions [9]

Principle	Description
Equitable use	The design is useful and marketable to people with diverse abilities
Flexibility in use	The design accommodates a wide range of individual preferences and abilities
Simple and intuitive use	Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level
Perceptible information	The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities
Tolerance for error	The design minimizes hazards and the adverse consequences of accidental or unintended actions
Low physical effort	The design can be used efficiently and comfortably and with a minimum of fatigue
Size and space for approach and use	Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility

This list of principles become a base for many works in UD area. In particular, Erlandson in his book Universal and accessible design for products, services, and processes [12] slightly modified the list of principles and added the eighth one. In Erlandson's model, the list looks as follow: *Ergonomically sound, Perceptible, Cognitively sound, Flexible, Error-managed (proofed), Efficient, Stable and Predictable, Equitable.*

Erlandson proposed not only the extended list of principles but a hierarchical structure, which allows grouping of the principles and establishes relationships between them. All principles were distributed in three main groups: Transcending principles, Process related principles, and Human factors principles (Fig. 1).

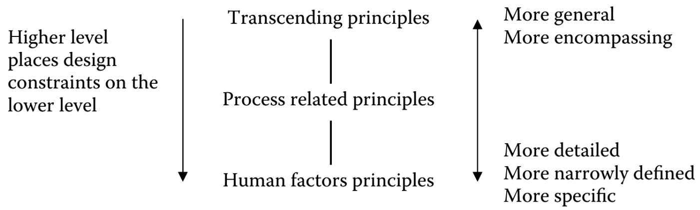

Fig. 1. The hierarchical structure of the universal design principles [12].

On the lower level are the human factors principles, which include ergonomics, perception, and cognition (Table 2). The situated in the middle process principles deal with activities and participation (that are, processes). They include flexibility, error-management, efficiency, and stability/predictability. The *transcending* principle deals with *equity* and as such, it is very different to the others. Equity is a value judgment. As a design community, we are stating that we desire universally designed entities to be equitable [12].

Table 2. UD principles in hierarchical model by Erlandson

Levels	Principles
Transcending principle	Equity
Process principles	Flexibility
	Error-management
	Efficiency
	Stability/predictability
Human factors principles	Perception
	Cognition
	Ergonomics

Erlandson notices that the principle states at the higher-level places constraints on the structure or design of the lower level. Operational laws and principles, such as the various psychometric laws, physiological principles, psychological principles, and the biochemistry of brain and neurological and neuromuscular functioning, form the basis for what and how people behave and function with respect to the human factors principles. The process principles place constraints on the various human factors principles and design strategies.

Erlandson's model appears important because, in addition to the process related principles, which are a usual part of the common usability frameworks, it explicitly adds the transcending and human-factor-related layers. While those principles are often omitted in typical human-computer interaction (HCI) evaluations, we argue that they should be critical when one designs the wearable devices.

In the following parts, we discuss and propose the design and evaluation tools from the existing frameworks, which could be used in a combination to cover all three layers of Universal Design principles.

3 Transcending Equity Principle

The Transcending Equity Principle is an umbrella for all principles situated below. Equitability imposes constraints to the other design principles in that they must be applied so that the designed entities are accepted by a broad spectrum of users. In a most fundamental way, equitability forces the integration of the other universal design principles [12].

3.1 Equity Principles

Equity Impact Assessment (EIA) is a method for healthy policymaking proposed by Mann and Gostin in 1994 [13]. EIA originates in Human Rights Impact Assessment (HRIA). In HRIA study, authors have discussed issues when specific population groups can be uncovered by newly designed human rights policies. Among other human right principles, HRIA also states equality and non-discrimination principles: *"All individuals are entitled to their human rights without discrimination. This includes paying particular attention to vulnerable and marginalized individuals and groups, as well as gender. It also involves taking steps to ensure that all affected and impacted women and men, girls, and boys, are empowered to understand and participate in decisions that affect them"* [14]. HRIA method may address some of the issues considered in a company's environmental, social and health impact assessments [15].

EIA mainly covers three areas—human rights and business, right to health, and trade agreements [16]. There are other frameworks, aiming at equality assessment in different domains. Examples of these domains can be international development [17], patient admission [18], public sector [19], etc.

3.2 Equity Evaluation Frameworks

For the human-computer interaction field, currently, we have found no specific methodologies for equality assessment for design artifacts in HCI. However, a few attempts have been made in other fields and subjects, to address the issue of equality assessment.

One framework that can be provided as an example is an Equity Framework for Health Technology Assessments (HTA) [20]. In this framework, several different domains are used to determine the degree to which the equity is fulfilled by an evaluated concept. These domains are equity/equality, adequacy, legal obligations, general principles and embedded inequity.

A Framework for evaluating house-level accessibility [21] also provides an assessment framework for equity, but this time for spatial equity, which is a concept that concerns architectural requirements to inform accessible building policies. This framework looks at factors for accessibility as a social construct, making assumptions to what degree social groups are included or excluded from certain spatial points of interest, such as a park or other communal elements of a city.

Another framework is related to the educational context [22]. Three different theories are combined: Adult learning theory, transformative learning theory, and critical social theory. These are matched with the pedagogical concepts of reflection, discourse, and policy. The way a framework is formed is geared at informing persons in educational leading roles, to form an equitable environment that will seek to reduce discrimination against learners.

A related to health sector framework of the National Institute for Health and Clinical Excellence (NICE) [23] we consider as the most relevant framework for HCI. The objective of that framework is to determine the equity of approaches used in a public health guidance.

3.3 NICE Framework

The NICE framework [23] constitutes several determinants and factors. The main factors are social, economic, political, psychological and biomedical factors, which are used to group certain influence on health. If either of these factors is individually deficient, a health state may be reduced. Individual health is determined by causes of health and disease in terms of individual pathology, causal pathways, prevention of diseases and promotion health.

We have selected this framework as a basis for evaluation of the accessibility of wearables because one aspect of the framework includes a strongly defined set of grouping properties as fundamental characteristic. These are broken down into the following impacted group characteristics (see Table 3). In our context of design for the wearable technology, each of these groupings is relevant in terms of raising awareness with respect to potential pitfalls that might discriminate against certain groups of users. Naturally, it is difficult to address all the different user groups at once, but with an enhanced awareness to each of them, we can expect an optimization in terms of designing artifacts that will include a wider user group than has been possible before.

The different characteristics can be used in a checklist that will test any design-artifact against using it for the different types of audience. For example: as we design a wearable device that will help visually impaired users to recognize items in their environment by using voice output, this will be inclusive for many of the characteristics, except people with aural disabilities. This group is excluded unless we include support for textual output or sign language support in some fashion. In the Table 3, we list the checklist as adapted from the NICE framework [23]. Each of the protected characteristic is assessed how they are affected by the wearable, while the result should be only neutral or positive checkboxes.

Table 3. Adapted checklist from the NICE framework

Protected characteristics	Impact
Age	Positive/Negative/Neutral
Disability	Positive/Negative/Neutral
Gender reassignment	Positive/Negative/Neutral
Marriage and civil partnership	Positive/Negative/Neutral
Pregnancy and maternity	Positive/Negative/Neutral
Race	Positive/Negative/Neutral
Religion or belief	Positive/Negative/Neutral
Sex	Positive/Negative/Neutral
Sexual orientation	Positive/Negative/Neutral
Disadvantaged groups	Positive/Negative/Neutral

4 Process Related Principles

Erlandson defines a process as a collection of related tasks or activities that lead to a particular result. Being situated in the middle, the process-related principles are constrained by the transcending principles and at the same time provide the constraints to the human-factors principles. The process-related principles aimed primarily at the process deal with flexibility, error-management, efficiency, and stability or predictability.

Bellow, we will show that the process-related principles can be found in different usability guides.

4.1 Usability Heuristics and Process-Related Principles

Usability is strongly related to user interaction processes. Usability testing, according to Dumas and Redish [24], among other things, aims to give the users real tasks to accomplish.

One of the popular high-level guidelines (or heuristics) for usability evaluation is proposed by Nielsen [25, 26]. Heuristic evaluation originally involved a small set of evaluators examining each element of a system to identify potential usability problems [27]. Usability heuristics are used for evaluation of a high range of concepts, from general to specific, which can include for example technologies [28], devices [29], applications [30], or even more complex concepts like patient safety [31].

As the name states, *10 usability heuristics for user interface design* of Nielsen consist of the following components: Visibility of system status, Match between system and the real world; User control and freedom; Consistency and standards; Error prevention; Recognition rather than recall; Flexibility and efficiency of use; Aesthetic and minimalist design; Help users recognize, diagnose, and recover from errors; Help and documentation.

We have compared Nielsen's heuristics with Erlandson's process-related principles and have found the following matches (See Table 4).

Table 4. Match between process-related principles and usability heuristics.

Process-related principles	Usability heuristics
Flexibility	Flexibility and efficiency of use
Error-management	Error prevention
	Help users recognize, diagnose, and recover from errors
Efficiency	Flexibility and efficiency of use
	User control and freedom
Stability/predictability	Consistency and standards

As it is shown in the table, all the process-related principles are covered by the usability heuristics. Several remaining heuristics are hard to specifically match with any UD principle. Including or excluding these heuristics from the evaluation can depend on the nature of the evaluated design artifact. For example, in a case of wearable devices, the heuristic *Match* between *system and the real world, Recognition rather than recall,* and *Aesthetic and minimalist design* can be relevant. At the same time, the *Help and documentation* heuristic can be less relevant for the wearables comparing to the web-based user interfaces.

Heuristic evaluation can be adapted in many ways. Rather than inspecting individual elements, it is often carried out by asking the evaluator to step through typical user tasks. This can combine heuristic evaluation with some of the benefits of a cognitive walkthrough [27].

5 Evaluating Human Factor Principles

On the lower level of Erlandson's model, the *human factors principles* are situated, which include ergonomics, perception, and cognition.

The human factors discipline is the study of the characteristics of people and their interactions with products, environments, and equipment when they perform tasks and activities. The goal of human factors is error-free, productive, safe, comfortable, and enjoyable human-system interaction. By considering human factors, engineers and designers should ensure that human-system and human-environment interactions will be safe, efficient, and effective [32]. Human factors engineers are called upon when the human element is an important interaction with a device, system, or process [33], and that is the case for wearable devices.

Dong et al. [34] have reviewed six design tools, which are recommended for using by professional designers and students to include inclusiveness into the design process. We have found that the Inclusive *Design Toolkit* (IDT) reviewed in that study is specifically focused on human abilities, which are directly related to Erlandson's human factors principles.

5.1 Inclusive Design Toolkit

The Inclusive Design Toolkit (IDT) is a well-known framework for the assessment of human factors. It is developed in the Cambridge University and available at the web site of the Engineering Design Centre http://www.inclusivedesigntoolkit.com. The website contains of guidance and resources, which reflect 12 years of inclusive design research, conducted by 3 successive inclusive design research consortia.

Professionals well value IDT: according to Dong et al. [34], professional designers liked main features of IDT including interactivity, navigation, case studies, usefulness for business cases, easy accessibility on the web, free cost. Design students appreciate features like comprehensiveness, accessibility, free cost, nice information architecture, clear instruction, useful user capability data, well-structured contents, good illustrations. Both professionals and students noticed that the toolkit can be used for research, or design (in both initial and final stages).

IDT focuses on product interactions, which place demands on the users' capabilities. If any of users' demands are higher than their capabilities, users may be excluded from using a product. For example, a product with very small text requires a high level of vision capability. People with age-related long-sightedness will be excluded from its use.

IDT proposes to make an initial assessment by rating the demand on each capability on a scale from Low to High (Fig. 2). To do this, there are various factors that should be considered [35]:

- For *Vision* — the size, shape, contrast, color, and placement of graphical and text elements;
- For *Hearing* — the volume, pitch, clarity, and location of sounds produced by the product;
- For *Thinking* — how much demand the product places on a user's memory, how much it helps the user to interpret its interface, how much attention it demands, and how much prior experience it assumes;
- For *Reach and Dexterity* — the forces, movements, and types of grip required to use the product. The demands will increase if tasks should be performed with the hands reached above the head or below the waist;
- For *Mobility* — whether the product requires the user to move around. If designing an environment or service, consider whether it provides suitable features to assist balance and support mobility aids.

The human factors defined in IDT very well align with Erlandson's human factors principles. The vision and hearing allow to check the design artifact against the perception, the thinking — against the cognition, and the reach, dexterity, and mobility — against the ergonomics.

The scales for demand in each of the five categories range from low to high, where low and high provide a relative measure when one product or scale is compared to another [36].

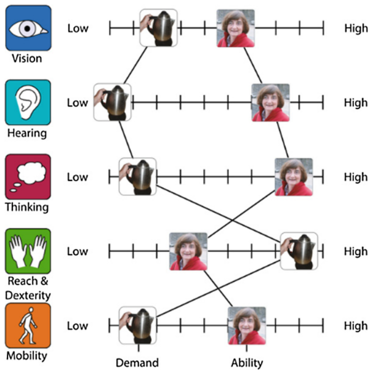

Fig. 2. Scale for the level of demand that a product places on various capabilities [35]

Although the scale measurements may look crude, they are easy to use as an initial tool and can provide an effective visual comparison between alternative products or concepts. This can be useful for initially setting up the design requirements, as well as for evaluation working prototypes in the following design stages.

Using the IDT scale is especially useful when designers provide a set of personas, based on the target user groups with the different abilities. In that case, the user demands of the design artifact can be mapped on the abilities of the personas on the same scales.

Many people experience more than one capability loss in the form of multiple minor impairments. For this reason, estimating the number of people who would be excluded from using a product requires a single data source that covers all the capabilities required for cycles of product interaction [36]. IDT proposes for that a separate tool, which is called Exclusion calculator[1]. The calculator can be used to estimate the proportion of the population that would be unable to perform specific tasks that require a specific level of demands. The process of estimating exclusion highlights the causes of frustration and exclusion, and prioritizes these on a population basis [37].

6 Conclusion

In this study, we have presented the layered UD model of Erlandson and proposed a set of evaluation tools that cover all layers of that model (Table 5).

Table 5. Composition of the evaluation tools with corresponding layers of DU principles

Groups of principles	Tools for evaluation
Transcending principles	NICE framework
Process related principles	Nielsen's usability heuristics
Human factors principles	Inclusive design toolkit

The proposed UD-based framework can be used in the early design stages, like defining business cases and initial scenarios and for the late evaluation of the prototypes of wearable devices. In both cases that will help to have more attention to the personas with different abilities and to introduce more empathy in the design [38].

We propose to start evaluation in a top-down manner, from general to the specific. For assessment of equity, the NICE framework is recommended. It can focus the attention of designers on the potential groups of end-users, that could be occasionally excluded from the design. Precise determination of such groups will help to avoid crucial errors during the initial phases.

When the equity assessment is finished and the design is adjusted in accordance with results of the first-step evaluation, the usability step should be conducted by using the Nielsen's usability heuristics evaluation method. This will help to ensure that the process-related principles are addressed in the design.

After finalizing usability checking and making sure that process-related issues are solved, the design demands for human factors can be evaluated. The IDT can be used to implement this evaluation with detailed results. After understanding human demands, the set of prepared early personas can be used again, to check their abilities against measured demands.

[1] http://www.inclusivedesigntoolkit.com/exclusioncalc/exclusioncalc.html.

The framework proposed in this paper should be useful for introduction of Universal Design principles to the design of wearables, but can be applied to other types of technologies as well. The goal is to develop an efficient, unified tool, which can help to evaluate design ideas or prototypes of students and professional designers.

Considering the practical implementation, the framework still requires additional development. Eventually, the designers should have a possibility to use all three tools as unified approach. This can be implemented in a form of the paper-based checklists or in a form of the web-based and mobile applications. A possibility to use these tools on mobile devices will allow the designers to quickly test their design of the wearable devices in the field.

For the next step, we see a necessity in use and evaluation of this framework on specific wearable design projects.

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Moti-Meter: A System for Visualizing Personal Learning Motivation

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Abstract. In recent years, e-learning systems have been introduced and used at many educational institutions. However, because of difficulty in maintaining student motivation in classes that use these systems, e-learning systems for self-study may foster user dropout; more precisely, because users are isolated during self-study, they may be highly motivated to engage in e-learning initially, but this motivation may gradually decline over time. In this study, we introduce "Moti-Meter," a system intended to support the maintenance of user motivation and avoid psychological reactance by enabling users to visualize their own motivation. Estimation of users' motivation is done using regression analysis of data collected from non-invasive sensor devices, such as smartphones and wearable devices. Visualizing one's motivation has potential for applications in a range of other fields as well, for instance in healthcare.

Keywords: E-learning · Motivation · Wearable device

1 Introduction

In the first decade of the twenty-first century, e-learning systems have been introduced and used at many educational institutions [1, 2]. In Japan, too, the Ministry of Education decided to formally adopt digital textbooks in elementary and junior high schools [3]. However, because of difficulty in maintaining student motivation in classes that use these systems, e-learning systems for self-study may foster user dropout; more precisely, because users are isolated during self-study, they may be highly motivated to engage in e-learning initially, but this motivation may gradually decline over time. For these reasons, the current study examines how motivation may be maintained when using e-learning systems.

2 Relevant Studies

Narumi and colleagues [4] investigated the "Sotsuron-Watch" (*sotsuron* is the Japanese word for a graduation paper at university), a tool that collects and shares information about students' progress toward finishing their graduation papers [4]. This system succeeded in helping students maintain the motivation to write their graduation papers.

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However, users' motivation may decline if they use e-learning inappropriately. This concept, called "psychological reactance" [5] refers to the adoption or strengthening of a view or attitude contrary to what was intended, which also increases resistance to persuasion [5]. Asao [6] provided evidence for the importance of psychological reactance for e-learning through his questionnaire entitled "Feelings of Usefulness of Information Transfer in Interactive Mathematical Web Materials for Teenagers." Some student respondents said that the help function of the system they used was meddlesome, and that more appropriately functions should exist [6]. The study showed that psychological reactance could be minimized, and motivation maximized, by providing users with timely help.

In this study, we introduce "Moti-Meter," a system supporting user motivation in relation to studying by enabling users to visualize their own motivation. Estimation of users' motivation is then done using data collected from non-invasive sensor devices such as smartphones and wearable devices. This system aims to maintain users' motivation and avoid psychological reactance.

3 Utilization of Wearable Devices

In this study, we estimate the motivation of users using data collected from wearable devices. In chapter, we summarize today's studies in this field.

Nowadays, miniaturization and price reduction have improved the performance of various wearable devices such as smartphones. Thanks to these devices, many studies have been launched, for example, in the health field, on using bio-information, or registering and sharing Lifelog and healthcare support services. Yonekura et al. [7] investigated a system forecasting user motivation in mental health care using data collected from wearable devices alongside other data collected by answering a questionnaire, for example on weather favorability, time spent on relaxing activities such as sports or video games, or time spent on necessary daily commitments such as students' classes or jobs [7]. The experiment conducted in this study show that this method enables to forecast motivation with high accuracy, over a long period.

4 How to Visualize Motivation

4.1 Method

In this study, we use lifelog data such as activity data by having participants use wearable devices. We also got data on, for instance, weather favorability, by answering the questionnaire. From these data, we propose a system which visualizes motivation for studying: the "Moti-Meter" (Fig. 1).

We asked our participants to study English every day during the experimental period. Before studying, they manually entered a self-assessment of their motivation to study into the Moti-Meter.

Models of user motivation are estimated using regression analysis of the manually entered motivation ratings along with the following data collected from non-invasive

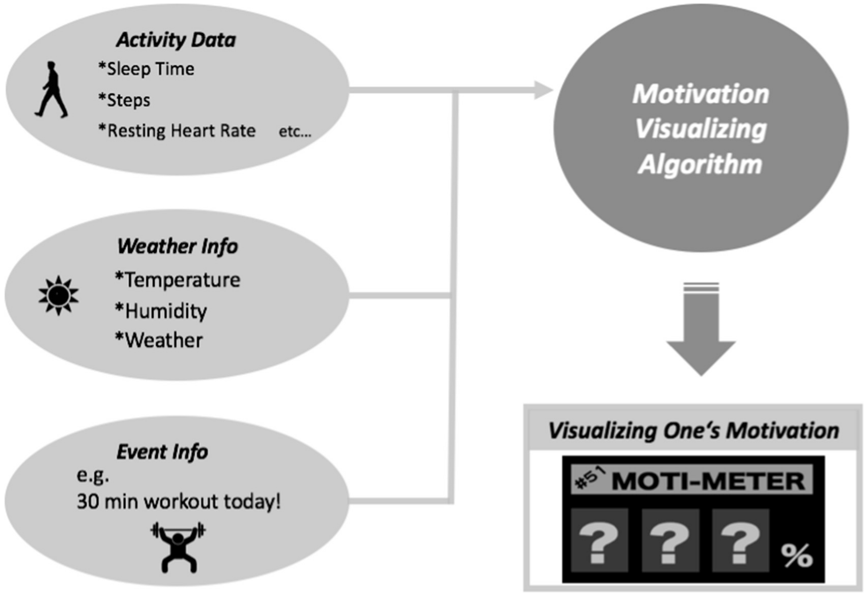

Fig. 1. General view of our method.

sensor devices such as smartphones and wearable devices: sleep time; resting heart rate; active time (as defined by Fitbit); steps; calories burned; and other data collected by answering the questionnaire: weather favorability; time spent on relaxing activities; time spent on necessary activities.

4.2 Acquisition of Activity Data and Weather Information

To get physical activity data, we use the Fitbit Charge HR (Fitbit, Inc.), wristband-shaped wearable device (Fig. 2) [8]. The Charge HR has various sensors, including a heartbeat sensor, GPS, acceleration sensor, etc. In this study, participants were always wearing the Charge HR, yielding activity data.

We also gave the participants a questionnaire to get weather favorability, additional data we could not gather through the Charge HR.

4.3 Acquisition of Event Information

Yonekura and colleagues classify each event in terms of the categories of "relaxing" or working on a "task" [7]. According to them, a task is an event in which one participates and which one must respond to even against one's will, such as going to class or going to one's part-time job, while relaxing is action that follows one's will, such as sports or playing video games.

In this study, we event information following the Yonekura et al. definition, by distributing a questionnaire to the participants and have them answer with time values, like "Today I had a 30-min workout!"

Fig. 2. Fitbit Charge HR.

5 Experiment: Estimating a Model of Studying Motivation

5.1 Objects of This Experiment

To develop the motivation visualizing system, Moti-Meter, we first have to experiment to estimate it, which we will endeavor to do so by percentage.

5.2 Experimental Method

Participants were required to do classwork using the e-learning system for TOEIC (Test of English for International Communication) every day for 15 days. The system was produced by Newton Inc. During the period of the experiment, participants always wore the Fitbit Charge HR except when impossible, for example while taking a bath.

We made participants evaluate their own subjective motivation for studying before they had the chance to during the experimental period. We also made them answer questionnaires (Fig. 3) to get event information and weather favorability every day.

Date	Task min	Relax min	Weather (-2 ~ +2)	Humidity (-2 ~ +2)	Temperature (-2 ~ +2)	Today's Motivation	Notes
9/Dec	360	70	1	1	1	60	
10/Dec	360	150	-1	1	1	40	
11/Dec	120	90	2	1	1	30	

Fig. 3. Questionnaire to get some data.

The parameter to estimate the motivation model is summarizing in Table 1.

Table 1. Parameters for estimating motivation visualizing model.

Dependent variable	Motivation for studying (subjective value)
Explanatory variable 1	Yesterday's sleep time
Explanatory variable 2	Resting heart rate
Explanatory variable 3	Active time*
Explanatory variable 4	Steps
Explanatory variable 5	Calories burned
Explanatory variable 6	Weather favorability (subjective value)
Explanatory variable 7	Humidity favorability (subjective value)
Explanatory variable 8	Favorability (subjective value)
Explanatory variable 9	Time for relaxing
Explanatory variable 10	Time for task

"Active Time" is an activity indicator defined by Fitbit, using the MET (Metabolic equivalents). Based on the point of view that "10 min of exercise at a time is fine," which is mentioned by CDC (Centers for Disease Control and Prevention), Fitbit defined "Active Time" as exercising more than 3 MET for over 10 min [9].

5.3 Analytic Method

Based on the hypothesis that the "Dependent variable and the Explanatory are linear," We adopted the linear multiple regression analysis for the analyses. We tried to derive a regression model of motivation for studying, and a visualizing algorithm.

5.4 Results and Analysis

We succeeded in getting 82 days' worth of data from 6 participants' 15-day data. Participants were all college students in their 20 s. We did the linear multiple regression analysis, and Table 2 is a summary of the results.

Table 2 shows that the parameters of Weather and Relaxing Time were significant and that of Temperature, marginally significant. However, Temperature has very little coefficient (−0.0307), meaning that it has little relation to one's motivation for studying.

Other parameters were not significant, and adjusted multiple correlation coefficients (R-squared value) were very small (0.08). This result means the model is not linear.

5.5 Discussion

Improvement of the motivation estimating model

The result of regression analysis yield a correlation between Measured and Estimated Motivation (Fig. 4).

Table 2. Results of linear multiple regression analysis.

	Coefficient	Standard deviation	t	P-value
Intercept	50.186	36.913	1.360	0.178
Sleep time	−0.918	1.331	−0.690	0.493
RHR	0.229	0.618	0.370	0.712
Active time	−0.078	0.162	−0.484	0.630
Steps	0.000	0.001	0.395	0.694
Calories burned	−0.003	0.012	−0.245	0.807
Weather	6.200	2.546	2.435*	0.017
Temperature	−5.154	2.840	−1.815*	0.074
Humidity	2.904	3.038	0.956	0.342
Relaxing time	−0.037	0.018	−2.023*	0.047
Task time	−0.020	0.020	−0.968	0.337

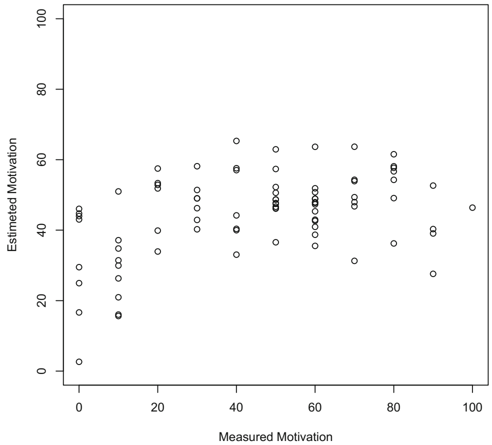

Fig. 4. Correlation between measured and estimated motivation.

As Fig. 4 shows, this relationship does not have a tendency to monotonic increase. That is why we conclude that the model is not linear. In our future work, we are going to try to conduct analogous analyses using nonlinear modeling, GA (genetic algorithm), or other methods to yield the most optimum motivation estimating model.

The Influences of Seasonal Factors

Based on the results of multiple regression analysis, the parameters Weather and Temperature were significant. This means that motivation for studying has a generous correlation with weather favorability. The experiment was held in December 2016, when the weather is very cold and stormy in Japan. Because of this seasonal factor of Weather, we guess that the motivation for studying has been affected.

Before the Experiment whose results are presented in this section, we conducted a preparatory Experiment in October 2016, when the weather is better. In the pilot, parameters related to weather favorability do not have any big correlation with motivation for study. These results should be compared with those of studies in other seasons, for reliability and validity.

6 Conclusion and Future Work

We conducted an experiment to get a regression model of motivation for studying. The results failed to yield a significant regression model. However, parameters related to weather favorability had a generous correlation with motivation for studying.

In our future work, we are going to try other methods of analysis, such as nonlinear modeling and GA, to support the findings; reflect the findings in the "Moti-Meter" algorithm, and test them.

We also intend to develop a "Moti-Meter" application for Android smartphone. Storing active data from Fitbit's API (application programing interface) to throw it into the algorithm will help us better measure user motivation.

In this study, we assumed that e-learners study on their own, and tried to visualize their motivation. However, we certainly did not investigate all potentially relevant variables, such as diet. This methodology can be applied to such cases to flesh them out also.

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Wearability and User Experience Through User Engagement: The Case Study of a Wearable Device

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Abstract. The text presents the results of a Transnational Research Project (SAF€RA Joint Call 2014) called "POD-Plurisensorial Device to Prevent Occupational Disease", within a consortium made up of Design Department of Politecnico di Milano, Delft University of Technology and Comftech S.r.l. (an Italian Company specialized in electronic/smart textile). The research project aims at developing a novel concept of wearable system to prevent respiratory diseases inside the specific working environment of a coating plant. The paper will present the results of the research project based on a human-centred approach, from the user analysis sessions to the system development. In the process we have considered the user as the ultimate experts, those who can properly assess design innovation, propose changes, and ultimately, integrate end products within their environments.

Keywords: Wearability · User engagement · User experience · Health

1 Introduction

Objective of the research was the development of a protective and interactive system for workers in a small and medium Coating Plants. Workers in Coating Plants are regularly exposed to hazardous conditions, which caused raised percentage of occupational diseases recently. This is a serious individual and social problem. The research deals with sociological and psychological problems of this phenomenon, understanding the cultural, educational and professional aspects involved in it.

The project aimed at creating an innovative wearable interface for monitoring the workers' health status and surrounding environment potential risk sources, giving him/her useful real time information and/or alarms, as well as allowing data transmission with a body gateway enabling to share information and a possible high level risk management service.

During the research, lasted two years, an entire wearable system was developed. The system is made up of three elements [1]. A protective mask (mandatory for workers) with the integration of air quality detection sensors; [2] an alert device/gateway to

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receive signals from the devices and alert the user (vibration, lights, text) about his/her conditions and air quality; [3] a mobile application.

The wearable device developed during the research activity required addressing issues by meeting not only technological requirements, but also user needs. Taking on a human-centred approach requires an investigation of demands of the workers, in terms of behaviour, environment and peer group. This means to figure out both product requirements and proper application for emerging wearable technologies in order to gain appropriate functionality and true usability for the identified user.

When designing wearable technologies/interfaces it is important to understand the needs of potential users/consumers. In the case study here presented the challenge was to design both a mask and a smart belt, which are easily adaptable to the different body sizes, unobtrusive, aesthetically pleasant and comfortable to wear (Ferraro and Ugur [10]; Motti and Caine [11]).

The user has then been involved in the process using design thinking process - a creative human-centred discovery process followed by iterative cycles - that shapes the design process in five phases: empathy, define, ideate, prototype, test [5, 6, 9].

2 Method

The research project aims at developing a wearable system addressing issues by meeting not only technological requirements, but also user needs with a human-centred approach. The project developed using a combination between different approaches (design thinking and participatory design).

Taking on a human-centred approach requires an investigation of demands of the workers, in terms of behaviour, environment and peer group. This means to figure out both product requirements and proper application for emerging wearable technologies in order to gain appropriate functionality and true usability for the identified user [9].

In this section, authors describe: (i) the Empathize phase from design thinking, with the aim to understand the people for whom the project is designed and the context in which the system will be used; (ii) the Define Phase where the user needs are translated into requirements for the wearable system; (iii) the Ideation phase that is the concept generation and the concept evaluation.

2.1 Participants

For the user analysis, the choice of the proper participants was relevant. We decided to choose workers of coating plants. This choice is strategic for the project execution for two main reasons: workers of this environment are highly exposed to the inhalation of several damaging agents (volatile organic components, organic dust, chemical contaminants, paints, varnishes) that cause respiratory disease; the high level of proportion between number of operators and sales volumes all over Europe. Thanks to the support of Anver (Associazione Italiana Verniciatura) three SMEs from northern area of Milan were identified.

The three companies perform similar activities within their Coating Plants such as coating of furniture and small-medium mechanical parts. Main reason for choosing these companies was the understanding that in big companies the operation of lacquering or finishing is automated and not performed by workers. Besides, in small companies it is obviously easier to have direct contact with workers and observe their behaviour at work. The chosen Coating Plants have less than 20 employees.

2.2 User Analysis: Empathy Phase

The user analysis, performed in each of the three chosen companies was divided into two parts:

- Observation: focused on the analysis of the users and their behaviour in the context of their work in order to understand the way they use the current PPE;
- Interviews: done with workers and employers, in order to understand what is their perception about the risk in the working place working, what is motivating or demotivating them about wearing the personal protective equipment and how much they are willing to accept the advanced protective monitoring system.

Both observation and interviews involved a total number of ten workers and were carried out between December 2015 and January 2016.

The Observation phase was fundamental to immerse into the field of application and have first thoughts about workers behaviour. Thanks to this phase we first learnt that a Coating Plant designed according to the law needs an aspiration system in order for the Coating powder to be taken away by flowing water. In fact, the operation of the coating should take place in coating cabin with an aspiration system. About the PPE, the workers use two different masks: (1) Disposable Protective Mask (with a small valve that helps the respiration) and (2) Reusable Half Mask with carbon filters (solid or liquid particles gas and vapour).

During one-hour observation in each coating plant we realized that the workers occasionally use the mask. They use it when they need to paint complex geometry that usually generates a cloud varnish so-called "overspray". We realized that the decision of wearing the mask is based on personal perception (when they smell bad odors or see and feel the overspray).

The Interviews led in each company were helpful to confirm some findings of the observation phase and to understand better workers' needs and requirements for PPE and working environment. The interviews were carried out on ten workers, four from company number one, four from company number two and two from company number three, through an open questionnaire.

The questionnaire was framed in four (4) main topics: (i) Working activity and protective equipment; (ii) Mask's aesthetic and comfort; (iii) Safety perception; (iv) Personal devices.

About the topic of working activity and protective equipment, all interviewees asserted that they decide autonomously when to wear the mask, which is personal and stored in a drawer. They usually wear the reusable mask for 1, 5 h a day. The decision of wearing the mask depends on their subjective smelling of some annoying odours or on the geometry of the piece.

When it comes to the mask's comfort and aesthetic, according to all the workers the mask is uncomfortable due to several reasons such as the rigid elastic connection to the face (too tighten), not breathable material, lack of breathing (the valve is not efficient to achieve a good breathing). They all asked for a new mask designed with more attention to the wearability and comfortable materials.

The interviewees were asked about the perception of safety. Eight interviewees on the total number of twenty are aware of the level of risk connected to the work they do because of the toxicity of the paint. They asserted that the protection level of the mask is good. They would like to have information about the quality of the working place and the personal health condition.

Finally, the interviewees were asked about the possibility of wearing personal device equipped with sensors to detect both their personal parameters and environmental one. Seven of the workers were positive on wearing a mask with some sensors able to detect the air quality and would like to try the personal device to detect the healthy condition (breathing and heart beat) but also have the information through an application on the phone. About the type of information, they would like to know about daily data (environment and personal health) but also seasonal ones.

2.3 Define Phase

The empathy phase highlighted some findings such as that: (i) generally, workers prefer not to wear the mask. That is because they think their work is not that dangerous, apart from some specific occasions in which they do wear the mask; (ii) Workers also do not wear the mask because it is very uncomfortable; (iii) Workers would like to know more about the health condition of their working activity.

During the observation and the interviews, we surprisingly realized - contrary to our first thoughts - that the most important thing for worker is not the safety but the comfort of the mask. Workers need to be able to move easily, have a good and wide visibility, to sweat as less as possible and to be concentrated. Requirements for Design imposed respect to the problems described previously, would be: (i) Form and dimensions of the product shall respond to anatomy of the user and be as small as possible; (ii) Possibly, anti-allergic breathable and light materials; (iii) Provide filtered, better air quality to workers (mask); (iv) Offer monitoring and sensing system that would be connected with some sort of device and application with possible alert (portable device);

2.4 Ideate Phase

Since the concept of the system was considered to be wearable the aim was to create the components that are able to satisfy user's comfort and interaction so that it can also enhance the users interest and consciousness. Natural interaction language between user and devices was suggested, language that it is understandable and engaging to him and that can influence the motivation and perception about his health status.

Three concepts were developed; each of them was approached to be innovative through the right selection of technologies and materials: form the use of smart textile technology and micro electronic technology to the soft technology. All three were interpolated in order to reach objectives imposed by the Brief.

Among all the elements of the system the Protective Mask was the most diversified one not only on technological level but also on formal level it showed the most diversity between concepts. (See Fig. 1).

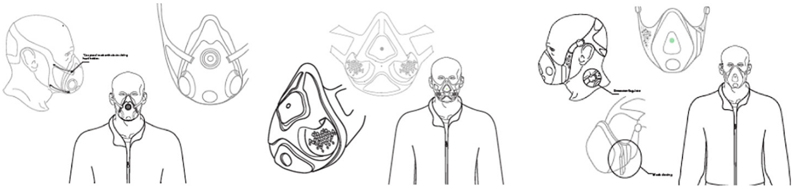

Fig. 1. The three protective masks' concept

About the so-called electronic nose device research brought to three solutions where the main difference is in the way the device gives information to the user.

There were presented three different modes of communication, starting from the simplest one where there are only two steps of communication: turning on and alarm (Concept 2); trough more complex one where there are three levels of communication: turning on, warning and alarm (Concept 1); and the last that is communicating also on three levels but there is an implementation of the graphic that is represented in the way of mood: happy, so and so, sad (Concept 3). All Devices combine vibration, LED response, and potentially sound (See Fig. 2).

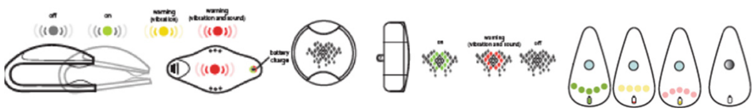

Fig. 2. The three electronic noses' concept

The last part of the system is the Mobile Application that shows three different solutions where two are dedicated to the workers while the third one is for the employer. The principle for designing that was applied here is very similar to the one for the Electronic Nose Devise. The idea was to propose two different solutions for the workers where there is a complex one with possibility to make a personal profile, impose settings and have results (Concept 1). Another application concept is focused only on the results of monitoring (Concept 2). All this concepts were made in form of mock-up in order to understand the real overall dimensions, how they respond to the meaning of wearability and how clear is design to the users (See Fig. 3).

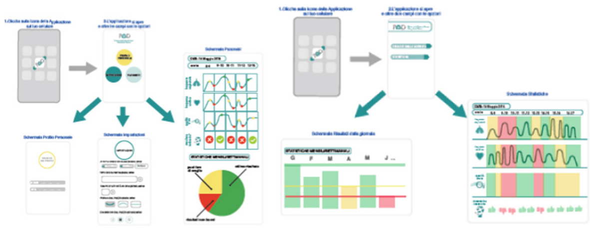

Fig. 3. The mobile application concept

2.5 Testing Phase

The objective of making the mock-ups was also to test them on the users. They were tested with the users in form of focus group and interviews.

The purpose was to understand if suggested concepts met needs of the users that were detected and investigated in the first User Session.

The session is needed to choose the final design solution. Workers were indeed asked to evaluate each part of the system on different levels - from aesthetics trough function, comfort, mode of use etc.

User session was held in two of three previously visited companies. During the session, participants tried all Mock-ups and analysed them. In the first visited company there were four workers and employer involved in the session while in the second one there was involved only one person.

After wearing and trying each concepts workers were provided with questionnaires based on quantitative valuation, for the difference of the one used in the first user session that was based on qualitative valuation. Each part of the system was validated with grades from 1 to 5 for different characteristics that were given in the questionnaire. During the session participants' voices were recorded and photos were taken (Fig. 4).

Fig. 4. Some pictures from the focus group

During the session workers were able to give general comments and discuss between each other. After the session of trying they were given questionnaires to do separately. What was difficult to simulate during the session is Mobile App that was provided in form of screen's graphics and it was explained step by step to them. They were also able to validate the App in the given questionnaire.

Once that session were concluded all material was gathered together and prepared for analysing and organising.

Data gathered during the session were analysed one by one and than organised to detect principal problems of the idea that were presented and tested with users. The goal of the session was not to choose exactly one of those solutions but to understand good characteristics of each and try to combine and improve it subsequently. It was of high importance to understand if the users liked the idea to have textile as a material in contact with skin. Users showed preferences for certain solutions, both for the Mask and Electronic Nose. For the application they were sure what they would like to have the Concept 2 of the Mobile App Concepts, the one that is giving only simple feedback.

For the Protective Masks results showed that from each concept there is something to be applied but they showed preferences for the Concept 1 for aesthetics. For the comfort good valuations were given again for the Concept 1 and for the Concept 2 of Protective Mask Concepts. Concept 3 was validated with lower points in general. General results for the Protective Mask. Concept can be seen in the charts below (Fig. 5).

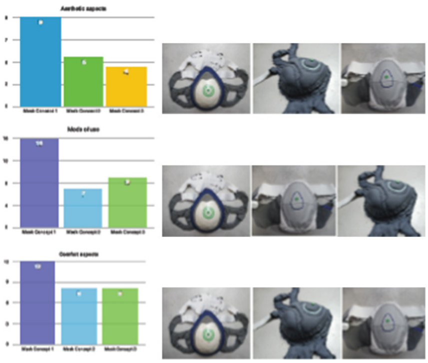

Fig. 5. Mask's concepts evaluation

When it is about Electronic Nose the concept that was liked the most in sense of mode of use is the Concept 1 while interaction that was the most comprehensive is the one of the Concept 3 of the Electronic Nose Concepts. General results about Electronic Nose Device can be seen in table below (Fig. 6).

The Mobile App liked the most was the Concept 2. Beside the App for workers there was shown also the App for employers. Employers were rather delighted about the idea so the valuation was very positive. They showed interest of seeing average of wearing the Protective Mask and to be informed about the quality of the air in their Coating Plants. This could help maintenance of ventilation systems in Coating Plants. Results about mobile App applications can be seen in the charts below (Fig. 7).

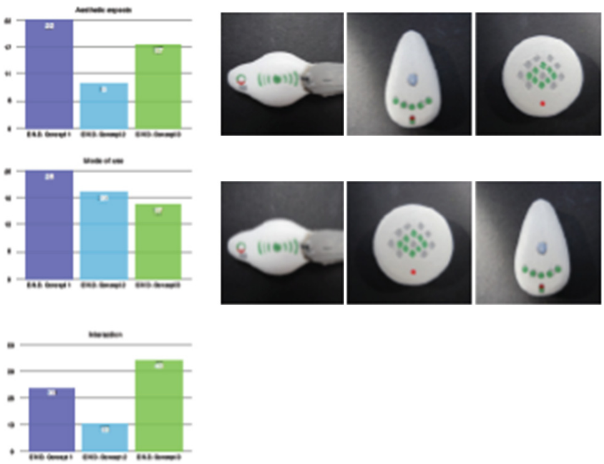

Fig. 6. Electronic nose's concepts evaluation

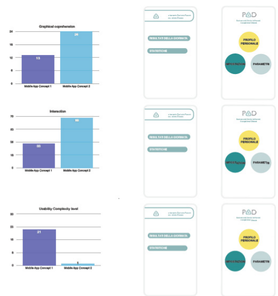

Fig. 7. Mobile application evaluation

3 Results

The results of the user session led to the development of the wearable.

The Plurisensorial Device to prevent Occupational disease is a wearable system based on sensor technology with a purpose to monitor air quality and worker's vital parameters by enhancing and increasing workers perception. The design of the wearable system was developed using a guidelines for wearable systems that stresses the importance of shaping the technology in an unobtrusive way suggesting also the suitable shapes to use in different body areas. [7] the system consists of: a Personal Protective Reusable Mask, a wearable alert device called Electronic Nose Device, a Mobile Applications (See Fig. 8).

The design of the protective mask (1) whose objective is to protect the user followed the user requirements about the aesthetic and materials. Workers were very positive about the idea to replace traditional materials with textile and this improvement removed barrier, which increased interest in wearing more regularly the mask. The new

Fig. 8. The wearable system

product is then made up of thermoformed spacer textile padded with soft foam instead of rubber that is one of the reasons why the mask is uncomfortable and is not worn regularly by the workers.

The mask is also equipped with a Temperature and Humidity sensors aimed at monitoring human breath but also to know if the Mask is worn or not. In fact, when Mask gets in contact with the face the sensor automatically turns on. Each time the sensor turns on the information about wearing is transmitted to Mobile Application via Bluetooth.

The so-called Electronic Nose Device (2) gives real-time feedback to the user about the air quality in the Coating Plant. It replaces the human nose in sensing the surrounded.

Its functioning is based on monitoring the level of Volatile organic compounds. The VOC Sensor is set on three levels: (i) ignition (green LED on) and it remains in this state until air does not exceed acceptable value; (ii) informing user that the level of VOC is starting to exceed acceptable value and it gives a feedback in form of yellow LED ignition and low vibrations; (iii) When VOC in the air reach high risk values the user is informed with red LED ignition and strong vibrations that repeat in the time. The air quality parameters are transmitted to Mobile Application via Bluetooth. The possibility of having real-time feedback reminds the user to wear the Protective Mask and since he is not able to perceive hazards the device is doing it for him. This might be the first step in increasing the benefits of wearing regularly the Mask.

The Mobile Application (3) is based on the storage of all information gathered by the three devices but it provides the user three simplified parameters thorough icons: breathing rate, the air quality (related to the level of VOC) and Protective Mask wearing frequency.

Thanks to the application the user can have a complete image of his condition and behaviour - if he was wearing Protective Mask when the air is polluted and how and when his breathing frequency is getting worse. Data are shown on daily level but also in form of statistics. The statistic data represents an element that increases the visible benefits in using the protective device; the worker can see the health progress that he is making during the time he wears the mask.

In this way we have created a plurisensorial wearable system with several features: (i) replace the human nose in sensing properly the environment providing the user with objective data; (ii) monitor the respiration giving the user feedback in real time to increase awareness about personal health; (iii) show statistic data of mask wearing frequency in relation to the presence of dangerous particles.

The system consequently creates a "plurisensorial new experience" that enhances workers' perception and should generate a change in the individual and group behaviour.

4 Conclusions and Further Development

The main goal of our research project was to create an interactive experience based on existing sensorial technology in order to increase worker consciousness toward their health.

Twenty workers have been observed, interviewed and engaged in order to understand their needs. The observation was focused on the analysis of the users and their behaviour in the context of their work in order to understand the way they use the current IPD (Individual Protective Device) individuating strength and weakness. Then, a semi-structured interview was submitted to the workers.

The interview had the objective of defining and setting the users expectation from the novel system. Finally a focus group was carried out to figure out, define and set with the worker the requirements and the experience that the system should provide.

The engagement of the user helped us out to stress the main core and added values of the system:

- Increase the awareness of health condition by monitoring environment and personal indicators in order to define the working condition based on objective data;
- Improve the comfort of use by generating a new smart system designed with more attention to the wearability, material (breathable) and to the connection to the body/face.

Currently we are in the phase of realisation of the functional prototype that will represent formal and technological result of our research. The next step will be testing of the prototype with end users and formulation of obtained results in order to understand if our objective was reached.

We firstly have to understand if we shaped the technology in an acceptable and desirable way for the user.

We expect and are positive to have results showing that: (i) the improvement of the mask aesthetics (i.e. the use of textile material) reduces barriers related to the comfort, (ii) the use of wearable technology and design solution creates benefits related to the perception, motivate and educate users; (iii) the way the information elaborated by the technology is clearly transmitted to the user.

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A Study of Viewpoint and Feedback in Wearable Systems for Controlling a Robot Arm

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Abstract. This study examines the feasibility of an integrated motion and vibrotactile system for controlling a humanoid robotic arm using natural and intuitive movements rather than a complicated control schema. We examine a head-mounted display integrated into a system of arm-based motion sensors that control a humanoid robotic arm to determine if there is an observable difference between third-person and first-person perspective in the control of the robot arm. We look at vibration as a form of haptic feedback to relay the limitations of the robot arm back to the user. An experiment shows 30 participants were able to complete both gross and fine motor control tasks without fail indicating that this type of sensor based control systems is intuitive and easy to use. The majority of participants found the method of control to be intuitive, the inclusion of first-person perspective to be beneficial, and the vibration feedback to be either inconsequential or confusing.

Keywords: Personal sensor networks · Telepresence · Human-Robot Interaction · Wearable systems

1 Introduction

As communication technologies have become more sophisticated, we have begun to see an emergence of telepresence applications that allow for realistic human interaction. However, programs such as skype, facetime or snapchat cannot deliver physical interaction with the remote environment. As robotic technologies also become more sophisticated, robotic telepresence has begun to take a more important position as it bridges the physical gap of telepresence and allows the user to interact with the distant physical world instead of being a passive observer.

Intuitive robotic control through telepresence also allows for many new and important applications that may not even be possible through normal human physical interaction. Robots, when used as an assistive device, allow a disabled person the ability to perform difficult tasks. Robots also have the potential to be stronger and use sensors not available to humans, providing controllers with superhuman abilities they could not normally possess. In order to facilitate the ease of use of this emerging technology, it is important to understand the best practices for maximum usability, with one of the most important being system intuitiveness.

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We propose a system that does not adapt recorded human movement to fit robotic restraints but instead influences human movement to the limitations of the robotic avatar. This allows better direct control of robotic parts without diminishing the intuitiveness of interface all the while providing a more natural reaction from the robot.

2 Background

Human-Robot Interaction (HRI) has many interesting aspects; however, we focus mainly on control interactions as opposed to autonomous robotic interactions with humans. It is important to take into consideration the perceived interaction with the avatar and it has been shown that autonomic behaviors such as breathing or blinking help to improve the quality of interaction [1]. With this addition, the human participants felt more of a presence interacting with the android than with the same controller through a video monitor. Tsui et al. [2] performed a survey of minimal non-manipulative telepresence robots and found that human poses lead to more perceived positive interactions with coworkers (i.e. eye contact, facing coworkers, and adaptive vocalization). Moreover, a control scheme that can reduce the cognitive load of the user would lead to more positive interactions; so an intuitive system is ideal.

Kristofferson et al. [3] found a correlation between robot formation (i.e. spatial position and rotation) with the human subject and perceived quality of interaction as well as feeling of presence for the controller. It was hypothesized that if the telepresence avatar moved into a similar formation as a human when interacting (such as following, face-to-face or side-by-side) there would be a much higher perception of co-presence. If the consensus is supported that robotic interactions are more pleasant for the human when having human-like interactions, then it makes sense that human-like motion would also be a preferred method of interaction, as well as being an intuitive method of control to ensure effective co-presense.

Key technologies in human motion controlled robotics are the motion capture system, the robot control system, perspective and telepresence. We discuss these next.

2.1 Motion Capture Systems

Three common types of human motion tracking systems are optical marker-based systems, optical depth camera systems, and inertial measurement unit (IMU) systems.

The traditional form of motion capture involves a series of infrared cameras that surround a capture space [4]. The subject must wear reflective markers specifically designed for camera capture. The advantage of marker-based capture systems are in a much greater capture accuracy, generally found to be less than a millimeter [5–7]. A number of factors affect accuracy such as: marker size/distance [8, 9], number of cameras/positioning [8–10], environmental lighting [9], and occlusion as a result of body positioning or environmental effects [10]. The space requirements make such capture systems only usable in preconfigured environments [11]. As a general input device, the need for very controlled environments makes such systems unsuitable for many applications, especially robot control in unconstrained environments (such as outdoors), which this work addresses.

Depth camera tracking is becoming more popular due to inexpensive entertainment devices such as Microsoft's Kinect [10, 13], which is composed of an infrared emitter, depth camera and an RGB camera, as well as a development kit that allows for skeletal joint tracking and facial recognition. The Kinect system senses depth by emitting an infrared light pattern into the environment and creating a depth map of these dots using the infrared camera [14]. Depth camera tracking suffers the same occlusion disadvantage as other optical capture systems, usually to a much greater degree due to the smaller number of cameras in use. Furthermore, depth cameras that use an infrared pattern projection system are only useful in an indoor environment and limits the general usage opportunity that outdoor assistive robots could provide.

Inertial Measurement Units (IMUs) are sensor-based motion capture system that require the direct application of a series of sensors (including accelerometers, gyroscopes and magnetometers) to the body. This type of sensor network has been shown to be useful in entertainment and exercise applications, both for its relative low-cost and encouragement of active play [15–17]. The main advantage of wearable IMU sensors is the ability to track motion in any environment thus increasing the number of useful applications [11] as well as avoiding the issues of occlusion that are common in optical systems. A wireless IMU system allows for captures in a natural setting for situations that would be difficult to capture traditionally (such as skiing [11] or skydiving), as well as the convenience of motion capture not being tethered to a single location. There is a perceived inaccuracy of IMU systems when compared to traditional optical motion capture. However, a recent study by Godwin et al. [18] observed modern IMU error rates and found a rotational error of less than a degree when the sensor is motionless, and less than four degrees during constant motion. Similar error rates were found when compared to a market leading optical maker-based system in an ideal environment. Moreover, the broader range of use in different situations (i.e. outdoors) makes them particularly attractive for motion capture applications in unconstrained environments. For these reasons, we choose to use IMU-based motion capture systems.

2.2 Robot Control Systems

A noted problem in robotic control using natural human movement is the effective handling of swift and complex human motion. A study by Pollard et al. [19] suggested an algorithmic solution in which motion data is retargeted to constrain the human motion to the robot's range of motion. This technique has its drawbacks, as subtle human movements are lost. This technique is only effective with pre-recorded motion due to the difficulty matching robot movements to human motions in real-time.

Gesture recognition [20], has the advantage of being able to detect specific motions in real-time, and map them to repeatable and predictable robot movement. This, however, is not useful for tasks that require unique motions not found in the gesture library, or for tasks that require fine motor control precision as critical for success. Moreover, it requires the user to learn and remember a dictionary of gestures to complete tasks reducing its intuitiveness.

Applying real-time human motion to animated characters, Shin et al. [21] suggested an importance-based real-time kinematic interpretation algorithm that would decide the importance of joint angles and end effector locations based on situation. Instead of just using the desired end position of limbs like hand position for a grasping task, this approach takes into account joint angles and gives them an importance level to preserve using a series of algorithms. This approach maintains the problem of discrete aspects of the human motion not being retained on a 1-to-1 scale. However, a robot being a physical avatar and an animated character being virtual, the similarities are encouraging. We examine the 1-1 motion mapping control system in this work.

Due to the relatively low barrier-of-entry, the majority of studies using optical-based real-time motion capture for robot control have used depth cameras that provide skeletal tracking algorithms. A multitude of studies have provided different proof-of-concept control schemes using the Kinect as the main control input [22–25]. Many studies have used the Kinect's built-in tracking system as the basis of gesture recognition for robotic teleoperation with some degree of success [26, 27], allowing the user to relate natural motions to robotic actions, although not on a 1-to-1 scale. The Kinect sensor is also capable of using its skeletal tracking software to transmit joint angles to a robotic counterpart in real-time [28–30]. However, given the small capture space and single-camera fidelity of the capture, the accuracy is limited, as are the practical applications for the outdoors.

There is some precedent in using IMU sensor systems for robot control. Miller et al. [31] developed an IMU system for controlling NASA's Robonaut [32], a humanoid telepresence robot designed for use on the international space station. The problem of human-robot motion matching was again indicated, wherein the human either moves too fast for the robot servos to match or tries motion to compensate for the latency of the robot, suggesting that haptic feedback could alleviate the issue. Another similar robotic build is the Telebot prototype [33], which includes IMU motion control and a head-mounted display, although no publications have been released aside from the initial design of the prototype. As modern IMU sensors become more accurate, it seems like an obvious choice for real-time telepresence avatar applications due to the low cost of the sensors, the ease-of-setup, the avoidance of environmental problems like occlusion, and the option for use in unconstrained environments.

Haptic Feedback in Robotic Control

There is some precedence of using haptic feedback in robotic control. This is usually used as a form of sensory feedback to give the user a sense of presence by virtually simulating touching an object, as well as to allow for more accurate control by providing more information about the robot's environment, as used in [34, 35]. This is especially useful in robotic-assisted surgery systems, in operations that normally are more accurate with a sense of touch (such as feeling the flesh when suturing) [36].

In this study, we do not use haptic feedback in the traditional form of creating a virtual object, but instead use it to create a tangible virtual boundary to allow the user to "feel" the limits of the robot.

2.3 Perspective and Telepresence

A discernable gap in the research literature is evident when it comes to the most efficient perspective for telepresence or robotic avatar control, with the majority of studies not addressing the possibility of perspective differences at all. We have seen from virtual reality studies that there is some debate on the use of different perspective modes. The majority of studies done with motion control of a robotic avatar either utilize a third person perspective in the same room as the controller (as in [20, 28–30]), or a first person perspective for use with telepresence robotics without questioning the effect different perspectives could have on the operation (as in [31, 33, 37]). Some studies provide the assumption that a first-person perspective will provide a feeling of virtual presence to the user due to an egocentric perspective or a more natural control [37], but this assumption has not been adequately explored Formal comparisons of perspective differences do not exist in these studies.

An experiment on robotic teleoperation by Jun [38] suggested that more research into perspective differences is required, when it was found that a group with a first-person perspective performed with 25% more elapsed time than a group that was allowed both third and first person perspectives. Okura et al. [39] also confirmed that the addition of another viewpoint allowed for more accurate teleoperation. Rybarczyk et al. [40], found that a third person view allowed for more precise learned control of the avatar's limbs, although the self-reported feeling of presence was higher in a first-person perspective. The question of whether a perspective difference is beneficial in controlling telepresence robotic avatars becomes the basis of our work.

3 System Overview

The prototype device consists of four main parts: the humanoid robot, the motion control sensors, the feedback system, and the Oculus Rift head-mounted display, as shown in Fig. 1. The motion sensors and the vibration motors are built into a wearable jacket to control the humanoid robot using normal body motion.

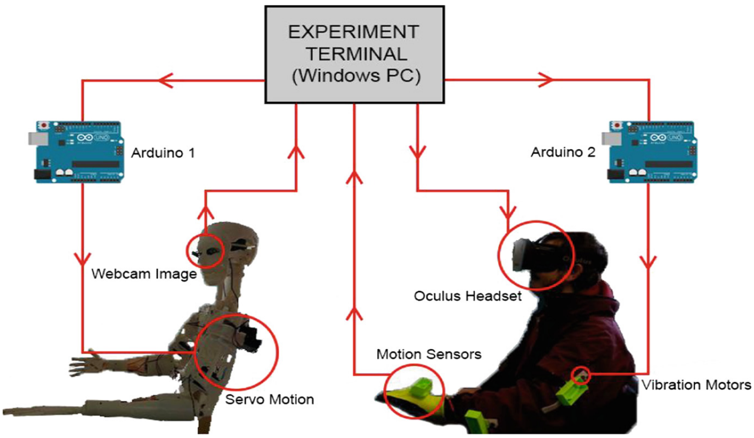

Fig. 1. Full device overview

The 3D-printed shell of the robot is based on an open-source project the creators have dubbed InMoov [41] and is functional including arms, hands, head and jaw motion. However, for the purposes of this experiment only the left arm is used. The digital servos are controlled through an Arduino system, and are sent updated servo positions every program cycle should a difference of more than half a degree of rotation be detected from the IMU sensors.

The system uses inertial measurement units (IMUs) to track the motion of the participant at three locations on their left arm. The IMU sensor used was Microchip's now-unsupported Motion Sensing Demo Board, which is composed of an accelerometer and a gyroscope chipset [42]. Before each task, the user must be sitting with the elbow of their left arm bent at a 90-degree angle. This calibration pose ensures that the coordinate system of the sensors match the robot's coordinate system [42].

The wearable jacket also housed the wiring and vibration motors needed to provide vibrotactile feedback. This feedback differs from other types of haptic feedback in robotics, in that it is a signal to notify the participant when they were near or outside of the robot's range of motion. A glove was also fashioned to the haptic jacket in order to allow finger control. Due to the lack of robustness of the finger ligament design, the fingers had a simple binary state of open or closed. The flex glove was a simple work glove outfitted with a flex sensor that detected the angle of the user's fingers to detect an open or closed state.

To provide a first-person perspective, two HD cameras are mounted in the eye sockets of the robot. The images are sent to the display of an Oculus Rift virtual reality headset simulate first person perspective so the user has the viewpoint of the robot as seen in Fig. 2.

Fig. 2. Example of first person perspective left and right eye views

Device Limitations

A major problem with the robot design is the difference in possible movement times between the human arm and the robotic arm components. The further away from the controlling servo the point of rotation is, the longer it takes to move the part. In terms of human parts, this means the part corresponding to bicep rotation moves significantly slower than wrist rotation, which is almost instant. This is most likely due to the fact that as we move further from the tip of the hand the servo is required to move more weight. The shoulder servo also tends to move faster when rotating downwards as opposed to upwards due to the benefit of the force of gravity.

4 Experiment

The goal of the study was to examine the usability of the motion controllers, to determine if there was a difference in usability when in first or third person perspective, and to determine if one style of vibration feedback was a more effective form of vibration for notifying the participant about the range restrictions of the robot.

Testing involved eight tasks to be completed by the participants with different combinations of variables for each task. The session can be broken down into two main blocks of tasks, involving completing four tasks with and without the Oculus Rift (OR) virtual reality headset to obtain the first-person and third-person perspectives of the robot. As well, each task needed to be completed using both of the different types of haptic feedback. The two tasks involved using the wearable jacket to move the robot arm with both a gross motor movement task and a fine motor movement task. Task completion time is used as the metric to measure usability by comparing the time to complete each task under the various testing conditions.

After all eight tasks were complete, the participants were asked to complete a questionnaire regarding the tasks completed and devices used in the session. Participants were asked to provide their opinions about the prototype and the technology.

Each of the eight tasks performed by the participants had one of two objectives. The first task (gross motor task) involved moving the whole robotic arm in whatever way was easiest for the participant in order to move a 15 × 15 × 15 cm. cube off of a raised platform. The task was considered complete once the cube was entirely off of the platform area, with no part of the cube touching the platform. This task was designed to require larger, less accurate movements. The second task objective (fine motor task) involved grasping a mug by its handle on a raised platform without knocking the mug off. This task required a finer control of the prototype than the gross motor task in order to position the robot fingers within the handle. Figure 3, shows the setup of both tasks. A maximum time of five minutes was permitted for each task before it would be considered a failure. Order of the tasks was randomized.

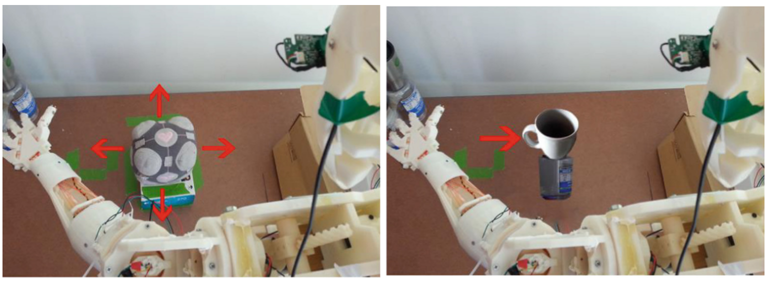

Fig. 3. 3rd person perspective setup of the gross (left) and fine (right) motor tasks.

5 Results

A sample of 30 individuals completed the study, with ages ranging from 19 to 53. The majority of respondents fell into the range of 20–30 years of age. Due to the small sample of ages in other ranges, it is difficult to perform a meaningful age comparison. No exclusion criteria were required aside from the participant being physically able to move their left arm in a meaningful way to perform everyday tasks. Out of 30 participants, 17 were male, 13 female, with 23 participants being right-handed. Ages ranged from 19 to 53. Of those thirty participants, 23 reported having previous experience with motion controllers, with 13 of those 23 reporting a good amount of experience. Every participant completed all eight of the tasks without fail.

Prior Experience

Although there is a large disparity in sample size between those who self-report having experience with motion controllers ($n = 23$) and those who are on the opposite scale ($n = 6$), there is not a large difference when comparing the means between these two groups. The experienced group did have slightly lower mean task completion times of 26.77 s versus 29.40 s for the less experienced group. However, we cannot call this finding significant as the sample difference is too large.

It is worth commenting on the significance value of gross vs. fine motor task comparison, which is approaching a significant value. Although it is not significant in this instance, this suggests that further research might find a significant value if a larger sample was used or confounding factors were minimized. This would suggest that those participants with experience using motion controllers have an easier time completing fine motor tasks than those without prior experience.

Perspective

Using a within-subjects t-test, it was determined that there was not a significant difference between the timing data of a first-person perspective versus a third-person perspective. When examining the fine motor tasks specifically, we get a t-value of 0.505301721 and a p-value of 0.617167 at $p < .05$, clearly not a significant result. When we compare the average gross motor tasks in the same vein, we obtain a similar result (t-value of −0.816134797, p-value of 0.421076529, not significant at $p < .05$). It would seem that perspective, in the way we have defined it, did not have a statistically observable difference on task completion times in this study.

Feedback

Vibration A, a type of vibration that is switched on as soon as the user leaves the safe range-of-motion, and Vibration B, a type of vibration that increases in intensity as the user nears the boundary of that range was examined. Using a within-subjects t-test, the mean time of all tasks completed with Vibration A was compared to all tasks completed with Vibration B, and was found to be not significant at $p < .05$ (t-value of 1.652456473, p-value of 0.109241). However, this value is approaching significance, and should not be disregarded completely. Yet, when separating perspective viewpoints in the analyses, the 1st person perspective completing the fine motor task (t-value of −2.000623429 p-value of 0.05487268) is significant. The value for the gross motor task is also approaching significance under the same conditions (t-value of

1.876909188 p-value of 0.070624863). This suggests that Vibration A, the binary vibration style, is more effective at providing feedback for fine motor tasks when the participant is wearing the Oculus Rift headset in the first-person perspective. Perhaps this indicates that Vibration A is easier to interpret when the user cannot observe their own arm position due to the binary simplicity of the feedback (there is no range of strength to judge, only ON or OFF). When asked for a preference on the post-questionnaire, more users reported a preference for Vibration A.

Carry-over effects are a possible weakness of within-subject experiments like this one [43]. The prototype was designed with the intention that it would be intuitive enough for any person, technical or non-technical, to use effectively on the first try. In order to determine if any learning or practice effect was present when using the device, the first random task completed by each participant was noted. The timing data of the first tasks were then compared to the mean of all the remaining tasks (not including the first task) using a within-subject t-test to determine if there was a significant difference not accountable to individual differences (i.e. the difference is not accountable to an individual's level of expertise with the system, but the system itself). This was found to be significant at $p < .05$ (t-value of 2.640795829, p-value of 0.013185). This shows a statistically observable difference between the timing data of first task recorded and the subsequent tasks completed, suggesting that the first-time user does, in fact, encounter at least some learning curve. The variance of the first task timing data was also higher when compared to all other tasks (var. 890 with SD of 29.8, the var. of other tasks were all below 440 with standard deviations below 20).

It is safe to interpret that at least some practice effect was occurring between tasks. If we observe the average time for tasks in the order they were completed, we can observe an obvious downward trend as in Fig. 4.

Fig. 4. Average task time by task completion order

Comparing the mean performance on the first four tasks with the mean performance on the last four tasks, we see a greater significant difference (t-value of 2.964105416, p-value of 0.006013228). If we take the first four tasks as the learning time, this suggests that there is an average learning time of 122.01 s (the sum of the first four task means).

As we can see, the majority of learning occurs between the first and second tasks. To isolate this learning effect, all the statistical tests were completed again, this time removing the first completed task from the analysis. When examining the mean task times, we again find insignificant values for perspective difference, and in fact find a much less significant comparison of the haptic feedback vibration (p-value of 0.793 versus the original p-value of 0.109). This may indicate that the vibrotactile feedback is helpful in learning to use the system. However, more study is required.

Self-reported Results

In order to determine consensus, mode and interquartile range (IQR) is calculated for each item since comparing means may not be valid for ordinal data. The strongest consensus found on the post-questionnaire was in regards to the motion control. 83% of respondents agreed that the motion control was intuitive, with no respondents disagreeing with that claim (with a strong consensus indicated by an IQR of 0). This would indicate some degree of success in the original goal outlined in the problem statement of creating a system intuitive enough to be controlled without training. Confirmation was found when examining the rephrased question.

Another finding is the consensus that the use of the Oculus Rift headset was beneficial to the experience, to which 23 users agreed with a mode of 4/"agree" and an IQR of 0, indicating a strong consensus. This finding seems to be confirmed when we examine the inverted questions for reliability. When asked about perspective specifically, users reported that it was easier to visualize how to move (mode of 4/"agree", IQR of 2) and easier to control (mode of 4/"agree", IQR of 2) from a first-person perspective, although the consensus is not as strong. However, actual performance times do not necessarily support these perceptions.

The haptic feedback was the core topic with the most discordant opinions received on the post-questionnaire. There was a disparity of preference for Vibration A, with 13 respondents preferring it to Vibration B, which 6 respondents preferred (although the mode response was neutral, with 11 respondents). For questions regarding the understanding of the vibration signals, there was more confusion than understanding, as in the question "I was easily able to tell what the vibration signal meant" with 16 users disagreeing (mode of 2/"disagree", IQR of 2). This finding was corroborated in the inverted question "I couldn't tell which sensor the vibration was indicating", with 15 users agreeing (mode of 4/"agree", IQR of 1.75).

The strongest consensus found for vibration comes from the question "The vibration feedback made me more likely to think a task wasn't possible", which was disagreed or strongly disagreed with by 19 respondents with an IQR of 1 and a mode of 2/"disagree". Effectively, this means that the vibrotactile feedback did not hamper the ability to complete a task.

6 Conclusions

In this work, we presented an initial study on a wearable system that allows users to easily learn to control a robotic arm to complete tasks involving picking up and moving objects. The system as a whole showed to be intuitive with a very low learning curve, with users able to learn to use the system in just a couple of minutes. Importantly, we examined how to communicate limitations of the robotic arm to the human controller and showed that a vibrotactile wearable system made the users feel more comfortable controlling the arm in first person perspective.

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Enabling Touch-Based Communication in Wearable Devices for People with Sensory and Multisensory Impairments

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Abstract. Tactile signing and touch-based alphabets are among the primary communication systems for people who suffer from sensory or multisensory conditions, such as, blindness or deaf-blindness, respectively. In the last decade, several research projects based on sensory substitution focused on developing novel interfaces. However, people who are sensory-impaired still lack reliable technology for interacting with the world. To this end, wearable devices could have a significant role in providing individuals with support for daily activities, communication, and social inclusion. In this paper, we introduce a categorization based on technology for sensing and representing the main components of touch- and gesture-based communication systems (i.e., movement, gesture, pressure, and touch) to provide an understanding of the technical and human factors which affect or foster the development of new assistive technology.

Keywords: Deaf-blindness · Sensory substitution · Touch-based alphabets · Tactile languages · Wearable devices

1 Introduction

People who are blind or deaf rely on sensory replacement to compensate for their condition, and to interact with the world: hand-based communication techniques, such as Braille or sign language, are among the most common forms of communication for the blind and the deaf, respectively, in addition to residual vision or hearing.

Conversely, individuals suffering from multi-sensory impairments primarily use touch to communicate. Touch cues are the basic element of functional communication, which is utilized for expressing simple needs, concepts, and sensations. Also, advanced tactile signing techniques and tactile alphabets, such as, the deaf-blind manual, Lorm, or Malossi, are widespread among people who are deaf-blind, though their communities are organized in niches in which small groups develop, use, and share their own communication systems.

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In the last decade, several tangible interfaces explored touch-based communication as a way to transmit tactile sensations remotely [1]. Also, recent devices introduced the possibility of incorporating touch-based languages into wearable technology in the form of gloves to help the deaf-blind interact with the world [2–4]. However, lack of attention to human factors led to demonstrators with little usability, to prototypes having poor acceptability, and to individually-crafted pieces of technology which are not suitable for manufacturing. Consequently, even the most developed technology for the largest group of people who are affected by sensory conditions, that is, Braille displays for the visually impaired, is available to 5% of the blind population, only, due to its requirements and costs, and to poor literacy [5]. Situations in which multiple sensory impairments occur show lower rates due to additional issues (e.g., cognitive conditions). Indeed, especially in the field of assistive technology, ergonomics play a crucial role in regard to usability; in addition, the degrees of freedom of the hands inherently involve major design challenges. Furthermore, industrial manufacturing poses additional constraints, though it offers valuable insights into the feasibility of specific solutions, and it suggests improvements to the design patterns.

In this paper, we focus on the design glove-based assistive technology for people with sensory and multisensory conditions, and we discuss its challenges from both ergonomics and feasibility perspectives. To this end, we detail the dynamics of touch and motion cues involved in tactile signing techniques and alphabets, in order to categorize them with specific regard to their implementation in wearable technology.

In particular, we identify the four basic components of hand-based functional communication and tactile languages, that is, motion, gesture, pressure, and touch; we discuss how they can be leveraged to encode information, from concepts to words and letters. Also, we describe the implementation of the four basic components into wearable devices by means of different types of sensors and actuators. Moreover, we review current wearable technology for enabling people with sensory and multisensory impairments to communicate, and we analyze their pros and cons in regard to usability and feasibility.

Furthermore, by taking into account additional human factors in the use of tactile languages (e.g., dialects, abbreviations, personalization of gestures and touch cues, and role of individuals' milieu), we address the dynamic complexity of the adoption of glove-based technology from technical (both hardware and software) and ergonomic perspectives, from qualitative and quantitative standpoints.

Finally, we evaluate and suggest several design patterns for incorporating touch-based communication systems into viable hand-based devices. By doing this, we aim at providing a better understanding on the development of new glove-based devices, at offering insights on how to improve existing solutions, and at fostering a more user-oriented approach in the design of wearable assistive technology.

2 Modeling Tactile Languages

In order to evaluate technology and techniques for sensing and representing touch-based alphabets, we identified the main components involved in the representation of languages in tactile form. Indeed, we can describe all tactile languages and touch-based alphabets as consisting of sequences of symbols based on touch cues. However, they significantly differ from one another in components, such as, structure, representation, type of actions, and informative content. For instance, Braille utilizes small blocks incorporating six tiny dots that can be perceived using the fingertip of the index finger; sign languages involve different configurations of the hand and their position with respect to the chest, the head, and other areas of the body, and they convey the meaning of words and concepts; tactile signing utilizes the surface of the palm and the back of the hand as a space for representing letters by drawing a shape; the Malossi alphabet utilizes specific spots of the palm which can be pressed as in a typewriter.

We categorize the majority of tactile languages as based on three types of actions, that is, gesture, pressure, and touch. The former consists in peculiar configurations of the body and, specifically, of the hand; pressure involves stroking, pushing, or tapping on a smaller area of the body; the latter consists in smooth differences within a tiny portion of space, such as, the texture of a surface, which require fine perception. They are described in detail later in this Section, and they primarily consist of a static configuration (e.g., dots in Braille). Additionally, symbols can be represented by gestures and cues having dynamic components (e.g., touch cues in the deaf-blind manual). As a result, movement can be regarded as an essential part of the alphabet which can span across gesture, pressure, and touch, as an additional layer. This distinction is consistent with the approach adopted by Pederson: in [6], he introduces the egocentric interaction model, in which concentric circumferences are defined based on the distance from objects and on the type of interaction (i.e., observation, manipulation) that can occur in that specific portion of space.

From an interaction design standpoint, touch-based communication can be regarded as consisting of three different systems of actions occurring at a different scale of the human body. For instance, let us imagine a third observer located in front of two individuals communicating using different touch based languages. Gestures involve configurations of the whole hand; usually, the whole upper part of the body participates in the delivery of a specific meaning, also. Consequently, gestures are visible and they can even be understood from some distance. This results in an interaction area which is a 3d space that can be modeled as a cube having sides of approximately 1 m each. Conversely, pressure cues are realized on smaller portions of the body (usually the hand); although the observer would see that the individuals are exchanging messages in tactile form, he/she would be able to visualize tactile cues without any possibility of understanding the content of the messages. Pressure utilizes an interaction space which is smaller compared to gesture. It can be modeled as a bi-dimensional surface over the skin (e.g., over the palm or the back of the hand) having the size of a sheet of letter paper. Finally, a third observer would neither see nor catch any communication occurring via touch cues, as they are realized in a space which is smaller than the fingertip. Usually, communication via touch cues can be modeled as a one-dimensional space, because its atomic components can be represented on a single line. Figure 1 shows the interaction space in which the components of touch-based languages are located.

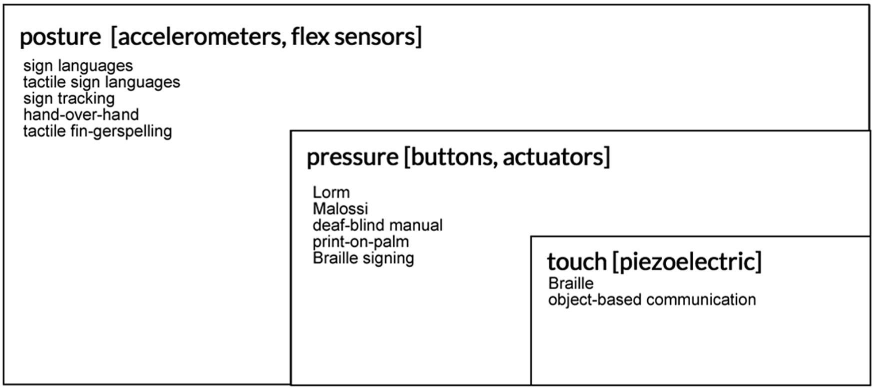

Fig. 1. The main components of tactile cues, and their hierarchy in space.

Categorizing languages into their tactile components has several advantages, as it enables an easier classification in terms of technology for sensing and representing tactile cues, and it supports the definition of common design principles. Also, as shown in Figure languages can be grouped with respect to their components: there is strong correlation between language clusters, interaction spaces, type of interaction cues, and sensors and actuators which support acquiring and representing their components. Tactile communication systems based on languages include sign languages and their modifications, including adapted sign languages, tactile sign languages, sign tracking, hand-over-hand, and tactile fingerspelling; conversely, languages which rely on pressure cues include speech-reading techniques, such as, Tadoma, or on-body signing methods, such as Lorm, Malossi, deaf-blind manual, print-on-palm, and Braille signing; finally, touch cues are utilized in Braille and in tactile symbol systems which utilize specific textures and patterns in the surface of objects to represent concepts.

As shown in Fig. 1, there are no intersections between languages, which results in a better distinction in terms of sensors and actuators supporting their implementation. Nevertheless, our categorization includes infrastructure-based devices, such as [7], or [8, 12], which use a webcam and Leap Motion, and Microsoft Kinect, respectively, to acquire gestures and translate sign language into text. However, in this paper, we focus on wearable interfaces, only, and particularly, on glove-like devices. As a result, infrastructure-based systems are beyond the purpose of this work. Although we discuss only a small niche of the large ecosystem of assistive technology, our findings can have a broader impact on other fields.

3 Sensing and Representing Touch-Based Alphabets

In this Section, we focus on the interaction components of languages (i.e., gesture, pressure, touch, and movement) and we discuss their implementation using technology for sensing and representing stimuli in the tactile form. To this end, we review the literature and identify common issues and potential solutions.

3.1 Gesture

Gesture refers to the static configuration of the hand, mainly represented by its components: orientation over three axes, that is, 3 degrees of freedom (DOF), flexion/extension, abduction/adduction, and supination/pronation of the wrist (3 DOF), and flexion-extension of the five fingers, each having 4 DOF (except the thumb, which has 5 DOF) [9]. As a result, the gesture of the hand alone has a total of 27 degrees of freedom. For the purpose of this work, we will consider movement as a separated from gesture, and we will focus on the static component of gestures. As 27 DOF pose important challenges on hardware and software development, the majority of projects limit orientation to 3 degrees of freedom, by eliminating the wrist, and by considering the palm, only. To this end, the main components for sensing gesture are inertial measurement units (IMUs), which became a standard thanks to the development of miniaturized sensors that were included in smartphones and immersive head-mounted displays. IMUs acquire the components of movement over each axis using a combination of accelerometer, gyroscope, and magnetometer, thus, leading to a total of 3 to 9 DOF. This strategy is utilized in [10, 11], and in many different research papers, which mainly describe interfaces supporting sign languages. Indeed, both the literature and commercial devices demonstrated that IMUs are the most appropriate equipment for sensing orientation and acceleration of the hand. As the interaction space in which gestures are realized is always aligned with the frontal panel of the individual, any movement has a relative orientation. Therefore, 6 DOF (accelerometer and gyroscope) suffice for detecting movement. Nevertheless, adding magnetometer enables additional significance and interaction opportunities which goes beyond tactile languages; for instance, a magnetometer-equipped glove can be utilized in combination with GPS sensor and data to provide individuals with information about the surrounding environment when users are pointing their hands towards a specific building.

As regards to movement of fingers, a large amount of work realized in the Virtual Reality can be leveraged for enabling gesture-based communication. There are two prominent types of technology can be utilized for acquiring fingers' movement: flex sensors and inertial measurement units, which represent the gesture of each finger using 1DOF and 3–9 DOF, respectively. Although they support detecting flexion/extension and adduction/abduction, each phalanx has 1 degree of freedom (i.e., flexion/extension), leading to 4 degrees of freedom of each finger (the thumb has 5). Consequently, precise detection would require incorporating arrays of 4–5 sensors for each finger. As a result, accurate recognition of the movement of phalanxes can be realized with expensive equipment, only. Nevertheless, the majority research studies considered 1DOF as enough for recognizing all the possible configuration of a single finger in almost every existing language based on gestures. The authors of [13], coherently with several research papers, incorporated flex sensors in wearable gloves for the recognition of sign languages. Usually, five sensors are mounted on the back of the hand. Although this positioning avoids having sensors on the palm and, thus, does not interfere with grasping, it leads to several issues in producing industrial products, mainly due to the mechanical stress insisting on different areas: the proximal part of sensors, that is, where they are soldered to the rest of the device is subject to rotation during adduction/abduction, and to increasing stretching during flexion; also, the area between the proximal and the middle phalanx is critical, because it forms a sharp angle wider than 90° during flexion, which, in turn, affects the accuracy of the sensor.

A different approach was adopted by [10], in which a device incorporating surface electromyography (sEMG) sensors capture electric signals which can be analyzed to decode the degree of flexion-extension of fingers with some degree of accuracy. Nevertheless, they show low reliability in recognizing fine movements of fingers, and thus, they are not suitable for representing sign languages in which there is a rich variety of gestures, because they would require extensive effort for disambiguation. Therefore, the most suitable devices for sensing gestures are IMUs and flex sensors. However, further investigation about their accuracy, computational cost, mechanical reliability, ergonomics, and user experience is still required.

As regards to representing gesture, there are several limitations in reproducing gestures using wearable devices. As a result, the only attempts of actively displaying the configuration of the hand have been realized using motorized hands or robots [16], which are extremely expensive and, thus, not suitable for any actual context of use. Consequently, the majority of devices based on gestures are input-only.

3.2 Pressure

In our work, we define pressure as single or multiple cues which can occur – individually or in a sequence – on specific areas of the hand. Two main components of pressure can be modulated, that is, intensity and location, resulting in communication systems having 2 DOF. In [2, 4], the authors present two devices based on pressure cues which exactly reproduce the layout as defined in the Lorm and Malossi alphabets, respectively. However, they use location only, to simplify the implementation of their gloves. This is mainly due to the complexity of current pressure sensors, and of the difficulty of incorporating them within the very small area of the hand. As a result, three types of sensors have been proven to support recognition of pressure: tactile-feedback switches, capacitive sensors, and piezo-resistive sensors.

Also, the authors of [14] introduce an American Sign Language translator based on 8 capacitive touch sensors placed over the palm, and on the tip of four fingers. However, this results in modifying the alphabet, which involves additional training, longer adoption curve, and higher risk of discontinuation.

Moreover, several alphabets based on pressure (e.g., deaf-blind manual) include letters consisting of multiple simultaneous cues, multiple independent channels have to be defined for sensing input. In this regard, languages have three additional degrees of freedom, that is, simultaneousness, duration, and sequence of cues. The former refers to the number of locations that can be elicited at the same time; duration can be utilized to distinguish letters, such as, in the Morse code, or to represent icons and concepts; the latter is specifically utilized to represent concepts as shortcuts, or to discriminate among letters involving cues on the same space. Indeed, as incorporating sensors in viable glove-like devices has to take into consideration manufacturing issues, one-wire capacitive sensors still are the primary detection equipment, though they involve additional issues in terms of compensating for spurious signals due to interference caused by the hand.

In regard to representing pressure cues on the hand, the most viable approaches so far have been described in [2, 4]. Both introduce two wearable communication and translation devices for the deaf-blind incorporating a number of vibrating motors that can elicit tactile stimuli in the form of displacement over the surface of the skin. The Lorm glove utilizes one degree of freedom, only, that is, different areas of the hand are stimulated with the same intensity in order to reproduce tactile sensation. Conversely, the authors of [4] utilize two degrees of freedom: by adding intensity, they can represent up to 5 distinguishable pressure cues over the skin, and elicit different tactile sensations.

3.3 Touch

Touch is the least utilized tactile cue in communication, especially at the beginning of the training of a new language, because it requires individuals' perception to be accurate and trained. Despite the difficulty in recognizing different textures on a surface, Braille is the most utilized method for writing and reading, though according several studies on Braille literacy, up to 90% of people with sensory and multisensory impairments are not able to perceive or understand it and, therefore, are considered as Braille-illiterate. Unfortunately, not only tactile alphabets based on touch cues require very expensive hardware, it is extremely hard for users to finely control their touch in order to represent letters and symbols with one finger, only. As a result, languages based on touch use an array of pressure cues to both sense letters. This is compatible with the one-dimensional structure discussed previously. 6 to 8 buttons can reproduce Braille dots at a larger scale, and provide individuals with an easier and more reliable input system. Also, beyond piezoelectric cells in Braille displays, touch cues can be represented using large vibrotactile actuators each representing a dot in the Braille encoding system. As a result, all glove-based devices do not support touch sensations which exactly match the communication system of choice.

4 Human Factors

In the previous Section, we followed a merely mechanical approach to the implementation of tactile languages. Nevertheless, identifying hardware and software requirements and specifications would be sufficient to achieve a viable solution which matches the dynamics of the communication system of choice. Several research and commercial projects followed this direction and led to the development of demonstrators and prototypes which were utilized in controlled test environments, only. In this context, human factors have to be integrated as design patterns: as interaction in the context of disability is always situated, further investigation on common issues and on potential solutions can be realized. In this Section, we focus on the human factors which play a crucial role in facilitating adoption and in preventing discontinuation in the context of assistive technology.

4.1 Barriers to Co-design

Among the main issues in designing assistive technology for people with multisensory impairments there are demographic factors and, specifically, lack of census data and information about individuals' condition, and poor access to user groups. These, in turn, are inherently sparse and, thus, it is very difficult to reach them. Additional human factors involve limited communication and interaction, which affect participatory approaches to the design process. Large diversity between users, education levels, cognitive conditions, and willingness to collaborate, limits the design phase to a top-down activity, only. In this regard, there is a need for identifying and involving patient innovators, who made the difference in developing the first – and still the most utilized – tactile communication systems, such as Braille, Malossi, and Lorm.

4.2 Understanding the Context of Use

Especially if there are no additional conditions (e.g., cognitive disorders), people who are sensory impaired have a much wider and detailed set of needs and requirements with respect to other users in the context of disability (e.g., autism). Therefore, understanding the context in which they will interact with technology and the purpose for using assistive devices is among the most important activities. Specifically, in addition to basic communication needs, they have advanced requirements, such as independent access to information, training, socialization, and work. As a consequence, they have higher expectations about technology as an enabler.

4.3 Training and Frustration

People with sensory or multi-sensory impairments are a very sensitive population. As a result, we expect devices to work since their very first use, and to be 100% reliable. Prototypes and demonstrators frequently lead to frustration in their early adopters if they do not work as expected since their very first use. However, even with mass market devices, such as, smartphones, keyboards, or other wearable devices, time and training is required to achieve a minimum degree of training. If people who are sighted were to avoid using a new smartphone because the autocorrect function fails in completing their messages, smartphones would not be among the most disruptive devices. Also, training is needed in new technology. To this end, individual's milieu (i.e., family, assistants, organizations) have the responsibility to support individuals in their adoption process, rather than discarding technology if they do not work as expected the first time and they create frustration.

5 Market Factors

The design of any technology has to take into consideration both the technical and the human factors. However, this is even more important in the development of assistive technology, and specifically, in the context of people with multisensory impairments, because there are several barriers to including the final user in the design process, such as, the limited number of users who will benefit from technology, and the fragmentation of this niche market into smaller groups.

5.1 Bi-directional Communication is Crucial

There is an urge for additional research on enabling output in touch-based communication. In this regard, recognition and representation of touch work in a completely opposite fashion with respect to other senses, such as, vision, and hearing. In this context, output devices are increasingly effective and performing in representing images, videos, and audio in very high definition. Although they are still far from the human eye or ear, screens and speakers have dramatically been improving their quality and reducing their size, in the last decade. In contrast, image and speech acquisition techniques evolved at a slower pace, and their performance increased in the last few years, only. As a result, output devices have a longer history and are more effective compared to input devices. Conversely, there is a large gap between input and output in touch-based devices. Specifically, very little has been done on eliciting tactile cues, compared to the body of research and commercial work on input devices.

5.2 Glove-Based Devices Can Be Different Than Gloves

Several research projects about enabling touch- and gesture-based communication for people with sensory and multi-sensory impairments resulted in the development of glove-like devices. Unfortunately, several factors make them unsuitable for production and for adoption by their target users. Indeed, mechanical stress on electronic components and stretching of parts including connectors, and flexing areas in which soldering renders the majority of devices which are conceived as a glove unpractical. In contrast, the results studies from other fields about non-conventional interfaces and their social acceptance led to the design of interesting concepts which have better appeal and durability. Similarly, other structures and shapes could accommodate for sensors and actuators, and simultaneously provide higher durability, social acceptance, and easier access to the production phase.

5.3 Organizations as Gate-Openers

Organizations have a key role in fostering research on the introduction of new technology as can be a facilitator or an entry barrier to innovation: with respect to the former, several of them do an excellent work with technology leaders. However, less is being done to support novel devices, because sometimes the need of preventing frustration from the adoption of the wrong technology affects the development of new, effective devices.

6 Conclusion

People who suffer from sensory, or multi-sensory conditions, such as, deafness or deaf-blindness, respectively, rely on sensory substitution to be able to communicate and interact with the world. This includes using languages based on the conversion of words into gestures (e.g., the American Sign Language), in presence of damage to the sense of hearing. On the contrary, blind and deaf-blind people use touch as their primary communication channel for reading and writing, and even for any types of communication need.

In this paper, we specifically focused on touch-based alphabets and communication tools which are currently available to people with sensory or multi-sensory impairments. Specifically, the purpose of our work was evaluating the characteristic which lead to viable glove-based devices for end users. To this end, in addition to describing the features of languages based on touch, we introduced a new approach to the design and development of assistive technology. Specifically, we categorize the majority of tactile languages as based on three types of actions, that is, gesture, pressure, and touch. This, enables further classification based on other dimensions, such as, the space in which they occur, the type of tactile component which they include, the type of sensitivity required, and other components. Also, future work will include the dynamic component of tactile alphabets, that is, movement, and will focus on how it affects the static aspects. Nevertheless, the proposed classification enables to standardize and simplify the understanding and the implementation of both the hardware and the software components of assistive systems.

Furthermore, we described how the four main components of tactile alphabets can be implemented in wearable devices for supporting communication and interaction. Hence, we identified several best practices from the literature and we proposed new evaluation criteria in the selection and in the use of hardware. In this regard, as several design patterns emerge from the scientific literature and from commercial devices, we foster the creation and the adoption of a standard, in order to reduce risk of developing prototypes which increase fragmentation in the scenario of assistive technology without providing any benefit to the final users.

In our discussion, we highlighted several issues, including the lack of output devices and the consequent need for haptic interface which support bi-directional communication. This is particularly important as input-only systems create a barrier to the adoption of technology for touch-based communication, as the user will have to switch between two different interaction systems.

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Wearable Sensor System for Lumbosacral Load Estimation by Considering the Effect of External Load

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Abstract. Anteflexion of the spine is a crucial motion in performing many tasks during work and daily life. It is particularly important in tasks such as providing care to others and carrying objects. To devise measures for preventing back pain, it is necessary to determine the postures associated with high risk of low back pain. Postures that increase lumbosacral load should be identified to reduce the risk of low back pain. In previous work, the relationship between posture and intervertebral loading was clarified, and the centers of gravity in the upper body and the waist shape were estimated. Moreover, individual differences were considered to improve the accuracy of the estimation. This method can estimate the lumbosacral load with sufficient accuracy. However, lumbosacral loading was examined in relation to posture and increases with external load. Therefore, the external load should be included in lumbosacral load estimation. In this study, we developed a back muscle exertion estimation method by using stiffness sensors to measure back muscle exertion, because the back muscle exertion changes with the external load. We conducted experiments in which participants wore the sensor system and the lumbosacral load was estimated from the external load. Estimation using the muscle stiffness sensors was better than previous estimation methods.

Keywords: Lumbosacral load estimation · Wearable sensor system · Muscle stiffness sensor

1 Introduction

Anteflexion of the spine is necessary in performing many tasks during work and daily life. It is particularly important in tasks such as providing care to others and carrying objects. However, anteflexion causes considerable loading on the lumbar spine [1] and deforms the lumbar discs [2]. The book ‘Low back pain: Guidelines for its management’ [3] is intended for use in primary care and was developed from European evidence-based guidelines for the prevention of low back pain in 2004. To reduce the load on the waist, the guidelines specify that operations, such as nursing tasks, are

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made by ultrasound [4]. Anteflexion deforms the lumbar discs and places load on the lumbar spine [3]. Nachemson [1] studied lumbosacral loading in relation to posture and found that lumbosacral loading increases with the degree of anteflexion. To devise measures for preventing back pain, it is necessary to determine postures associated with high risk for low back pain. However, Nachemson's methods are impractical for routine measurement of lumbosacral load. To reduce the risk for low back pain, postures that increase lumbosacral load must be identified.

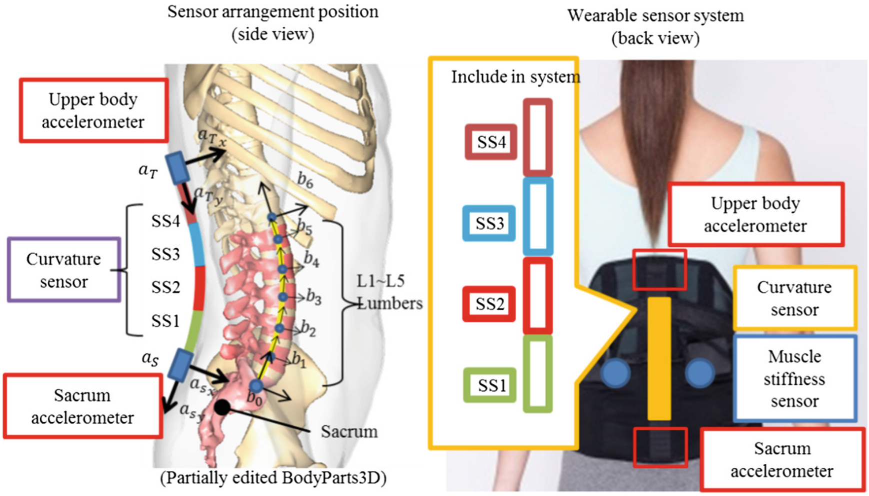


Fig. 1. Sensor arrangement position in wearable sensor system (partially edited from Body-Parts3D [7]).

Thus, we developed a system that can measure the lumbosacral load easily and routinely (Fig. 1). We constructed a wearable sensor system to measure lumbosacral load daily. We also developed a system for identifying postures associated with high risk for low back pain. For this system, it was necessary to calculate the lumbosacral loading from movement and posture parameters. In previous work toward this goal, the relationship between posture and intervertebral loading was clarified, and the center of gravity in the upper body and the waist shape were estimated. Moreover, we considered individual differences to improve the accuracy of the estimation [5]. This method can estimate the lumbosacral load with sufficient accuracy.

However, lumbosacral loading increases with the external load [1]; therefore, the external load must be considered in estimating lumbosacral load. Electromyograms measure muscular activity and they have been used to investigate the relationship between external load and posture angle [6]. However, electromyograms are not suitable for daily measurements because electrodes must be attached to the skin directly. In the present study, we develop a method for estimating back muscle exertion using a muscle stiffness sensor.

2 Wearable Sensor System

We developed a wearable sensor system for estimating lumbosacral alignment and lumbosacral load. The system, composed of three sets of flex sensors and two accelerometers, was developed based on X-ray image analysis. The flex sensors are embedded into compression sportswear. Using a pair of flex sensors, the shape of the lumbar skin curvature is measured during retroflexion and anteflexion. The upper-body accelerometer is located at the top of the system above the flex sensor and the sacrum accelerometer is located at the bottom of the system below the sensors on the sacrum. The upper body, defined as the region around the thoracic vertebrae and above, is considered as a rigid body in the upper-body posture measurements. The upper-body accelerometer is used to estimate the posture of the upper body, and the sacrum accelerometer is used to estimate the posture of the pelvis. The muscle stiffness sensor is placed between the L3 and L4 lumbar vertebrae.

3 Estimation of Lumbosacral Load

Figure 2 shows the flow for estimating the lumbosacral alignment and load with the wearable sensor system. The lumbosacral alignment and load are estimated by acquiring values from each sensor in real time. The lumbosacral load is the pressure force between each vertebral body from the S1 to T12 vertebrae.

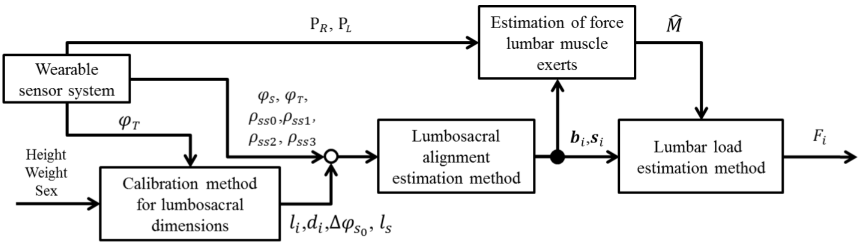


Fig. 2. Estimation algorithm for lumbosacral alignment and lumbosacral load with the wearable sensor system.

3.1 Lumbosacral Load Estimation Method Using Lumbosacral Alignment Estimation

Lumbosacral alignment is obtained by the forward kinematic approach with a coordinate transformation matrix. This estimation method uses the lumbar skin curvature values $\rho_i (i = 0{-}3)$ and the sacrum attitude angle φ_s, which are obtained by the flex sensors, together with the sacrum acceleration values $\ddot{a}_{s_x}$ and $\ddot{a}_{s_y}$ in Fig. 3. To achieve this, we proposed a method [4] to correct for lumbosacral dimensions and estimate lumbosacral alignment with higher accuracy. In the lumbosacral alignment estimation, we consider individual differences in three parameters: distance between vertebrae (interbody distance), distance between the skin and vertebrae, and pelvic posture correction angle. The correction method for each parameter uses the upper body

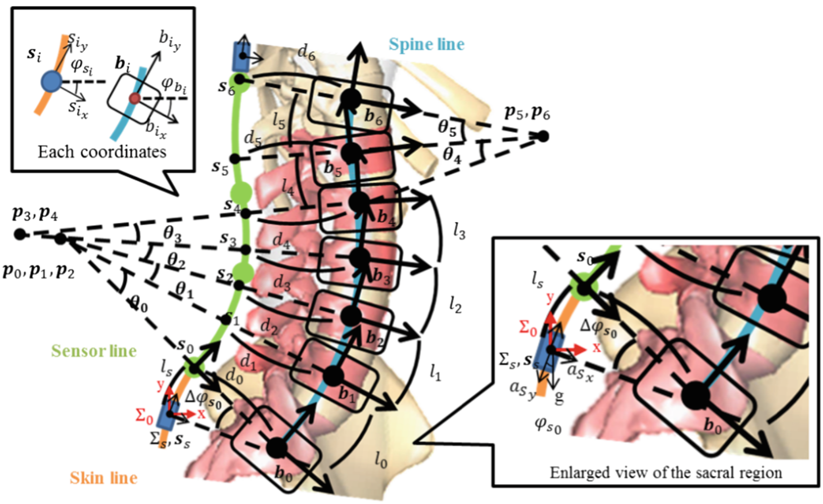


Fig. 3. Lumbosacral coordinates. This model is based on the lumbosacral alignment estimation. The method for calculating the posture angle from the accelerometer data is also shown

posture angle and the body surface area of the physical features. We estimated the body surface area by following this method [8], which creates a lumbosacral alignment model in real time.

3.2 Estimation of Lumbosacral Load by Estimating the Force of Lower Back Muscles

The lumbosacral load is calculated from the musculoskeletal model by using the estimated lumbosacral alignment. We previously estimated center of gravity of upper body using the estimated posture and shape of the lumbar spine [9]. In the present study, the musculoskeletal model has a back muscle and an abdominal muscle (Fig. 4). Wilke et al. reported that lumbar load increases due to external load and changes in manual load [10]. Therefore, we estimate the muscular strength by measuring the stiffness of the back muscles during the experiment. We assume that the motion is anteflexion in changing the manual load (Fig. 5).

The muscle stiffness sensor measures back muscle exertion, because the back muscle exertion changes with external load. The estimated manual loads have loads in the upright position, and a model is built to estimate the force of the lumbar muscles when performing the anteflexion motion. The muscle stiffness sensor measures the left and right back muscles. The measurement value of the left erector spinae muscle is P_L, and that of the right muscle is P_R. It is assumed that the left and right back muscles have the same movement.

$$\overline{P_s} = \frac{P_R + P_L}{2} \tag{1}$$

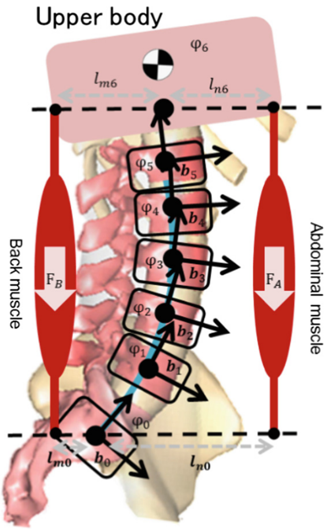


Fig. 4. Musculoskeletal model for lumbosacral load estimation including a back muscle and an abdominal muscle.

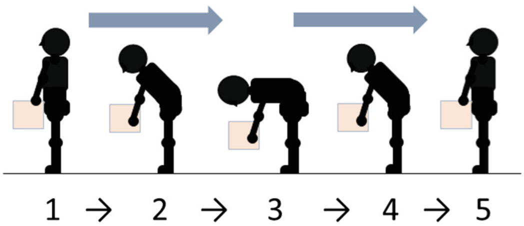


Fig. 5. Measurement motion of anteflexion as the manual load changes.

$\overline{P_s}$ is the measurement value of the erector spinae muscle. The muscle exertion of erector spinae muscles is estimated from $\overline{P_s}$. The L1 vertebral body load, F, for the static model is obtained from the following relationship.

$$-F_B l_{m6} + F_A l_{n6} + Mg l_g \cos \varphi_6 = 0 \tag{2}$$

$$-F_B l_{m0} + F_A l_{n0} = 0 \tag{3}$$

$$F_B + F_A + Mg \sin \varphi_6 = F \tag{4}$$

F_B is the back muscle exertion and F_A is the abdominal muscle exertion. l_{ni} is the distance from the center of gravity of the vertebral body to the abdominal muscle attachment point. Similarly, l_{mi} is the distance from the center of gravity of the vertebral body to back muscle attachment point. F_B is estimated from the relationship between F_B and $\overline{P_s}$ during anteflexion, by using the following Eq. (5)

$$\widehat{F_B} = \alpha \ln\left(\overline{P_s} + C\right) + \beta \tag{5}$$

$$C = P_{S_{Max}} - 2P_{S_{Min}} \tag{6}$$

Parameters α and β are calculated by using the least squares method. C uses the maximum value and minimum value from $\overline{P_s}$ during anteflexion. Thus, this method is calibrated by the bending motion before lifting loads.

The abdominal muscle, $\widehat{F_A}$, is updated during the calculation by using the estimation of the back muscle, $\widehat{F_B}$. The changing upper body weight is estimated by using $\widehat{F_B}$. The lumbosacral load is updated during the calculation of musculoskeletal model with the changing the upper body weight.

$$\widehat{M} = \frac{\widehat{F_B}}{gl_g \cos\varphi_6}\left(l_{m6} - l_{n6}\frac{l_{m0}}{l_{n0}}\right) \tag{7}$$

$$\widehat{F_A} = \widehat{F_B}\frac{l_{m0}}{l_{n0}} \tag{8}$$

$$\widehat{F_B} + \widehat{F_A} + \widehat{M}g \ \sin\varphi_7 = \widehat{F} \tag{9}$$

4 Estimation of Lumbar Muscular Strength

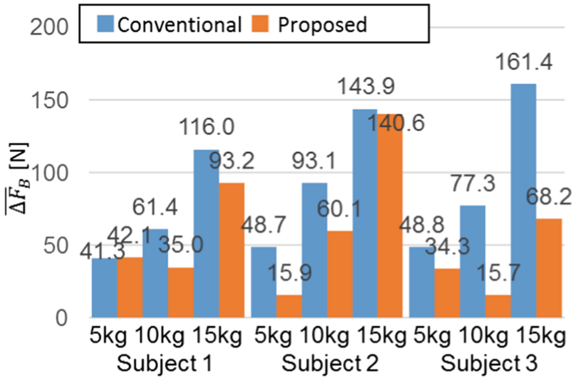
We estimated the lumbosacral load with various external loads in experiments where participants wore the sensor system. The participants were three healthy men, and the experiments were performed with the consent of the participants. The motion in the experiments is shown in Fig. 5. The participants maintained posture 1 for 3 s, changed from posture 1 to 3 in 3 s, and maintained posture 3 for 3 s. Finally, they changed from posture 3 to posture 5 in 3 s, and maintained posture 5 for 3 s. Table 1 shows each participant's weight and height. The back muscle force was estimated from the change in manual load. For each participant, the parameters α, β, and C were calculated from the data for a 0 kg manual load, and the static model including the hand load was calculated to obtain F_B. Back muscle F_B was estimated by using the proposed method and the conventional method. The conventional method estimated the back muscle F_B without the muscle stiffness sensor by using the lumbosacral alignment estimation result. The average error ($\Delta\overline{F}_B$[N]) of F_B was determined by comparing the calculated value (F'_B) of the manual load considering the static model with the estimated value ($\widehat{F_B}$).

The average error for all participants is shown in Fig. 6. For all three postures, the error was smaller in the proposed method than in the conventional method. The error was reduced by up to 35% (Fig. 6 (b)). For 5 kg, the error was reduced by 34%; for 10 kg, it was reduced by 52%; and for 15 kg, it was reduced by 28%. In addition,

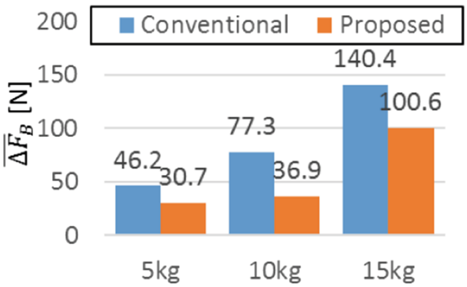
Table 1. Participant body data for lumbosacral load estimation experiment.

Participant	Height [cm]	Weight [kg]
1	165.0	69.0
2	167.0	60.4
3	157.3	58.8

Fig. 7(a) shows the lumbosacral load, $\widehat{F}$, of participant 3 with a manual load of 15 kg. The error was smaller in the proposed method than in the conventional method.



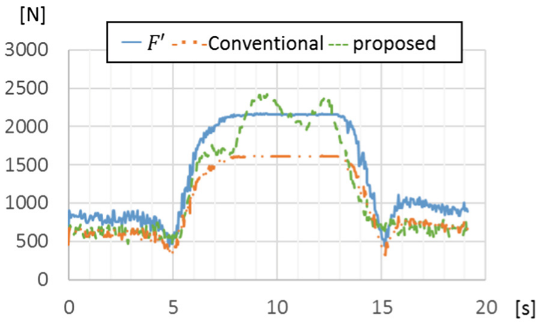
(a) Results for each participant



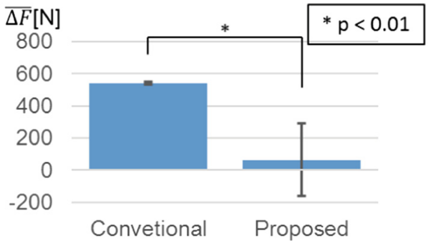
(b) Results for each load

Fig. 6. Estimation results for the average value of $\Delta\overline{F}_B$.

The proposed method was evaluated by the average error of the stooped posture with the highest lumbar load. Figure 7(b) shows the average error $\Delta\overline{F}$ in the experimental motion for 7 to 12 s. ΔF was determined by comparing F' for the manual load calculated with the static model with the estimated value, $\widehat{F}$. The proposed method was better than the conventional method, and reduced ΔF by 88%. Thus, the lumbosacral load estimation can determine the manual load by using the muscle stiffness sensor.



(a) Estimation results over time



(b) Average error during the stooped posture

Fig. 7. $\widehat{\mathbf{F}}$ of the lumbosacral load estimated by the conventional and proposed methods.

However, the muscle stiffness sensor is important in this system. The increase in SD was caused by changing waist circumference, which must be addressed. Thus, it is necessary to identify the cause of the change in the waist circumference in the experiment.

5 Conclusion and Future Work

We developed a wearable sensor system for estimating lumbosacral load. The wearable sensor system measured the back muscles by using muscle stiffness sensors. Furthermore, we proposed a method for estimating lumbosacral load considering external load. The error in lumbosacral load from the proposed method was lower than that from the conventional estimation method. The increase in SD was caused by changing waist circumference, and the cause should be identified.

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Storytelling-Based Hand Gesture Interaction in a Virtual Reality Environment

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Abstract. This paper focuses on emotional effects of storytelling-based hand gesture interaction in a VR (Virtual Reality) environment. Unlike using depth cameras like Kinect sensor, a wearable band is proposed to detect users' hand gestures to create a virtual reality film. The VR film is created using a storytelling-based hand gesture recognition system and focuses on the users' emotional effects. For the design, the hand gestures suitable for the story in the film are derived from research on users and are applied to the VR film titled 'Not Alone'. In order to recognize the hand gestures of the user, the data collected from the wearable band is analyzed to classify movements of the hand through machine learning, which helps to solve problems of the existing hand gestures. This study proposes hand gesture interaction that is most suitable for users with two free hands in the head mounted display HMD (Head Mounted Display) based VR environment and tries to maximize users' emotional responses in narrative-based film content by developing storytelling-based hand gesture interaction.

Keywords: Virtual Reality · Storytelling · Wearable band · Hand gesture · Interaction

1 Introduction

Currently, the VR (Virtual Reality) market is growing rapidly around the hardware market. VR was developed decades ago, but the currently rising HMD (Head Mounted Display) -based VR market started to emerge as a new future market when Palmer Luckey founded a startup called Oculus in June 2012, and Facebook CEO Mark Zuckerberg acquired Oculus for US $2,300,000,000 in March 2014 [1]. With the release of the Oculus CV1 to the public in March 2016, large companies have continued to produce HMD devices such as Samsung Gear VR, HTC Vive, and Sony Playstaion VR. This is because VR devices are attracting attention as a new platform to replace the already saturated mobile device market, and many companies are heavily investing to capture a piece of the VR device market in advance. However, in order for this VR market to be successful, the development of content suitable for such a platform is essential prior to the formation of a hardware-oriented market. This is because the VR platform is not as simple as moving content from the existing web space to the smartphone. The HMD-based devices among the VR platforms should be designed

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basically for one user. For this, the development of a story and interaction suitable for a user-oriented VR environment is an absolute priority.

User-oriented VR games are growing fast in the game market. Games are the easiest to realize the VR environment based on 3D graphics and enable real time interaction with users. Real time interaction with users is one of the biggest advantages of VR, and this is an essential factor for VR content as the success of the VR content depends heavily on how to make good use of this interaction. However, in films based on linear narratives, it is very difficult to produce films using real time interaction.

With the development of sensor technology, content that utilizes the motion of two hands or the whole body in real-time interaction with HMDs while using 3D depth cameras, wearable gloves and bands, etc., have recently appeared, yet it is difficult to find a case that utilizes real-time interaction in films that are based on actual images.

Therefore, this study proposes storytelling-based gesture interaction using a wearable band in actual image-based VR films based on linear narratives. For this purpose, hand gestures fitting the story of the film are drawn based on a user survey and implemented through a wearable band.

2 Previous Studies

In the VR environment, studies on user oriented gesture interaction have been widely carried out in the past. Thanks to the development of sensor technology, studies that utilize the 3D depth camera, such as Kinect, to recognize the user's movements and use them as real time interaction have been conducted. Recently, thanks to the development of wearable bands, the interactions such as Myo have been recently developed.

Teaching Natural User Interaction using OpenNI and the Microsoft Kinect Sensor research propose that using Kinect offers opportunities for novel approaches to classroom instruction on natural user interaction [2]. They evaluate the current state of this technology and present an overview of some of its development frameworks by evaluating OpenNI. OpenNI and its libraries were found to be sufficient and advantageous in enabling Kinect-assisted learning activities. Kinect and OpenNI can provide students with hands-on experience with this gesture-based, natural user interaction technology.

The previous research related to this study - Affective Multimodal Story-Based Interaction Design for VR Cinema - used Kinect SDK to recognize the hand gestures and voice and Nite 2.0 driver for OpenNI 2.0 and hand tracking. A novel method of affective multimodal story-based interaction methodology for the VR cinema of HMD maximizes the users' emotional responses [3]. Contextual and implicit interactions enable the users to be more engrossed in the narrative of the cinema and affected emotionally through the experience.

However, when using the 3D depth camera for gesture recognition as in the above two cases, there is a limitation in the movement area of the user, and there is a problem of inconvenience that a separate installation such as for a Kinect sensor is required. Therefore, in this study, user hand gesture interaction has been developed using a wearable device that is most suitable for user oriented interaction.

GestureWrist and GesturePad: Unobtrusive Wearable Interaction Devices were presented in the research carried out by SONY to introduce two input devices for wearable computers [4]. Both devices allow users to interact with wearable or nearby computers by using gesture-based commands. The first device, called GestureWrist, is a wristband-type input device that recognizes hand gestures and forearm movements. Unlike Data Gloves or other hand gesture-input devices, all sensing elements are embedded in a normal wristband. The second device, called GesturePad, is a sensing module that can be attached on the inside of clothes, and users can interact with this module from the outside. Both of them developed an interaction device using wearable technology, yet they were devised for simple tasks or simple interaction, and their aim was different from that of this research for enhancing the emotional response of the content proposed in this study.

Therefore, in this study, hand gesture interaction based on the story of the film is proposed to maximize the emotional effects of the film content for the viewers who watch the VR film in the HMD environment.

3 Why Hand Gestures?

Thomas and Michal's CHARADE: Remote Control of Objects Using Free-Hand Gestures introduced many advantages to VR technology. Using free-hand gesture input has several expected advantages. The study lists the advantages of hand gesture input as follows [4].

- Natural interaction: Gestures are natural and easy-to-learn.
- Terse and powerful interaction: Precise position and movements of the hand provide the opportunity for a higher power of expression.
- Direct interaction: The hand becomes the input device.
- Fatigue: Gestural communication involves more muscles than keyboard interaction or speech.
- Non self-revealing: Gestural commands should be simple, natural, and consistent. Appropriate feedback is also of prime importance.

The advantages of such hand gestures are that they allow users to interact naturally and in an immersive manner in the VR environment. Especially, in the HMD-based VR environment where two hands are free, this free hand gesture method is the most suitable interaction.

Conversely, due to the current limitations of technology, the disadvantages of such hand gesture inputs are: first, lack of comfort; second, every gesture can be interpreted by the system, whether or not it is intended, so the system must have well-defined means to detect the intention of the gesture; and finally, segmentation of hand gestures. In order to solve these hand gesture interaction problems, this study recognizes the hand gestures of the user using a wearable wristband and analyzes and classifies them through machine learning.

4 Storytelling Based Interaction (SBI)

The SBI developed in this study is a scenario-based interaction methodology, and according to Norman's seven stages of action, the actions focus on user cognition. The user can easily get used to the meaning of hand gestures because they already know the "why" through their past experiences. Ulmer and Ishii [7] called it "expressive representation (ER)" meaning one's "reading" and interpretation of representations, acting on, modifying, and creating them in interactions.

Therefore, emotional interactions were designed, so the user could naturally interact from the main character's point of view through the story of the film. To this end, gestures were investigated through a survey of 50 male and female users in their 20s and 30s. Through this survey, hand gesture interaction suitable for the emotional elements required in the film of this study was designed. The survey was conducted such that users selected hand gesture interactions suitable for the emotional situation after observing the story of the film. The result is as follows (Figs. 1, 2, and 3).

1. What will you do when your hand is suddenly grabbed by a child' hand that everyone around you shakes off?
   Hold the hand. (4%) Shake off the hand. (81%). Open your hand. (5%)
   Lower your hand. (10%). Stroke the child's head. (85%)
2. What will you do if you find a child crouching and crying?
   Hold the hand. (15%) Shake off the hand. (0%). Open your hand. (0%)
   Lower your hand. (0%). Stroke the child's head. (85%)
3. What will you do when the child reaches out his/her hand again?
   Hold the hand. (94%) Shake off the hand. (2%). Open your hand. (0%)
   Lower your hand. (0%). Stroke the child's head. (4%)

Through this survey, three interactions were derived, that is, three hand gestures that fit the context of the film's narrative: the first, shaking off the child's hand; the second, stroking the child's head; and the third, holding the child's hand.

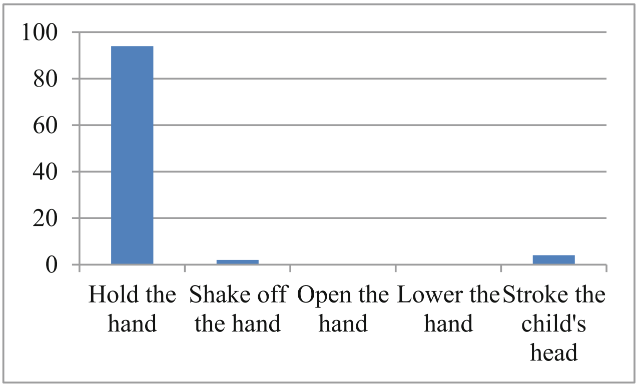

Fig. 1. Answer rate for question 1.

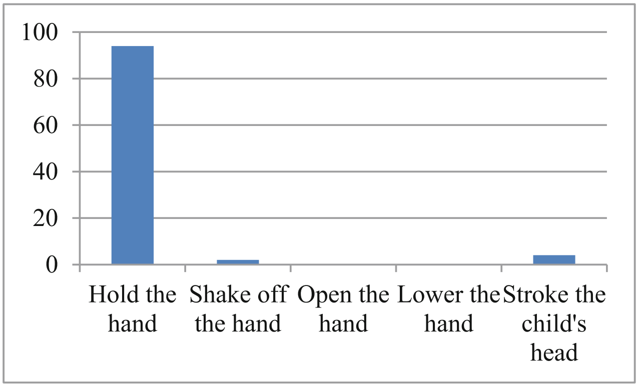

Fig. 2. Answer rate for question 2.

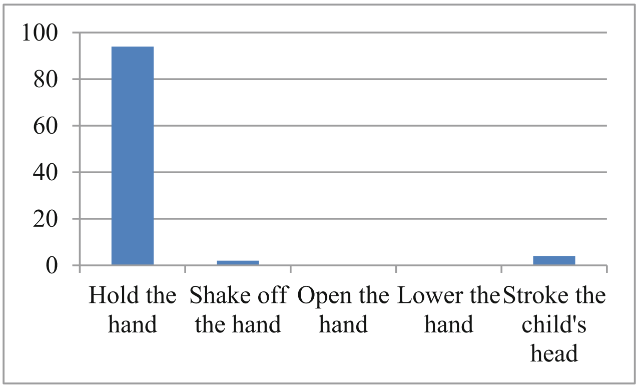

Fig. 3. Answer rate for question 3.

The above results show that the vast majority of users select the same hand gestures naturally in the situation of the story. These are gestures that are naturally perceived by the user's emotional state in everyday life. The user's emotional experiences were maximized on the VR film by using emotional gesture interaction that was already recognized by users through social experience in the situation of the film's narrative.

5 The Story of the Film

The title of the VR short film produced for this study is "Not Alone"; it is a story between an abandoned girl and a character played by the VR user. The film follows the 3 basic act structures, and it is organized in the order of the first act: turned away by people, the second act: the sadness of the child, and the third act: regained hope. Each time the story moves from the end of one act to the next act, the user experiences the action in first person point of view and interacts with the child based on the linear story line.

Act 1: A shabby child on the street is asking for help. Everyone around the child shakes the child's hands off and ignores the child's request. Finally, the child holds my hand and asks for help.

-> Interaction: I shake off the child's hand.

Act 2: Because of people's indifference to the child, the child gets even sadder and is crouching and no longer asking for help. At that time, I take courage and stroke the child's head.

-> Interaction: I stroke the crouching child's head.

Act 3: The crouching child gazes at me with her head lifted and smiles at me brightly. The child reaches out the hand to me again.

-> Interaction: I hold the child's reaching hand.

In this story, the child's hand, which everyone shakes off, means the society's indifference, and holding the child's hands again means the child that has regained hope.

6 Wearable Band for Hand Gesture Detection

The gesture recognition used in this study progresses as shown in the following diagram (Fig. 4).

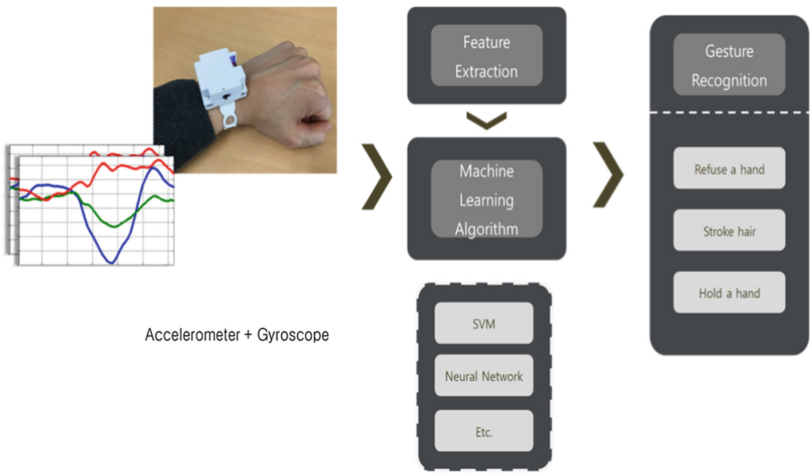

Fig. 4. Gesture recognition process.

The band developed for this study is equipped with an Inertial Measurement Unit (IMU) through which acceleration and gyroscope sensor data are collected from wrist motions. In order to recognize hand gestures, it is necessary to find characteristics that can be classified among the data captured by the sensor. To classify the three hand movements used in this study, that is, shaking off, stroking, and holding, motion speeds and continuous motion values were calculated. Then, the corresponding characteristics are learned through a machine learning algorithm, and the machine learning model that has been learned recognizes the hand movements of other users later (Fig. 5).

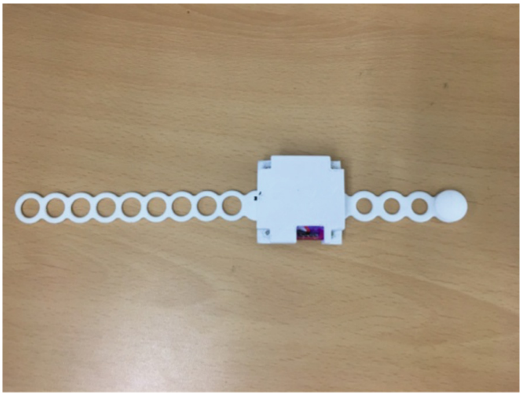

Fig. 5. The wearable band used in this experiment.

The above photo is a light, elastic wearable wristband developed for the experiment, so it is well made in a form that is suitable for the user to wear and interact in the HMD environment. By using this wearable band for hand gesture recognition, it is possible to solve a problem such as limitations of the gesture area, which is the problem of the existing depth-based camera. It is very suitable for the VR environment because it is easy to receive real time data.

7 Results

In this study, a natural gesture interaction method was developed through a user survey that was based on the story of a film in order to provide user oriented interaction method in the HMD-based VR film environment. It was designed for the user to recognize the situation naturally through the film's narrative and to improve the emotional reaction of the user in the film with the applicable interaction method. In this study, three hand gestures: shaking off, stroking, and holding were applied to match the story of the film and in order to realize this, the hand gestures of the user were recognized by using a wearable band based on IMU. This device overcame limitations of user's activity area, which was a limit of research using the existing Kinect sensor, and enabled users' natural interaction as it was simple to wear and light. In order to verify the effects of the storytelling-based hand gesture interaction used in this research, a user study on the user's emotional response should be carried out in the future through a comparative study of simple interaction. If the effects of this emotional response are verified, storytelling-based interaction in the VR environment, which is emerging as a new platform, will be used in various fields such as films, games, and education.

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Game Design Applications

Pokémon Go – an Empirical User Experience Study

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Abstract. Pokémon Go™ is an augmented reality game for iOS™ and Android™ released in July 2016. It is one of the most played augmented reality exergames in 2016. News programs all over the world reported about the high level of physical activity of people playing Pokémon Go™. Further medical and public health communities discussed the potential of this mobile game due to its potential influence on higher levels of sustainable physical activity for health benefits. We present results of an empirical study conducted 14 weeks after the official release of Pokémon Go™ in Germany. We investigated the effect of augmented reality on initial contact and user behavior within this augmented reality exergame. Participants were therefore divided in three groups (active, former and non-gamers) based on personal statement. The results present insights into the initial contact, experienced critical situations and user behavior including use of augmented reality and in-app purchases.

Keywords: Mobile games · Augmented reality · Pokémon Go

1 Introduction

In this online survey we investigated the effect of augmented reality on initial contact and user behaviour within the mobile game Pokémon Go™. This game is an augmented reality game and one of the most downloaded mobile games in 2016 [1]. Within the scientific community its influence on physical activity is well discussed [2–4]. In this context we wanted to explore whether the augmented reality function has an influence on the motivation to perform physical activity and intention to play this game.

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2 Method

2.1 Data Collection

Data was collected by an online survey, as it permits to reach individuals with particular characteristics or interests, i.e. the group of potential game users, best [5, 6]. The survey was introduced as a study about the incorporation of modern games like Pokémon Go™ to support western healthcare systems and was hosted on Unipark. Participants identified themselves as active, former, potential or non-Pokémon Go™ gamers. Based on this self-description further topics were investigated such as initial contact including use of the introduction tutorial within Pokémon Go™ and the source of information used to retrieve information about the functions and features of Pokémon Go™. Further the user behavior was evaluated including the time gamers spend playing Pokémon Go and whether they used the augmented reality function or performed in-app purchases. Also the experience of critical situations like crossing the street without paying attention to traffic was investigated. In the end demographics were queried. Closed-ended and open-ended questions were applied.

2.2 Recruitment

Recruitment was done by a Facebook™ advertisement. Further this online survey was promoted in two private groups named ‘RWTH Aachen University’ and ‘Pokémon Go Deutschland’. In total the ad reached 12,516 persons via Facebook™. Additionally the survey was promoted in an online community called ‘Pokémon Go forum’ and distributed by a mailing list for students at the University of Cologne. In total, n = 210 individuals participated in this online survey.

2.3 Data Exclusion

Due to the special scope of this paper we focused on active and former Pokémon Go™ users in our analysis. Therefore a sample of n = 73 participants was excluded as these participants had no experience with Pokémon Go™.

2.4 Statistical Analysis

Data was analyzed using SPSS statistics software, version SPSS 22 (IBM, USA). Several one-factorial analyses of variance (ANOVA) at a significance level of .05 were conducted. Further multivariate analyses of variance (MANOVA) with a significance level of .05 were conducted.

2.5 Ethics Statement

The Ethics Committee at RWTH Aachen Faculty of Medicine authorized this study and its ethical and legal implications in its statement EK236/16 in 2016.

3 Results

First we present demographics for the two types of Pokémon Go™ gamers (active and former) analyzed in this work. Afterwards results regarding initial contact, experienced critical situations and intention to play Pokémon Go™.

3.1 Participants

The sample included two user groups. One with n = 81 active players and a second with n = 56 former players. On average, participants' age within the group of active players was higher (M = 34.94, SD = 9.847) than within the group of former players (M = 25.59, SD = 8.433). This difference was significant t (135) = 5.786, p < .001. 66.7% of all participants within the group of active players were male. Within the group of former players 60.7% of all participants were male. There was no significant association between the user group and gender χ^2 (1) = .511, p > .05. 75.3% of the active players have a higher education, followed by 19.8% with medium education and 4.9% with lower education. Within in the group of former players 92.9% have a higher education, followed by 1.8% with medium education and 5.4% who are still pupils. There was a significant association between the user group and the level of education χ^2 (3) = .034, p < .001. Asked about their fan status regarding Pokémon Go™ the mean value was within the group of active players 3.05 points (SD = 1.331) and within the group of former players 2.68 (SD = 1.252) on a five-point Likert scale ranging from 1 = 'I am no fan' to 5 = 'I am a total fan'. The difference between these two groups was not significant t (135) = 1.642, p > .05. On average, active players had a longer time of use (M = 116.296 days, SD = 24.821) than former players (M = 47.04 days, SD = 38.43). This difference was significant t (135) = 12.817, p < .001.

3.2 Augmented Reality

Pokémon Go™ is the most downloaded augmented reality game ever [1, 3]. Our study revealed that 16.1% (n = 9) former gamers always used the combination of virtual and augmented reality. Further, 23.2% (n = 13) used the augmented reality depending on their real life environment. There is a different picture within the group of active gamers. Just 4.7% (n = 4) of these constantly used the combination of virtual and augmented reality. Further 3.7% (n = 3) stated to use the augmented reality function dependent on their real life environment. There was a significant association between the user group and the use of augmented reality χ^2 (2) = 19.061, p < .001. The augmented reality feature of Pokémon Go is rarely used within the group of active users. Just former users stated to have used this feature of the game.

3.3 Tutorial

66.7% (n = 54) of the active players and 62.5% (n = 35) of the former players stated to have not used the short introduction tutorial actively. Nevertheless 25.9% (n = 21) of the active players and 23.2% (n = 13) of the former players stated to be unsatisfied with the tutorial. The only given reason within the group of former and active players was the too short content of the tutorial. It was criticized that main features and important functions of the game are not explained and need to be explored by talking to friends or searching the internet. A univariate analysis of variance (ANOVA) investigating the effect of ‘tutorial quality’ on ‘time of use’ within the subsample of former users revealed no significant effect, $F(2, 53) = .344$, $p > .05$. Although the tutorial is criticized to be too short, no indication was found that the use of the tutorial influenced the time of use.

3.4 Critical Situations

Participants were asked about experienced dangerous situations while playing Pokémon Go™. 4.9% (n = 4) of active and 10.7% (n = 6) of former Pokémon Go players stated to have crossed the street without paying attention to possible traffic. Also 8.6% (n = 7) of the active and 7.1% (n = 4) of the former ones stated to have collided with a person or object while playing the game. This is not dangerous but a sign for engagement with the game. In addition, participants were questioned about losing the sense of time while playing Pokémon Go™. Within the group of active players 8.6% (n = 7) and within the group of former ones 5.4% (n = 3) stated to have experienced such a situation. If the number of experienced critical situations per user is calculated, the results show that users experienced between zero and up to 4 different types of critical situations. A comparison between the group of active and former users showed no significant difference χ^2 (3) = 1.600, $p > .05$. A univariate analysis of variance (ANOVA) investigating the effect of ‘number of experienced types of critical situations’ on ‘duration of use’ within the whole sample revealed no significant effect, F (3, 133) = .834, $p > .05$. Further, visualization mode in relation to experienced critical situations was analyzed; hence a univariate analysis of variance (ANOVA) was performed. The results show no significant effect F (2, 134) = 2.904, $p > .05$. Pokémon Go users are distracted by the game and behave in a dangerous manner. Nevertheless no significant effect was found linking the number of experienced types of critical situations and duration of use as well as visualization mode used.

3.5 Information Sources

Due to the too short tutorial users retrieved information from different source to get to know the game. The most used source chosen by active players within this multiple choice questions were internet communities with 79% (n = 64), followed by friends and family with about 33.3% (n = 27) and social media like Facebook with 25.9% (n = 21). Within the group of former players we found a different situation. 33.9% (n = 19) stated to have never searched for further information, followed by 28.6% (n = 16) who mentioned family and friends as source of information. The third most stated source were internet communities with about 27% (n = 15) and finally the less used source were social media with about 8.9% (n = 5). In both groups YouTube, a major source of so called ‘Let’s play’ videos [7], was mentioned once as information source. Due to the 'trail and error concept' of this game it was interesting to investigate whether the information retrieval influences the duration of use. Do novice or experienced users search for information more likely? How does information retrieval link to this sort of initial contact? A multivariate analysis of variance (MAONVA) investigating the effect of 'duration of use' on 'use of external information sources' revealed, using Pillai's trace, a significant effect, $V = 1.357$, $F(95, 585) = 2.295$, $p < .05$. Descriptive analysis shows an increased use of information sources as the duration of use increased. Main source of information were internet communities (meaning not social media) followed by friends and family.

3.6 User Behavior

Pokémon Go™ integrates real life physical activity into a virtual game context. Therefore, participants of this study were asked where and when they play this game. Answers were rated on four-point Likert scales ranging from 1 = 'I totally agree' to 4 = 'I totally disagree'. The mean value for rating whether the gamer takes time out to play Pokémon Go™ is 1.84 points (SD = .813) within the group of active gamers and 2.46 points (SD = 1.078) within the group of former gamers. Thereby active players take time out to play the game whereas former players preferred to play on the way. Regarding the question whether the gamer plays Pokémon Go™ while he or she is on the way, is rated 2.31 points (SD = .831) for active gamers and 2.00 points (SD = .894) for former gamers. This supports the findings of the first question as former players preferred to play on the way. Finally, participants were asked to rate whether they play Pokémon Go™ just together with their family and friends or without. The mean value was 2.96 points (SD = .928) for active gamers and 2.52 points (SD = 1.062) for former gamers on four-point Likert scales ranging from 1 = 'I totally agree' to 4 = 'I totally disagree'. Thereby active players prefer to play the game alone whereas former players showed a slight tendency for playing with friends and family. A multivariate analysis of variance (MANOVA) investigating the effect of 'player status' on the described user behavior revealed a significant effect, using Pillai's Trace, $F(3, 133) = 7.566$, $p < .001$. Thereby active and former players differ in their user behavior.

3.7 In-App Purchase

The analyzed sample of n = 137 active and former gamers spent €58.84 EUR (SD = €68.69 EUR) on average. The amount invested by active gamers ranges from €2 EUR up to €300 EUR with an average amount of €66.15 EUR (SD = €71.78 EUR). The invested amount by former gamers ranges from €1EUR up to €100 EUR with an average amount of €21.44 EUR (SD = €31.45 EUR). Interesting in this context is the question whether the amount of money spent within Pokémon influences the duration of use. Are users investing money to reach higher levels more quickly or do they increase invest money due to the duration of use? A univariate analysis of variance (ANOVA) investigated the effect of 'duration of use' on 'amount spent in Pokémon Go'. The ANOVA revealed no significant effect of 'duration of use' on 'amount spend'

F(7, 47) = .744, p > .05. Further a ANOVA was performed to investigate the effect of 'level' on 'amount spent in Pokémon Go' and revealed no significant effect F(18, 36) = 1.641, p > .05, too.

4 Discussion

Already published studies discussed the effect of Pokémon Go™ on physical activity and its potential to increase social contact [2, 3, 8, 9]. By our best knowledge, this is the first study, which tries to characterize Pokémon Go™ users and their experience of critical situations based on a comparison of active and former users.

Our results show that active users prefer the virtual reality visualization. Former users stated to use the augmented reality function rarely. The choice of visualization mode was independent from experienced critical situations. Future work should investigate other reasons like energy consumption or the poor augmented reality implementation (a picture is laid over the live view of the camera without a stereoscopic adaption) [1].

Pokémon Go is based on a 'trial and error concept' with a short initial tutorial. Asked about their experiences during initial contact no negative influence was determined of the perceived quality of the initial contact regarding duration of use. Nevertheless, active as well as former gamers commented the tutorial to be 'too short'. Both compensated this by retrieving information from internet communities, family and friends as well as social media. This process is independent from playing, as active as well as former users stated to prefer to play this game alone. Results show no indication for this hypothesis. Furthermore, former gamers stated to play Pokémon Go™ in cases they were already physical active. Active gamers stated to take time out and play it consciously. Further analysis of our data will reveal whether more detailed user types exist within Pokémon Go.

About 10% of this sample experienced a critical situation during playing. Therefore playing Pokémon Go™ could be dangerous. However, it is an underestimated risk, as the experience of critical situations had no influence on the duration of use. Due to the non-representative sample future research and a more detailed analysis of our data might find deeper insights.

5 Limitations

There are some limitations worth noting. Due to the recruitment method, no random sample of German Pokémon Go™ users is included. Subjects were interested in Pokémon or at least willing to support this online survey. Also due to the non-stereoscopic augmented reality in this game a transfer of our results on future more complex augmented reality functions is questionable.

6 Conclusion

To our best knowledge, this is the first study explicitly investigating the user adherence to Pokémon Go™ based on a comparison between active and former users. In our analysis, we found first hints for different user groups. There are for example differences relating to the use of augmented reality and information sources or possible in-app purchases. The game should be investigated more detailed to determine further user types beyond the determined active and former users. At this moment, our results indicate that the augmented reality function is rarely used.

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Development of a Game-Based and Haptically Enhanced Application for People with Visual Impairment

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Abstract. The objective of this study is to develop educational games for people with visual impairment to learn science in a fun and interactive method (i.e., a serious educational game). The paper comprises investigations of the effect of tactile feedback and collaboration on the game for visually impaired users within the framework of game-based science learning (GBSL). Results showed significant effects of tactile feedback and collaboration on participants' presence and immersion levels. The research will enhance the future development and application of game-based science learning.

Keywords: Game-based science learning · Tactile · Collaboration · Visual impairment

1 Introduction

Serious Game is defined as application fields that are related to many sectors overall such as health, defense, education, and training and is still expanding. As classified by Alvarez, a Serious Game addresses a set of fields: Educational games, Simulation games, Edutainment, Digital Game Based Learning, Immersive Learning, Social Impact Games, Persuasive Games, games with an Agenda [1]. The connection between playing video games and enhanced cognitive abilities are stated to be beneficial for students. However, the characterization of video games and why playing those leads to improved abilities has not been resolved [2, 3]. These video games contain several common properties: randomness, speed, high perceptual, cognitive and motor load, and decision-making skills. Many action video games contain violent content, making their suitability for children questionable. Hence, there is a need to investigate and experiment on non-action games and the beneficial factors for the children. In addition, not much research has been conducted about the cognitive benefits of non-action video games [4]. Although, fun and entertainment generally attract people to games, the engaging learning experience of game playing is contributed by the effective game principles embedded in game designs [5]. There are already a number of educational games created for science learning. But, the complexity of problems and tasks in the games are either too simple or too complex to solve.

The objective of this research is to develop educational games for the visually impaired people to learn science in a fun and interactive way rather than the traditional

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learning method. With a low-fidelity game demo and an interesting topic (Astronomy), the paper will answer the following questions: Is the presence and immersion levels higher among players with collaborative play compared to individual play? How effective is tactile feedback in comparison to non-tactile feedback condition?

2 Literature Review

2.1 Game-Based Science Learning (GBSL)

To demonstrate the potential of educational games for science learning, Clark summarized the results found in studies into four learning aspects: 1. conceptual and process skills learning, 2. epistemological understanding, 3. attitude, identity, and motivation, and 4. optimal structuring of games for learning [6]. Although the findings from these studies promise a future for game-based learning in science education, there is a lack of comprehensive evidence to support the effectiveness of this new learning technology [7]. Even though there is a research trend in game-based learning, with studies in science learning increasing [8], this area of research is still relatively smaller. In addition, most of the published review studies of game-based science learning mainly focused on the learning effectiveness or the outcomes classifications [6, 9]. On deeper research, two other important aspects seemed to be overlooked by previous studies were also explored. First, the way how games were designed and implemented. Second, the pedagogies or instructional designs embedded in the games that play a critical role to make learning more effective [5, 10]. Concluding from the data collected about GBSL from multiple other research, only few studies provided review on aspects other than learning outcomes such as game genre, purpose of game, study design, learning domain, and target learners [8]. This paper focuses on the game design and implementation.

2.2 Factors Effecting Game Design

Collaborative Learning. In these types of games, players can communicate with each other to solve problems and collaboratively achieve individual and group goals [10]. Collaborative virtual environments may be used successfully to improve the acquisition of abstract concepts.

Multiplayer games have learning potential, and studies focus on which types of learning these games support. The key element in multiplayer games is: the interaction between players to collaborate and communicate in the game [11]. The main attribute of this study is that the development of multiplayer educational game constructed as complex social environments, where students collaborate and learn through numerous interactions among other subjects, objects and tasks of the game, under specified rules. However, these factors has not been considered thoroughly and not enough research has been done on this factor for the visually impaired. Most researchers are restricted to multiplayer gaming among sighted players. Paraskeva et al. argues that multiplayer educational games can be a promising educational tool, an alternative to the current multiplayer gaming, which will promote collaboration among students [12].

Tactile Feedback. The most common expectation to be fulfilled by tactile feedback is to enhance the perception of virtual reality rendered by visual and auditory displays in medical, entertainment, education and military applications [13]. Combined with sound, haptics can create a viable alternative interface for blind and visually impaired people. However, according to Morris, et al. [14], players-particularly players who had limited experience using the Phantom (haptic), initially found the six-degree-of freedom input difficult to control. Moreover, players showed the tendency to make movements that can potentially damage the (expensive) haptic devices. This was because the haptic and game were immersive and the players were not treating the device with normal care. The rapid motion of the device caused damage to the devices.

Previous research supports the use of tactile feedback for the visually impaired to perform better. However, there are still significant human interface challenges associated with tactile feedback that has not been explored by existing games.

3 Methodology

3.1 Participants

Eight participants from Lamar University (with the age between 20 to 30 years old) were employed in the experiment. As the target group are students who are visually impaired, all the participants were blindfolded while performing the experiment. They were provided with written, informed consent form.

3.2 Independent Variables

Tactile Feedback. There are 2 levels: Tactile feedback and Non-Tactile feedback. In the tactile feedback condition, players are given representational models made from Play-Doh while performing the tasks. In the non-tactile feedback condition, players will not be given any representational models while performing the tasks.

Collaborative Mode. There are 2 levels: Individual Play and Collaborative Play. In the Individual Play condition, players play the game alone and in the Collaborative Play condition, players have a companion to collaborate, communicate and share the tasks in the game.

3.3 Dependent Variables

Presence. It is defined as a state of mind in a virtual environment experience. In this study, presence is used to measure how interactive and motivating are the game and its game features in serious educational games.

Immersion. Immersion is defined as being deeply involved in a given task. In this study, immersion is used to measure the involvement and engagement of a player when playing the serious educational game.

Dependent variables were measured by a questionnaire using Likert-type seven-point scales, in which 0 meant ‘not at all’ and 7 meant ‘a lot’. The questionnaire focused on the users’ evaluation of their own task performance when using the system, how well they understood the system, and to what degree they felt that they learned how to use the system, as well as their skill level in using specific features in the system.

The Cronbach’s Alpha (α) for the presence questionnaire and immersion questionnaire in all 4 conditions are as given in the table below. Cronbach’s Alpha was calculated to derive the correlation between the questionnaire items. The Alpha values from the 4 conditions clearly showed that the questionnaire was reliable (Table 1).

Table 1. Cronbach’s Alpha for 4 given conditions

Condition	Presence (α)	Immersion (α)
IP, with TF	.72	.79
IP, without TF	.83	.75
CP, with TF	.73	.76
CP, without TF	.75	.80

3.4 Equipment

Low-Fidelity Prototype (LFP). This is the initial raw presentation of the ideas and requires less time, less specialized skills and less resources. The purpose of building a LFP is not to impress the users or the end product, it basically gives us an insight of the demo. This game’s LFP was designed by using paper prints, plastic toys and Play-Doh. It also included eye-patches to blindfold (Fig. 1). Other equipment include Measurement Tool and End-user questionnaire.

Fig. 1. Low-Fidelity Prototype of an educational game developed by the authors

3.5 Tasks

The task is to clear the misconceptions by completing the game and the challenges designed in it. A single dice is rolled for movement in each turn. Some tasks had easy riddles, quests and identifications. The task is directly linked to its respective misconception. In the collaborative mode, participants were asked to play collectively as a team.

3.6 Procedure

At first, the participants were requested to fill in the demographics questionnaire. Then, participants were asked to review their respective material and instructions. All participants were blind-folded during the entire experiment. The participants played the game on the LFP and completed all the tasks. During the play the participants were under observation and assisted whenever required. In the end, the participants need complete a post-questionnaire. The whole experiment last around 1 h.

4 Results

A 2 × 2 ANOVA was conducted to analyze the data. The following table (Table 2) summarized the results of the statistical analysis.

Table 2. Significant effect for performance measures

Dependent variable	Effect	F-value	P-value
Presence	Tactile feedback	29.30	0.0010
Presence	Collaborative mode	98.19	<0.0001
Immersion	Tactile feedback	6.09	0.0430

4.1 Presence

The analysis revealed a significant main effect of collaborative mode ($F_{1,\ 7} = 98.19$, $p < 0.0001$) and tactile feedback ($F_{1,\ 7} = 29.30$, $p = 0.0010$). Post hoc analysis showed that the participants' presence in collaboration mode ($M = 28.68$, $SD = 1.74$) was significantly higher than that in individual mode ($M = 21.87$, $SD = 3.28$). The participants' presence in tactile feedback condition ($M = 26.93$, $SD = 2.90$) was significantly higher than that in non-tactile feedback condition ($M = 23.62$, $SD = 4.92$).

4.2 Immersion

Results revealed a significant main effect of tactile feedback ($F_{1,\ 7} = 6.09$, $p = 0.0430$). Post hoc analysis showed that the participants' immersion in tactile feedback condition ($M = 27.43$, $SD = 2.98$) was significantly higher than that in non-tactile feedback condition ($M = 25.06$, $SD = 3.47$).

The effect of collaborative mode was not significant ($F_{1,\ 7} = 1.78$, $p = 0.2234$). Post hoc analysis showed that the participants' immersion in collaboration mode ($M = 27.06$, $SD = 2.40$) is slightly higher than that in individual mode ($M = 25.43$, $SD = 4.09$).

5 Discussion

Previous research predicts and supports that if the immersion and presence levels are higher, players gain an interest to learn: which includes science and other educational topics. Feedback from the students to the questionnaire items confirms to what has been indicated by researchers, that educational games are able to create enjoyable and realistic learning environments for learners to acquire abilities and establish their knowledge in the process of playing games, so that they can further apply the knowledge and skills to relevant games as well as to real-world scenarios.

5.1 Effect of Tactile Feedback

Results from the analysis showed that tactile feedback had a significant main effect on presence and immersion. Previous research had limitations. For example, no synthetization of tactile feedback in serious educational games for properties as surface roughness, textures and temperature. However, in this research the tactile feedback was implemented and received valuable feedback from the participants. The game design was based on a Low-Fidelity Prototype and Play-Doh was used to induce various in-game features, such as temperature, size, weight and portability. Due to this, participants were able to complete the tasks more efficiently when compared to the condition without tactile feedback. As stated by Burdea, the effects of tactile feedback helped in enhancing the perception of virtual reality in the educational game and also aided friendly learning environment [3].

5.2 Effect of Collaborative Mode

Results from the analysis showed that collaboration mode had a significant effect on presence. Dickey and Manninen described that the key element in multiplayer games is the interaction among players in the game helps in collaborating, communicating, solving problems and learning [6, 11]. In this research, players communicated with each other to solve the tasks and also discussed about the topic on whatever information they previously gained. When players were playing in the individual mode, they showed lesser interest in continuing the game and talked less than the players in collaborative play. The participants learnt more new information during their interaction sessions in the game. These learning aspects were achieved as the players performed the game in an enjoyable way. Also, they were so immersed in the play that most of the students lost track of time while playing the game.

6 Conclusion

The study evaluated the effect of collaborative mode and tactile feedback on GBSL. The results showed that the participants' presence and immersion levels were significantly higher in tactile feedback conditions. Also, the presence level was significantly higher in collaborative play. On an over-all scale of the presence and immersion levels, the best condition with the highest mean scores was the condition with tactile feedback in a collaborative play. Most of the players solved the tasks more efficiently in the tactile feedback condition because the differences were notable. Such notable difference was caused due to the use of Play-Doh under different conditions such as, heat, cold, weight and size of the representational models.

The collaborative play with tactile feedback immerses the players in a collaborative virtual environment and enhances their efficiency performing the tasks. Therefore, learners are able to establish knowledge through the game-based learning activity and to promote their learning motivation to actively participate in learning.

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Game Design Creative Industry: An Overview of the Porto Digital Project in Brazil

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Abstract. The report completed in 2014 shows the Mapping of Digital Games Industry in Brazil, and was made by the Group of Studies and Development of the Creative Industry (GEDIGames). This project demonstrated the significant growth of the game sector in the country, pointing to the existence of 133 companies, and highlighting Pernambuco state as the higher growth in the Brazil Northeast region, counting 10 companies that currently develop games. This is probably due to the existence of the *Porto Digital*, which corresponds to a technological pool that aggregates several companies that develop new technologies. This paper aims to present the impact mapping of the *Porto Digital* Project on the development of the gaming industry in Pernambuco state, based on the companies installed in the technology park, observing how the development of the area was established by recovering its history and potential as a member of the creative industry in Brazil. A field research study was carried out to better understand the creative industry paths in Pernambuco, building a broad panel on the game industry. As a contribution, the research provided information for the development of tools that allowed professional improvement of those who directly dealt with the digital game design and broadcast content, as well as identifying trends for the next few years in the game industry.

Keywords: Digital entrepreneurship · Creative industries · Games

1 Introduction

The term creative industries emerged in the early 1990s in Australia, developing later in England, and tied to the context of public policies of culture [1]. Currently, refers to productive sectors in which creativity plays a fundamental role [2].

However, the impact of these sectors on economy is recorded. The United Nations Conference on Trade and Development (UNCTAD) characterizes this sector as: "*The creative economy is an emerging concept dealing with the interface between creativity, culture, economics and technology in a contemporary world dominated by images,*

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sounds, texts and symbols" [3, p.1]. Despite the multiplicity of concepts available in the literature, researchers understand how reasonable to adopt the concept below:

Creative industries produce goods and services using images, text and symbols as a means. Industries are guided by a system of intellectual property and push the technological frontier of new information technologies. In general, there is a kind of agreement that the creative industries have a core-group, which would consist of music, audiovisual, multimedia, software, broadcasting and all kind of publishing processes in general [2, p. 12].

Within this context, we include the set of activities related to the creation, manufacture and commercialization of cultural services and/or products, such as theater, movies, games, performing arts, journalism, photography, advertising, design, interactive and leisure software, music, Publishing industry, radio, TV, museums and galleries [1]. It is therefore a new phenomenon, whose concept is still in the consolidation process. Its relevance to the economy, however, looks like a peaceful spot.

Over the last few years, creative industries have been responsible for a significant economic movement of the developed countries. In Europe, for example, its represents 654 million Euros, corresponding to 2.6% of the Gross Domestic Product (GDP) of the European Union and grows 12.3% above the average of the economy.

In the United States, the value of copyright-based products exceeds the export rates of the automotive, agricultural, aerospace and defense industries [1]. Research by the Federation of Industries of the State of Rio de Janeiro [4] indicates that in Brazil, between the years 2004 and 2013, the creative industries grew 90%. In this period, the GDP moved by the sector grew 69.8% in real terms. The remuneration of the area's workers also worth mentioning: while the monthly income of Brazilian workers was $2.073,00 Brazilian Real in 2013, professionals in the creative industry came to win three more times.

In a survey conducted in Brazil, specifically aimed at the State of Pernambuco, Firjan [4] estimates that the creative sector generates a GDP of 2.2 billion Brazilian Real, 2.1% of state production, which puts it in 6th place between the other States of the Country and in the 1st position in the Northeast region. In terms of employment, there is an estimated 22,000 creative professionals. This number represents 1.3% of the entire labor force in Pernambuco, which puts the state behind only Ceará state (1.4%) in this factor.

In this scenario, researchers from the Game Design course and postgraduate in Creative Industries at Catholic University of Pernambuco (UNICAP) have been investigating how these companies are configured in the games sector in the city of Recife, located in Pernambuco, Northeastern region of Brazil, more specifically in *Porto Digital* pole because of its importance for the state economy.

This research is founded as relevant and necessary for three main reasons. (1) The phenomenon of the creative industry in a digital technology environment has manifested itself around the Catholic University of Pernambuco (Unicap). The *Porto Digital* park is located in a neighborhood close to Unicap. Its size and proximity make necessary an extensive research. (2) The research can represent a bridge between academia and market trends, highlighting the issue of entrepreneurship, without losing sight of the phenomenon critical analysis and its consequences. (3) The results of this research will also be reflected positively in the classroom of the post-graduate and undergraduate courses, as well as opening horizons for future projects.

2 Recife Porto Digital Overview

The prevalent Creative Industry segments are those related to architecture, advertising, design, software, publishing, film, television, music, fashion, performing arts and cultural expressions in general. Some of these segments in Pernambuco are associated with the urban technological park *Porto Digital*.

Founded in 2000 under the support of Academia, Market and Government, its area cover a total of 150 hectares of the neighborhoods of Recife Antigo and Santo Amaro. In 2011, official data indicated that this environment had 200 companies and institutions installed - among them IBM, Microsoft, Samsung, Motorola, HP - to which 6,500 employees were linked [5].

Since its foundation, *Porto Digital* has been concentrating its operations in the area of Information and Communication Technologies (ICTs). However, in 2010, the Park decided to expand its operations to the creative industry segment. The result was the inauguration, in 2013, of the Center for Entrepreneurship and Technologies of the Creative Economy, the 'Portomídia'.

Designed as the *Porto Digital* arm in the Creative Economy, Portomídia aims to transform Recife into the main technological stand hub by supporting the organization of seven business chains: games, video cinema, animation, multimedia, design, photography and music. In this way, we can verify the emphasis of initiatives that take into account the so-called monetization of creativity, what knowledge and intellectual capital are the main resources applied [1, 6].

From this perspective, it is assumed that, at times, the amount of hours incorporated into the production process, from the processing of the raw material to the final product, loses relevance. The value attributed to the goods produced will change according to the value added to the original creation, and it is precisely in this sense that it seems to give the *Porto Digital* investment, whose structure is divided into four functional centers:

- **Education**: two training rooms equipped with new generation of computers and software and can train up to 40 people simultaneously.
- **Entrepreneurship**: 'Incubator' equipped to receive up to 10 creative enterprises, offering training, infrastructure and networking.
- **Experimentation**: laboratories focused on various areas such as audio and video finalization for cinema, 3D prototyping and animation, certified Screen Test room, among others.
- **Exhibition**: digital arts gallery prepared to host exposures using interactive technologies, as well as speeches and other types of events.

The Portomidia facilities comprise the following spaces:

- Technical training: 3 classrooms and 2 mini-auditoriums for training
- Incubation: 2 rooms for 10 new business companies
- Experimentation: 5 laboratories for image, sound, design, animation, interactivity, scanner and 3D printer
- Exhibition: digital art gallery with sensors, interactive panels and displays.

3 Games Scenario in Brazil and City of Recife

Gaming is a voluntary activity, held within a certain limit of time and space, with freely consented and obligatory rules, accompanied by a feeling of tension and joy, plus an awareness of being different from everyday life [7]. The games are part of the Creative Industry products and its importance is connected by the vocation to promote technological innovation, reverberating to different economy sectors, such as: architecture and construction, advertising, health, education, defense and training, among others. In addition, it is one of the most promising sectors in generating employment and incomes.

In the economic context, it is estimated that in 2018 the sales of games will be twice as high as those of the music industry and should grow faster than those of movie industry. According to consultancy Pricewaterhouse Coopers - PWC, in 2013 the digital gaming market moved US$ 65.7 billion and is expected to reach US$ 89 billion in 2018, estimating a growth rate of 6.3% per year [8]. In Brazil, considered the third largest consumer market globally, the estimated growth is from US$ 448 million in 2013 to US$ 844 million in 2018, with a rate of 13.5% per year [9].

Another factor that influence the gaming industry growing consumption in Brazil is the increase in demand for mobile devices (smartphones, tablets and notebooks) that has overcome the number of inhabitants. An important data on smartphone application sales shows that 64% of users bought and downloaded games on their devices, versus 54% who downloaded social networking apps, according to Nielsen News in 2011.

However, Brazil doesn't only act as consumers for digital games and also develop games for the internal and external market, developing games for entertainment to adver-games (games for the advertising market) and games for training or instructional, called serious games. The first initiatives of game developers in the country go back to the 80s, founding the first companies in 1992. However, as of 1997, these companies were open to developing games or concept arts and animations for major international business games. In the following two years, Brazil had a record of founding companies related to the universe of games for consoles, computers and cell phones: 21% of the total.

According to the Brazilian Association of Electronic Games Developers - Abragames, in 2008 there were 560 professionals employed by 42 companies developing software for electronic games or part of them, such as art, 3D modeling and animations. At the time, the gross national product of the gaming industry was $87.5 million Brazilian Real, with 43% of the national production of gaming software being destined for export [9].

In 2014, the report on the Brazilian Digital Games Industry Mapping, produced by the Group of Studies and Development of the Creative Industry (GEDIGames) for the National Development Bank (BNDES) registered a growth of the industry in the country, pointing to the existence of 133 companies in the sector, most of them located in the South and Southeast regions of Brazil, such as the state of São Paulo, followed by Rio Grande do Sul and Rio de Janeiro [10].

According to the BNDES report, a company located in Pernambuco, more precisely in Recife, deserves to be highlighted due to its production for the national and international games market. "*Brazil has several game studios for PCs. We highlight some of them, which also work in other ecosystems such as the web and mobile market.* […]

*The company **Meantime** gained prominence by the games for smartphones, however the company operates in the market of web, social and PC. Among his games are: Garoto Vivo na Vila Cemitério e Danoninho Crush. The studio is from Recife, PE.*" [9].

In the same report, Pernambuco state stands out in the Northeast region, with 10 game developers (including companies and startups), probably due to the existence of the *Porto Digital*, a hub that includes several technology companies [9]. The term 'Startup' refers to the act of starting something, usually related to companies that are in the beginning of their actions and that explore innovative activities in the market. Startups are designed in a scalable business model, in other words, can initially supply only local needs, but their projects include strategic planning for expansion, anticipating further action in regional and global markets.

Among the Startups identified for BNDES survey, several emerged from initiatives of *Porto Digital* through Incubation Project in Pernambuco state. We can quote Mudcrab Studio e Playfull Games, developed in the Portomídia facilities. Many of these beginner companies are the result of projects from Technology Course in Digital Games at Catholic University of Pernambuco - Unicap, created in 2010.

The BNDES report was held in January 2014, which means that Pernambuco companies created after that date were not included in the document. Among them are Blackzebra Studios, yet started in 2014, PUGA Creative Studios and Diorama Digital, Both founded in 2015, which demonstrates the need for a broader range of studies, in order to characterize the work processes, teams and types of digital artifacts produced, whether this are games, applications or other content formats that use the technologies of the area.

Therefore, it's clear that there is an absence of research whose access is available to the public on the game market in the State that includes its history and local characteristics. Since 2005, Pernambuco has emerged as one of the leading states in game production. At the time, only 9% of the Pernambuco companies in the sector accounted for 16% of the gaming industry sales in the country, including the products export to Europe and Asia [9].

In view of the data reported, there is a need to carry out a more detailed local market survey, its characteristics and specificities, as well as the potentialities found in the game production scenario in the State of Pernambuco, especially at Porto Digital, in Recife. Our hypothesis is that the Porto Digital provided entrepreneurial initiatives for the training, maintenance and development of the Games scenario in Recife.

4 Methodology

This research integrates a broader project, called "Exploratory Study of the Creative Industry in Pernambuco: the *Porto Digital* Case". With the scope included in five other projects, that seek to observe the *Porto Digital* importance in different nuances, from the senses of innovation to the historical, political and economic aspects that enabled the emergence of the technological park and its maintenance within the Creative Industries context. It is applied research, and also exploratory research, since it allowed to investigate a concrete case, as well as to have an overview of the phenomenon, collaborating in the identification of tendencies for the sector.

The first stage of the research consisted of a mapping of the impact of *Porto Digital* on the promotion of the gaming industry in Pernambuco, based on the companies installed in the technology park. Soon after, a survey was started by the team of researchers about the subject in websites, books and papers related to following fields, creative industry, games and design, in order to deepen knowledge, as well as to observe how the development of the area was established by rescuing the History and potential of Porto Digital in relation to similar sectors in Brazil.

In order to observe which companies have the history linked to the development of *Porto Digital*, the team elaborated a questionnaire tool. Only five questions were asked: (1) year of foundation, (2) company current address, (3) operating situation, (4) production focus and (5) The company relationship with the policies of foment to the entrepreneurship and the area of games from *Porto Digital*.

The form was built using 'Google Docs' and posted to the IGDA-Recife group on Facebook (Facebook, 2017). Twenty companies replied the questionnaire. Other companies, such as Musigames, Guaraling, Meantime, Jynx e Icare Games, did not respond, but the data related to its operation were verified through online reports and institutional websites.

The premise that permeated during this phase of the research was the understanding of how the game industry was developed in Pernambuco, from Porto Digital, outlining future perspectives. Also intended to identify how many and which companies participated in the *Porto Digital* and which remain active, even analyzing the type of production, and create a system to classify them according to the type of final product designed.

5 Results

5.1 *Porto Digital* Companies

From the analysis of the digitized archives of the main newspapers in circulation in the city of Recife, *Jornal do Commercio e Diario de Pernambuco*, it was possible to explore the past of the technological industry in Pernambuco since its beginnings, documented by material published since 1990. From the news of the decade 2000, was verified the focus becomes the *Porto Digital* and the routes of the industry until reaching the initiative of the technological pole. As described in the Porto Digital website, the "Three Propellers" - state, private companies and academic institutions - guided the research in the analysis of material found, in order to perceive the preliminary elements for the formation of this model.

It can be observed that the Incubator creation, by itself, was not something new, others appeared in the national scenario, although none has surpassed the size and the influence of the *Porto Digital* in Recife. But the added value of the Incubator Project is its unique aspects. It emerged as an initiative in the integration and joint effort of three entities of society, Universities, Government and private companies aiming at the production of new knowledge, technological innovation and economic development [10], the initiatives are unique due to the fact that they brought investments in the initial stage of the *Porto Digital*.

In such ways, it has integrated action of the three elements, initiated by the Federal Government, by facilitating the installation of small entrepreneurs in the initial phase of business, with tax exemption, reduction in cost with space leasing, besides the construction of a large part of the infrastructure needed for the enterprise [5], decisive factors for the initiative. Not only for its value to infrastructure, but it added value attributed to the *Porto Digital* was obtained through the collection of resources guaranteed by the government and the implementation of these resources in a safe and planned way; from universities through the "Incubator" program; in addition to private investments. Companies have invested in this enterprise in two ways: by installing themselves in place, such as IBM and Microsoft; Or contributing to the infrastructure of the site, such as Embratel.

The analysis allowed us to investigate the emergence of *Porto Digital* as an attempt to develop the Information Technologies area in Pernambuco that expanded its original proposal, including the promotion of companies from other sectors like Startups from innovative initiatives and/or focusing on creative economics. The growing role of creative industries is seen in recent years, with the initiatives of Inloco and the Incubator, specially developed for this sector, the Portomídia.

5.2 *Porto Digital* Mapping

Around 1994–1995, in the Computer Center at Federal University of Pernambuco (UFPE) started what would become the embryo of the Center for Advanced Studies and Systems of Recife (CESAR). A team of experts and professors met to create a structure that would avoid the exodus of graduates from the Computer Science course. At the same time, had begun contacts with Pernambuco Government and private companies, aiming to expand the proposal to maintain the human capital formed at UFPE in Recife, Pernambuco. In this context, a planning began for the occupation of an area of the Recife neighborhood, commonly known as Recife Antigo, around the years 1997/1998, together with CESAR staff, making what is now the Porto Digital.

In 1997 two game development companies started their activities in Recife: 'Art Voodoo', for 3D games design and 'Mesa de Jogos', with focus on casual internet games. In 2000, the group Radix, search engine for information on the web created in Recife, became a partner-controller of "Art Voodoo" and more two Software development companies, the Mobile and Wiser, totaling an investment of $ million Brazilian Real of CVC/Opportunity fund [11].

The "Art Voodoo" later changed its name to 'JoyStudio', and designed the game *Seculum*, a strategy game based on the medieval universe. Among the attractions, the game had the chat feature and entered in 2001, in the *Mesa de Jogos*, oficial website from JoyStudios. This company remained active until the year 2003, when other companies appeared in Recife that absorbed the designers and programmers that time.

On the Porto Digital website [5] and in the list of Brazil Game developers [12] are cited companies that develop games. Some are no longer in operation. Others are located outside the geographical area of the *Porto Digital*, but are still relevant for the local games production, among them are: Big Hut Games, Escribo, Joy Street, Jynx Playware, Manifesto Game Studio, Meantime, PUGA Studios e Raid Hut.

The Big Hut Games, a mobile game developer, was founded in 2012. According informations from the company website, were designed, among others, the games *Skeleton Smasher, Boney: The Runner e 7 Seas*. The PUGA Studios in less than two years of acting has an experienced team that has been active in the games and advertising market for eight years. This company maked the games *Rio Limpo, Reciclo and Basquete - Sport Club do Recife*.

Being in the market since 2000, the Jynx Playware is a development studio in Recife focused on the creation of solutions based on games. Pioneers in the game development industry in Brazil, has a portfolio containing over 180 productions for national and international clients, such as Fiatville, Coca-Cola Footbag, Abril Pro Rock Fight Club and OJE. This company currently operates outside *Porto Digital* area.

The Raid Hut is a company that designs games for PC. There is no information about the games that was designed for them. There are also companies whose focus is not games per se, but related content, such as Blackzebra Studio, that develop Assets 3D for games; Escribo, with educational content and applications and, in a similar way, the JoyStreet, a producer of learning platforms. The Meantime, whose focus is on mobile games, is currently inactive. The Diorama Digital and Kokku Games are not located in the *Porto Digital* area, but also worth noting, because are companies relevant to the game scene in Recife.

As shown in Fig. 1, there is a concentration of active game developers in seven neighborhoods. At Recife Antigo (at Porto Digital Park), there are six companies. At Boa Vista there are four and at Casa Forte, north area of the city, there are two.

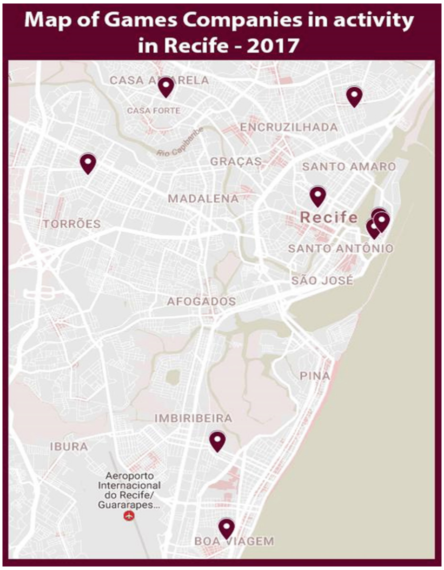

Fig. 1. Map showing the activity game companies in Recife.

The Table 1 below, shows a synthesis with the game companies in Recife, according to the current situation and production focus.

Table 1. Results of the games industries mapping in Recife

Company name	Founded in	Company situation	Current location	Company focus area
Art Voodoo	1997	Inactive	–	Games production (own)
Mesa de Jogos	1997	Inactive	–	Games production (own)
Jynx Playware	2000	Active	Casa Forte	Advergames and Gamut applications, and offer service for other companies
Meantime	2003	Inactive	–	Mobile games production (own)
Manifesto Games	2005	Active	Bairro do Recife	Games production (own)
PG Audio	2006	Active	Cordeiro	Audio production
Playlore Gameworks	2007	Inactive	–	Games production (own)
Musigames	2007	Inactive	–	Games production (own)
I2 Mobile Solutions	2008	Active	Boa Viagem	Gamut applications production
Joy Street	2010	Active	Bairro do Recife	Games production (own), Gamut applications, and serious game
Kokku	2011	Active	Boa Vista	Assets (art, animation and models) production
Icare Games	2011	Inactive	–	Games production (own) and serious games
Playful Games	2012	Inactive	–	Games production (own)
Guaraling	2012	Inactive	–	Mobile games production (own)
Big Hut Games	2012	Active	Bairro do Recife	Games production (own)
PUGA	2013	Active	Boa Vista	Assets (art, animation and models) production
Mudcrab Studio	2013	Inactive	–	Games production (own)
Perna Cabeluda	2013	Active	Casa Forte	Games production (own), Gamut applications, assets (art, animation and models) and serious game
Studios of Magic	2015	Active	Imbiribeira	Games production (own)
Blackzebra Studio	2015	Active	Bairro do Recife	Assets (art, animation and models) production
Expressive Chilli	2015	Active	Bairro do Recife	Games production (own)
Escribo	2015	Active	Campo Grande	Games production (own)
Raid Hut	2015	Active	Bairro do Recife	Games production (own)
Diorama Digital	2015	Active	Boa Vista	Games production (own) and assets (art, animation and models)
Feel	2017	Active	Boa Vista	Games production (own)

According to the survey results, between 1997 and 2017 there were 25 companies, of which 16 are active and 9 are inactive. In 2013, Recife had 13 companies developing digital games and content for the industry (art, animation and music) in full activity. The oldest active company is the Jynx Playware.

6 Conclusion

The data collected up to March 2017 includes information from the game developer companies present in Recife, whether or not installed in Porto Digital, as well as producers of content similar to digital games. Much of the research difficulties have arisen in the face of data and/or information outdated on institutional websites.

In the survey with members of the IGDA list, on entrepreneurship and Porto Digital games area support policies, only six of active companies claimed to know and participate in development actions of the technology park. Of these, two are located outside the geographical area of *Porto Digital*: the Studios of Magic and the Escribo. Among the inactive companies, the Playful Games and the Mudcrab Studio reported having benefited from Porto's policies, and were even incubated in Portomídia. Nine of the companies that answered the questionnaire sent informed that they didn't know or had no connection with the *Porto Digital*, even though were located in the same region. The other companies on the list didn't respond.

It can be seen that *Porto Digital* emerged as a center of operations, which initially helped the companies, having grown with their growth. Although all the beginning has been based on the actions of Computer Science course at UFPE, we cannot deny the technological pole in Pernambuco, that started from a minimum area and 15 companies, for more than 200 companies and almost 10,000 employees, working together with two 'Incubators' and two 'Accelerators', In a pulsating technological ecosystem, of unprecedented implementation in the national scenario until its launch.

Another point to be highlighted is that, despite a promising start and investments made, the information exchange promoted by Porto Digital network would not be sufficient to cover a market that is growing as dynamic as the electronic games. The search for constant innovation gives advantage to large and consolidated companies in the field. The support of academic institutions is still present, in addition to the support of other development agencies.

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Framework for Creating Audio Games for Intelligent Personal Assistants

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Abstract. Intelligent Personal Assistant (IPA) has experienced an important market growth, therefore, an increase in its development by having more people interested in devices that use this software. This opens possibilities for develop new games that people can be interested in. This article presents a framework proposal to create audio games using IPA enabled devices. In order to evaluate the framework, a prototype was designed and presented to 30 participants. The results obtained indicated that a 97.6% of the interviewees were attracted to the idea of playing a game using and IPA.

Keywords: Intelligent Personal Assistant · Google home · Siri · Cortana · Amazon Echo · Alexa · Games · Voice recognition

1 Introduction

In recent years, Intelligent Personal Assistant (IPA) has experienced an increase in its development. Examples such as Siri, Cortana, Alexa, Google Now, and others remark the acceptance of these software pieces among users. In fact, they can be found in massive usage mobile devices (i.e. mobile phones, tablets and smart speakers) [1]. Those assistants have inspired a new way to create and to approach interface designs, which could be found in Science Fiction few years ago.

In this article, we present a framework for game creation by using IPAs. Since the input and output interface are not the standard one for common video games, we faced an additional difficulty level, which was taken into account in the proposed framework for design. Additionally, the framework was validated by evaluating games that were developed for Alexa, and usability tests were executed in the prototype to assess the proposed framework.

The framework includes as its key components: game mechanics, story and goals. Even though those parts are present in most common types of games, relevant differences can be found in the way developers approach the key components in order to design an audio-based game using IPAs.

Due to the fact that at this moment open software development kits (SDK) for all the most popular commercial IPAs cannot be found, we decided to use Amazon's IPA, Alexa, during the prototype implementation process. Alexa can be implemented in a wide range of devices such as Amazon Echo and Amazon Dot and in tablets, cellphones and Digital Media Players [2].

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In order to validate the framework, a prototype of the game was developed and beta testing was executed to comprehend how the individuals reacted to the game and to the interface that was presented. As a relevant fact, the players who participated in the testing were familiarized with the prototype's game theme that was used.

Because the previously mentioned technologies are commonly incorporated into the market, we consider that enhancing the versatility of the device is an important endeavor. In fact, designing guidelines in a game that uses IPAs is an appealing idea to consider because the industry of game development is growing in the market.

The following sections in this article include background in the area of game-based research, the purpose and the explanation of the proposed framework for creating IPA games. Later, an evaluation of the proposed framework will be conducted before discussing the final results.

2 Background

Personal digital assistants (PDAs) were devices conceived to help people in their daily tasks. Their functionality includes patient management (devices as medical tools), information storage and connectivity [3]. These devices evolved into present-day smartphones. However, the idea, and the need, of a personal assistant did not disappear because the smartphones partially fulfilled that need.

New technologies and algorithms make it possible to develop new ways of assistance through new devices (i.e. Apple's Siri, Microsoft's Cortana, Google Now, and Amazon's Alexa). These devices or IPAs address diverse tasks such as contextual assistance and interest updates which must be fully personalized [1].

Additionally, thematic IPAs have been developed for research purposes. Sirius IPA is one of them. Sirius is an open end-to-end IPA web-service application that accepts queries (voice and images) and responds with natural language [4]. Also, multi-agent systems have been integrated into some interaction models that help to manage the activities of a project. The agents act like IPA's dispatching messages [5].

Regardless of the implementation, IPAs must be personal, dynamic to the learner, supportive, affable, and instructive. These characteristics allow the developers to tailor recommendations and to consider the interests and preferences of the users [6].

The interaction between the assistant and the players must be natural. In this manner, the communication they have should use explicit tasks and knowledge, that is gathered from their activities and exchanges, to achieve an intelligent dialog [7]. This knowledge can be obtained from different sources such as social networks (i.e. Facebook, Instagram, etc.), calendars, meetings, among others [6].

The IPAs that have been developed by top tech companies (i.e. Apple's Siri, Microsoft's Cortana, Google Now, and Amazon's Alexa) are controlled by voice or text in mobile devices, personal computers and smart speakers. This new kind of interaction changes the way users search, receive information and interact with computers not only because of the voice control use but also due to the dialogue-style nature of the interactions [8].

Furthermore, IPAs change the way people entertain themselves. Even when the use of voice as an input is quite unexplored, its use has significantly increased in video games. In fact, this kind of games that "embody a player's voice through their in-world character provides an opportunity to increase immersion" [9]. Amazon's Alexa, for example, has some games where the player personifies a medieval man [10] or a police officer [11].

Audio games are not new. These games were developed in the past as an alternative to visually impaired players since the emphasis is on the graphics of computer games [12].

The next section in this article describes the main components of the framework to design and to develop audio games. This framework includes the advantages of the available IPAs.

3 Framework Description

This section introduces the proposed framework by including the key elements that audio games should have. These elements are the result of years of developing both standard video games and audio games for blind people.

3.1 Game Design

Game design is an essential component that includes rules, gameplay, and story [13]. All of them combined facilitate the experience players will have when using games with IPAs.

The environment in which the game is developed must be descriptive enough for the player to be aware of his or her environment. Furthermore, the game should use audio elements, like sounds from the environment, to give the players a more immersive experience when they use the game.

3.1.1 Game Mechanics

Game mechanics can be defined as the way players interact and give input to the game. For IPA-based games, the mechanics will be different compared to standard video games since the interface that is used will vary because the commands will be audio based [14].

In the simplest state, the IPAs should be able to process the user's speech and to transform the input into text which can be incorporated into the game. Considering the current IPA state of art, this action can be accomplished, but the use of different voice recognition systems is a restriction.

In the case of the IPA, the core game mechanics should be voice oriented. The players will use their voices to communicate with the game. Assistance from the mobile can be added to the device paired to the IPA in order to give additional help.

To provide more variability and versatility to the games, IPA should enable different voice recognition and voice volume systems, which can be applied not only for gaming but for the general purposes of the device. With the available technology, the voice recognition and voice volume systems cannot be completed with any of the studied IPA, but it could be enabled by the manufacturers in the future (Fig. 1).

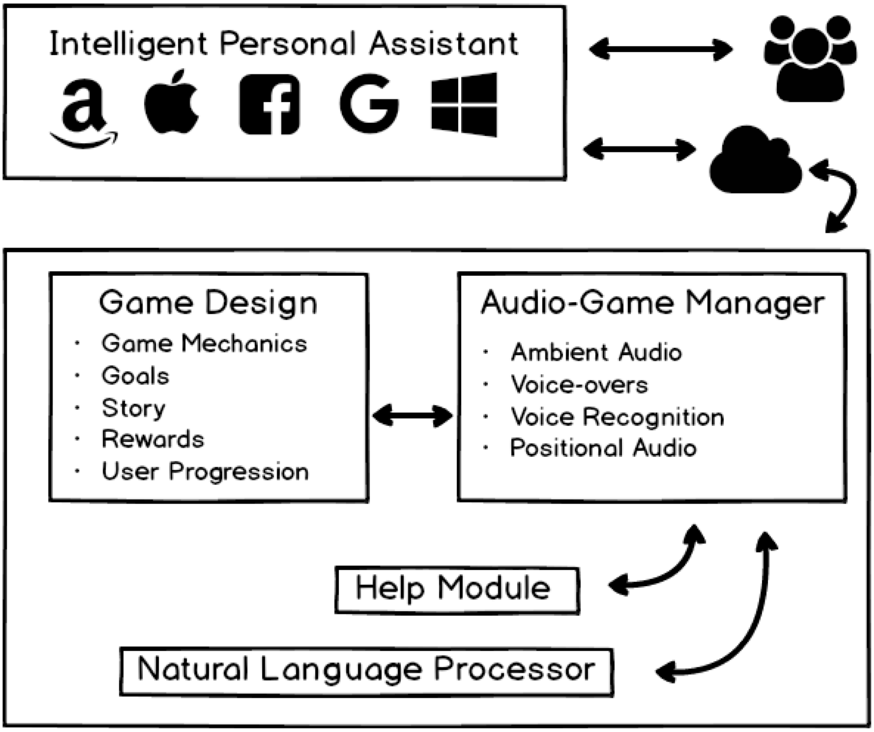

Fig. 1. Framework of the components and their interaction

3.1.2 Goals

Au pair with regular videogames and audio games need to have goals in order to keep the players engaged while reminding them which is the purpose for playing and helping them to stay focused on what they have to achieve. Additionally, goals will vary depending on each game genre and even during each game.

All the games should have short and long-term goals [13]. On the one hand, the short- term goals should be reached in a reasonable amount of time for the players to feel that they are moving forward and to avoid the frustration of being stuck too much time in the same place. Another function of the short-term goals is to help players work to achieve the long-term goals. Hence, both types of goals should be connected.

On the other hand, long-term goals will help players visualize what the main goal is, which can be more than one, and how to achieve it. In other words, this goal will connect all the actions in the game into one single storyline. Hence, long-term goals should be easy to track and to remember. For instance, they can be as simple as rescuing a princess from the evil dragon that held her locked in a cage.

3.1.3 Story

Players should be engaged in the storyline of the game. Because the story is an important part, it must motivate the players through an easy-to-pick-up event sequence to attract the users who are already part of the game and new ones who might come. The stories vary and their simplicity and complexity depend on the creators' criteria [15].

The story has to be aligned with the goals in the game. Moreover, audio games require a story that can be remembered and followed easily. In other words, the player's cognitive effort must be minimum since there is a lack of visual context to help them get immersed into the actions of the game.

Another characteristic of the story is that it must be engaging enough to replay the game. Aspects such as alternate endings or new characters, different competitions, and cooperation among the users can help to attract more players [16].

3.1.4 Rewards

Each goal accomplished must have a reward. The rewards encourage the users to continue playing [13], just like traditional videogames do. Rewards include: secret episodes, new armor, new characters, more hit points, among others.

Rewards should be aligned with goals, since this may help players feel they are progressing within the game. In audio games rewards can show a new spectrum, since besides the mentioned standard rewards, sound rewards can be unlocked. For instance, new music or sound effects that can help in-game to determine a path to choose for the player.

3.1.5 User Progression

The player needs motivation to complete the game. The progression module creates the illusion that actions and decisions allow them to get immersed into the storyline [16].

The game should make the player feel that progress is accomplished. User progression strategies include unlocking the game content as the player goes through the story or achieves a goal. Loops should be avoided since the user feels trapped.

3.2 Audio-Game Manager

Audio is essential for all the games developed for IPA devices. The main reason is because it will be the communication channel and the primary interaction mechanism between the game and the players [14]. The game should be responsible for transmitting the emotions in the environment, the different feelings of the characters, all the players' surroundings, hints, among others. Those elements will help the users feel part of the game.

All the audio-based games should have a game manager or -in this case- an audio controller which is going to be responsible for managing the sounds the game emits and also handling the user interaction. The software should be responsive at all times by giving a fluid input and output interaction for the players to establish a dialog with the IPA.

3.2.1 Ambient Audio

The goal of the ambient audio is to give a deeper experience of the game. The background sounds seek to give a richer experience to the players because they can be aware of their surroundings and understand what is happening at any given moment in order to make right decisions in the game [13].

These particular sounds do not allow the game to be dull because people could get bored easily when nothing else than the IPA default voice is playing. Ambient audios aim at helping the players to make the best in-game decisions and to seek the highest retention from people by preventing them to get bored prematurely.

Ambient audios can vary depending on the game that is developed and its genre. For instance, in a point and click genre, sounds are very important because the game should represent all the details of every location the player can go to. In that way, the user will be able to understand and picture the environment that surrounds the character.

If the game is a blackjack card game, the ambient audios, if any, are simple. It could be background music to fill the ambient because it is not as relevant as for other genres.

3.2.2 Voice-Overs

The games should use voice overs when applicable. Voice acting is an aggregate value for the players because it makes them feel more engaged and identified with the games [13]. Indeed, voice acting adds more versatility and variability to the game because it uses different voices with the characters instead of the default IPA voice.

With the use of voice overs, the character's feelings –anger, joy, frustration- can be expressed appropriately, which can help players in the decision-making process in the game. This device can also show characteristics like gender and age, all of which cannot be represented at the moment with the available default voices of the IPA.

The main goal behind voice-overs is to offer a natural interaction between the players and the game. When using them, the immersion of the users in the game increases by making them interact with a live form behind the IPA instead of a robotic machine that answers -in a standard form- all the input that is received from the world.

3.2.3 Voice Recognition

The system should be able to recognize different voices, pitch and volume. Players can get a personalized experience by having the mentioned characteristics. For instance, in multiplayer gaming, the game can determine whose voice is trying to execute an action. This can be even used to avoid players from cheating because they have to carry out actions in competitive games if the voice is not recognized.

In the current state of art, all the input and output depends on the provider that is being used. For example, Alexa does not let developers access the audio stream to process the bytes directly, and it has limitations over the audio quality, size and length that can be used to process the output.

The IPA systems are in process of developing; they are in constant evolution. In the future, it is likely that developers will be able to access the audio stream to process it or this feature could be added to the IPAs by default.

3.2.4 Positional Audio (Optional)

Positional audio support is a complement to extend the game experience in which players can locate objects of interest within the current scene. For example, the user can be aware of dangerous or interesting elements in the environment like people talking, a near road, and a dog at the right side.

Adding more versatility to this feature, aside from locating objects in cardinal points within the scene, can be a resource to improve the equation. In that way, players can know that a train is coming from the North West miles away and that the train will pass by them.

In order to enable positional audio, it will be necessary to have stereo speakers, a surround system or headphones capable of representing spatial spaces that are emitted from the IPA.

3.3 Natural Language Processor

A more natural IPA – player interaction has to be ensured. This framework module must deal with the different ways of expressing an idea or a phrase. For example, suppose that after a question, a player wishes to respond affirmatively. There are many ways to answer: (1) "yes, please"; (2) "yes"; (3) "of course"; (4) "sure."

Moreover, complex issues can be addressed by this processor. Most of these issues are still open topics (i.e. sarcasm recognition and onomatopoeia recognition). However, by adding complex features, the interaction is enhanced.

3.4 Help Module

Like videogames, audio games require a robust help system. This module has to make sure that the player knows the options, understands errors, and repeats questions if necessary [13].

The role of this module is vital in the story understanding. There is not a visible interaction space. Players need to remember the scene, options, and characters. Thus, the help module must be prepared to answer questions about the scene or the story. The given instructions must be clear and short. In addition, the player should be able to access this module at any time in the game.

4 Evaluation

Evaluation was conducted. This study required a prototype design that includes the modules of the proposed framework. Moreover, the study included the participation of thirty users (males = 19, females = 11, age range = between 19 and 42) familiar with technology.

The prototype presented an adventure game. Each participant played an investigator role to discover a mystery. The game included voices, music and ambient sounds to enhance the experience. For instance, when a game character approached, steps sounds were played; when a mirror was broken, glass crashing sounds were heard. Also, the game included questions to the players. Sequences of answers defined the path of the game (discover the mystery or not). Each question allowed two or more possible answers.

During this evaluation, participants were interviewed separately. The first part of the interview included questions to gather demographic data and information about IPAs experience.

Before the second part of the interview, a few minutes were dedicated to play using the prototype. Participants answered the questions and listened the story using the Wizard of Oz technique. All sounds, questions, music, and voices were prerecorded and played on demand. Additionally, an example of an available voice game (using Amazon's Alexa) was presented.

After playing the games, the second part of the interview was conducted. Questions gathered data about how natural interaction felt, the importance of the sound components, and the interest on future playing.

The results showed that most used IPAs are Siri (56.7%), Alexa (46.7%) and Google Now (46.7%). All participants use at least one IPA regularly. Besides, participants use the IPAs to (1) know general information like weather, time, restaurants, and commute (73.3%), (2) learn about vocabulary or Wikipedia content (60.00%), (3) request and play music (53.3%), and (4) manage the personal or work calendar (40.00%).

Only one of the participants used at least an IPA to play any kind of games. However, most of the participants said that "yes, I would like to play voice games" (44.8%) or "maybe I'll play a voice game" (37.9%). Only 17.2% said that they will not use an IPA to play any game.

The reasons to play a voice game included: could be fun, it is a different way of entertainment, more inclusive games, could be fun at social meetings and parties, and because it is a new game option.

After playing the game prototype, all players gave an answer using a 5-point Likert scale for how entertainment the game was. Although 44.8% said "yes, I would play a voice game" before playing; 63.3% said "yes, I want to play voice games". Moreover, before playing the prototype, 17.2% said that they will not play a voice game; however only one person (3.3%) said he/she will not play a voice game. Figure 2 shows the comparison between "before" and "after" questions about the interest playing voice games.

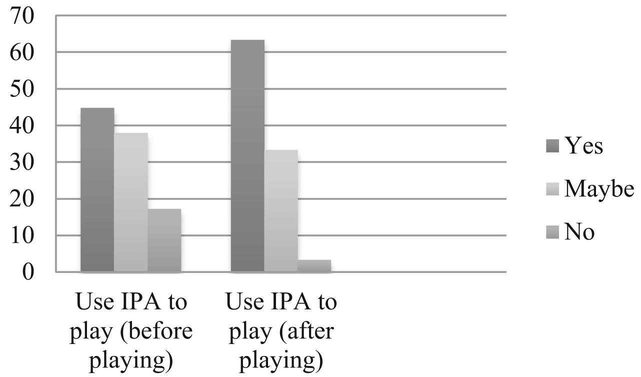

Fig. 2. Playing interest (before and after play the game).

Also, participants gave answers about how important the music, the ambient sound and the voice overs. Figure 3 shows the results. Most of the participants said that the music (66.7%), the ambient sounds (83.3%) and the voice overs (73.3%) are vital components. Only 6.7% or less considered a value of three (medium importance) as an answer. This was the minimum score obtained by the audio components.

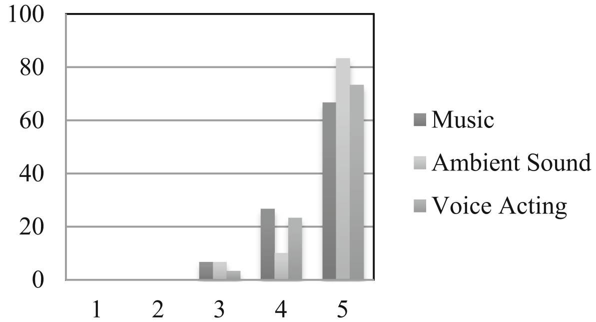

Fig. 3. Audio components importance (5-points Likert scale).

Finally, the participants gave answers about how natural the interaction was (using a 5-point Likert scale too). There is no trend in this answer: 36.7% answers 3 and 4 according the scale. Only 6.7% selected the interaction as natural (Fig. 4).

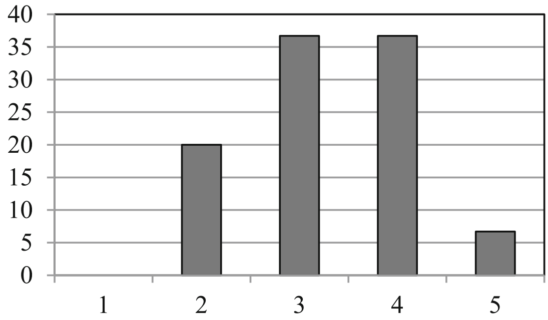

Fig. 4. How natural interaction feels (after playing the game).

Finally, the participants answer about if they will pay for this kind of games. Only 26.7% said "yes", 36.7% said "maybe", and 36.7 answers "no".

5 Discussion

Voice games are suitable for topic areas beyond the entertainment. For instance, marketing and education. Companies could use voice games to engage users with a product (i.e. movies, music, devices, beverage brands, etc.). In addition, this kind of games can be used to teach English (or any other language) grammar and vocabulary, to teach sciences, math, and many other specialized knowledge. The acceptance of the different smartphones and smart speakers enables the massive use of the IPAs in user's daily life.

Some features described in this paper are not yet available in some IPAs. However, many of them are possible to implement, technically speaking. Some of them are open topics and will require further research (i.e. sarcasm recognition, onomatopoeia recognition, among others).

Furthermore, audio games are an appropriate alternative for visual impaired people. Actually, most of the games are focused on an integral experience (including audio and video); but these games are not necessarily inclusive.

Evaluation showed there is a possible market for audio games. Players are minded to play and even to pay for audio games using IPA. Participants pointed the music and sound effects importance, as they feel those elements are transcendent to give a more immersive and better experience.

Additionally, the tests showed that some players that felt sceptic about playing a game without any graphic interface (about 20% of the interviewed persons) changed their mind after having the experience of participate in this kind of games.

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The Implementation of Acoustic in the Game Design - Insight from the Recently Popular "Onmyoji" Phenomenon in China

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Abstract. Phone game player always have trouble to involve the new game. It is difficult to quickly immersed in a game, this makes the game makers spend a lot of methods and strategies on the background of the game, lead the players into the game. Traditional control methods including gesture and touch sometimes cannot help players very well, so sound control then plays a essential role in game control. As an interactive product that can give people different modality (such as nervous, happy and exciting), game must give people multiple sensory experience. There are 2 reasons for this. First, human's sensory system can transmit all kinds of sensory. Any miss of sensory will make people aware the unnatural element around the atmosphere and then affect the immersion experience within the interaction of game. Second, to keep the game continuing, the basic requirement is to keep awaking state about player, and multiple sensory system stimulations can promote the awaking state of player. So even the game itself does not have sound, the customer needs and characteristics of game decide game will not stay on visual stimulation stage. As a result, the sound interpose to game is a inevitable result, it can help player to get abundant and happy experience, meanwhile, the sound can satisfy the customer experience. If we use Yin-yang master as an instance, a lot of Japanese comic original sound together attract comic fans this special group. The acoustic sound in the game let people feel comic joy during the game playing. This paper analyzes the sound in the role of game entertainment, popular use in China games phenomenon to explore the cartoon reality origin in game design methods and the application value. This article analyze the function of sound about game, and take a Chinese fashionable phone game yin-yang master as a instance to research acoustic comic sound's function and value in game design.

Keywords: Acoustic · Interaction design · Onmyoji · Game design

1 Introduction

Recently there is a very prevalent phone game in China. It leads a new entertainment trend and the game called Onmyoji[1] (Fig. 1). Its special Japanese elements are based on culture of Heian period in ancient Japan, especially from the book "Genji

[1] A Chinese famous phone game http://www.baidu.com.

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DOI 10.1007/978-3-319-60639-2_22

monogatari[2]". The game's background is set in Japanese Heian time, tells a story that famous Onmyoji "Abe No Seimei[3]" travelling between Yin and Yang World to find his own memory. After the game launched, Baidu searching index of the game is fast approaching 200000; At the same time, in the Weibo, Wechat[4] or other mainstream media, Onmyoji has become a hot topic. It has over 200 million downloads within 30 days, and get in the top 3 in the app store. A lot of people were attracted by its acoustic. Many famous voice actors in Japan such as Sugiyama Noriakim[5] joined this game and played a very important role. The phenomenas have demonstrated the well-recognized ability of Onmyoji to evoke public attention in China. Compare to traditionary TCG&RPG games, Onmyoji metamorphosis is flowery, its character has the distinct personality base on Heian times background. This game is a very good sample to study acoustic in the game. This article wants to analyze the prevalent phenomenon of Onmyoji, and discuss what the trend is and will be of acoustic game voice base on the analysis.

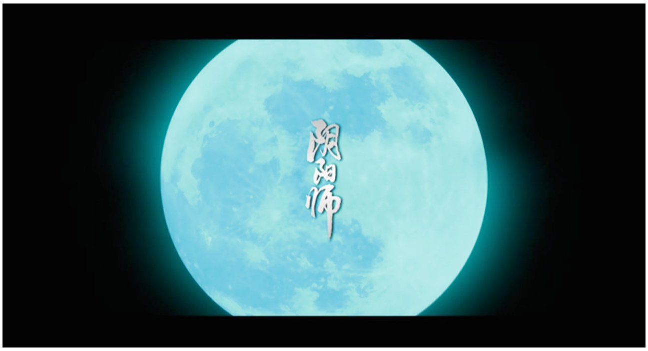

Fig. 1. Onmyoji design by Wangyi company (Copyright © https://yys.163.com/)

This article wants to analyze the prevalent phenomenon of Onmyoji, and discuss what the trend is and will be of acoustic game voice base on the analysis.

2 Background

2.1 The Sound Interaction is not Treated as Important as Visual Interaction by Designer

Communication is mainly base on visual and auditory sense between human and machine. In most times, visual sense does almost 90% of the work.

[2] A fanous history novel in japan http://baike.baidu.com/.

[3] A famous onmyoji.

[4] An online social networking tool by Tencent: http://www.wechat.com/.

[5] A famous actor in Japan http://www.baikebaidu.com/.

2.2 The Relationship Between Auditory Sense and Visual Sense

German aesthete Vischer said: "people of different senses are not isolated, it is a branch of the senses, can replace each other, a rang of the senses, the other senses As memories, as a symbol of harmony, as an invisible, namely resonance[6]".

Some musician and Painter combine auditory sense and visual sense together to make creation. A painter called Edvard Munch makes a famous painting called "Screaming" (Fig. 2). He draws the Screaming like waves that can be saw on the picture, this kind of creation about painting really shocks people who see it in the first time. In the environmental design, visual sense and auditory sense as two connected feeling, and they always been considered together, this is the synesthesia in the psychology.

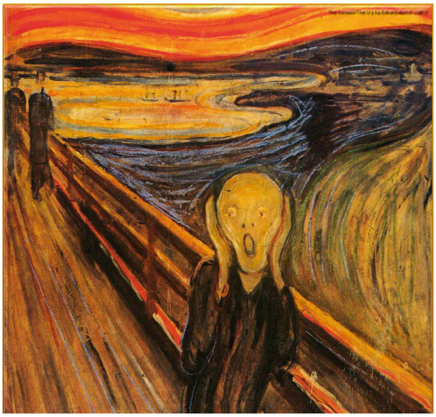

Fig. 2. Screaming painting by Edvard Munch (Copyright © baidu.com)

This is relate to the environment where people play these games. In an objective view, even the development of game music and sound are depend on the progress of technology, but the real reason is the psychological and multiple sense needs of players coming with the development of game.

3 The Objective Reasons for the Raise of Acoustic in the Phone Games

3.1 The Environment and Interaction

Game environment is the world of game, the design of game environment also has two parts: environment description and environment picture.

[6] *Aesthetik oder Wissenschaft des Schönen.* In six parts, 1846.

Environment description is a clear and essential statement for environment, it includes all critical elements about the game: such as all things or events that can interact with player. Environment description should let player know the game world as much as possible.

If the game environment is similar to a place of real world, then the designer can use photo of this place to design the environment. But in most of the time, game environment is a total virtual place, designers should draw the picture of game environment. Only good environment can give comfortable visual experience, and let the character connect with the environment.

3.2 The Sound and Interaction

The game sound includes all kinds of sound, like BGM and speaking voice. Game designer should fully consider the sound experience of player in the game since the sound almost surrounding player all the time.

Sound and music are critical for any game animation, almost all good game animation have excellent music. Some game sound are made by the experts. Watching an animation without sound will be very awful, only with sound, an animation can be interesting. So a good sound is just as important as vision.

In the situation of different language transfering, even the best translator cannot transit the initial willing of the writer to watchers, but music doesn't has this obstacle, player may feel confuse for the full screen of foreign language, but the acuting or relaxing music can transmit the atmosphere to player as the designer's initial willing.

In the same time, the best game cannot only has the real sound, it also need to make the sound solution connect with the game experience, then it can show a better interaction of the game. Without more explain, sound is the most direct connection between player and game of all game voices, it is the key point of auditory sense interaction.

3.3 Interface and Interaction

The game interface is a generic term, it includes all game elements that can be controlled by players in the game. For most games, designer should use the hardware that game can use, such as the keyboard and mouse. Designers cannot change these input hardware, but they can decide how to use these hardware.

The famous game designer Bill Volk[7], wrote an equation "interface + product key point = game". This equation is kind of same to another equation wrote by a famous program language designer Nicholas Wirth, called "arithmetic + data structure = program". His view point basically means game is equals to interface. Interface is the portal for all interactions in the game. No matter easily using a handle or using a multiple inputs and window based interface, designer's interface is always the bond between product element and player.

[7] A famous game designer http://www.billvolk.com/.

The interface should fit the using habit of player. Such as the position of the button, the distribution of the main interface, how the mouse will be clicked etc. Players should handle the interface freely and flexible, then the game could be interesting. So after all, the interaction design should consider the interface elements.

4 The Subjective Reasons for the Rise of Using Acoustic in Phone Games

4.1 Culture Interaction (Integration)

One the of most attractive point of "Onmyoji" is that it use the Japan culture (Fig. 3). It's very rare in Chinese domestic game since once Chinese designer use Japan culture to make a game, it will be very controversial cause it's not the Chinese own culture. In the same time, Chinese domestic players have prejudice for Chinese domestic game, many people will use an inertial opinion and think Chinese cannot make a good Japanese style game.

Fig. 3. Onmyoji (Copyright © https://yys.163.com/)

In history, Onmyoji and Onmyoji's magic use to be seen a Japanese culture product. But the Yin-Yang[8] theory is actually come from China. Yin-Yang is come from Chinese ancient philosophy. In the initial point, Yin-Yang is a very easy theory, stand for the place can be sun-shined and the place cannot be sun-shined. The part can be sun-shined is Yang, the other is Yin, after a while, Yin-Yang stand for the change of climate, the different of position, even the restless and peaceful status of motion etc. Chinese ancient philosopher then use Yin-Yang to explain all relative and opposite relationship, they also think the opposite between Yin-Yang is exist in everything. Further, they begin to think Yin-Yang theory is the basic rule in the university.

[8] yin-yang theory www.google.com.

Yin-Yang is come from the observation of human to human being itself and the nature world. During the West Zhou dynasty, Chun-Qiu period, China, the Yin-Yang theory with nature philosophy has already been made. From Warring State period to Han Dynasty, the Yin-Yang theory tracing the simple Yin-Yang concept and ethical Yin-Yang concept together to be the dualizational Yin-Yang theory.

Then it's not hard to figure out that Yin-Yang magic and Onmyoji are com from China, and now Chinese begin to make the game "Onmyoji" really stand for the culture integration. Just like Japanese come to China learn advanced culture and go back to Japan broadcast it in Tang dynasty. During that time, Japanese and Chinese culture are actually integrated with each other, tea and ikebana are the result of that time. This kind of culture integration really makes the world be more prosper.

There are other examples, Japanese also make some European culture games, such as "demon castle", American make a Chinese culture movie "Mulan", Chinese make European culture games too. Than Chinese make a Japanese culture phone game Onmyoji is not really a surprise.

Actually the number of Japanese culture game made by Chinese game designer is not very little. For example, Tecent recently brought the IP "Monster Hunter" and make a game "Monster Hunter Online"; Kumora make a game called "Spiral Boundary"[9], it's a typical Japanese culture game.

The culture background makes a very stunning UI for Onmyoji, to mate the Japanese culture, designers reflect the words in the book by cloth, name and accessory. By doing so, they project the culture into the game.

For the game itself, the culture integration gives new fun for players, the game "Onmyoji" collect lots of monsters' story and write them down by funny or touchable way. All of these give a new thinking pattern for new culture background game.

4.2 New Game Play for Card Game

Based on the new heavyweight phone game released on the first half year, no matter the "JX online" or "A Chinese Ghost story", All of them are belong to RPG phone game and this fit the market need recently. Phone games are popular from 2013 in Chinese market. The game "My name it MT[10] (Fig. 4)" opened a new time for card phone game. In 2014, the game "Dota Legend[11]" lead the most popular time for card game in China, base on the market data, there are over 500 phone card game get online in 2014. But with severe addiction phone game market getting more and more popular, card phone game meets its "Waterloo" in 2015.

The degradation of card phone game has a strong relationship with its lack of creation. There are a lot of game are very similar to each other in the market and almost all of them are card game. This lead a burnout psychology for players. Other than this, if the designer cannot make the right balance between rare card and deep cultivation, it

[9] A game name.

[10] A famous game in China http://mt.locojoy.com.

[11] A famous game design by blizzard http://baike.baidu.com/link.

Fig. 4. I am MT game (Copyright © http://mt.locojoy.com)

will make players who take the most proportion left, they are the players who spend a little money on the game. And will lead to an impression that card phone game is equals to "really expensive". But on the other hand, two best Japanese phone games that stay on the ranking list for a long time called "Puzzle and Dragon" and "Monster Strike" are typical card phone game. Except Japanese market is more prefer the card game, these two games have their own typical creation on play method. "Puzzle and Dragon" is "card + eliminate", "Monster Strike" is "card + shoot". The most popular phone game this year "tribal conflict: royal war" is a "card + strategy" and make it be the best example.

"Onmyoji" has its own typical game method which is half round system, on the traditional turn-based system, "Onmyoji" add the time line and a shared resource system called "ghost fire" to increase the strategy fun of the game. Other than the fight between card, the collection of pieces about "Hyakkiyakou", the collection of gears about "Orochi", the LBS system emphasis on social interaction etc. The designer team knowing how to make card + creation (Fig. 5).

Fig. 5. Onmyoji card (Copyright © https://yys.163.com/)

Different from other phone game, "Onmyoji" is focus on how to make players feel less tire and control the speed of player to dig the content. Base on the actual performance, following is how "Onmyoji" solve these problems:

1) Abundant game fundamental play method and structure, base on this, designers can build a more potential game content for players and make the game be more expansible.
2) Base on game's type and content, designer can give a special play method and make the method be very impressive, in the same time, this can give players a better experience. (Such as "Hyakkiyakou" and LBS social method)

For the first point, it is the most hard point for almost all the phone game on the market, include many famous games. Even with a good play method, this method cannot be reflected on the playing level, and only make players feel good in the beginning.

With players dig more deep with the game, all the creations become accessories but not the core content, the whole game become a math model, than become a fighting power compare.

In the same time, the high frequency and boring play method can make player feel tired, the whole game has only one way to play. This kind of concentrating play squeeze players and make creation's life be spend very soon.

"Onmyoji" saw this problem and add many new type of play to the game, and distribute players' energy, and then increase the life of game content.

4.3 The Interaction of Sound

There are really few games take sound as their special selling point like what "Onmyoji" doing right now. Sound is invisible, so when we talking about sound, usually use some terms of painting, such as the "color of sound" and the sound can "transfer the situation". Every individual movement has truthful and reliable sound, by doing so, designers of Onmyoji make a better experience for players. Onmyoji takes two kinds of methods, voice dubbing and sound image design to really give truthful and reliable sound.

Voice dubbing means use professional and experienced people to make voice for characters in the game. It makes the situation be more truthful. In Japan, the popularities of cartoon makes voice dubbing has a very good mass base. When the writer of this paper get in touch with Onmyoji in the first time, the voice dubbing is the most attractive point. It is better than find some celebrities to represent the game.

Sound image design has many functions: the first one is make the foundation of the atmosphere about the game. The BGM (Back Ground Music) can reflect the keynote of one game, all kinds of keynote can be transferred by BGM such as happy, relax, mysteries even dangerous. The second function is control the peace of game. This function can be reflected in the beginning of the game. In early games, same song was repeated a lot of times but with different rhythm. But recent games are more like to use different songs to represent different rhythm of the game. After all, rhythm of the game can be reflected by songs in the game. The third function is to distinguish the different characters. In the SRPG (Strategic Role Play Game) such as "Super Robot Taisen", different characters always have different BGM. When some character join the fight, the BGM always changes to notice player the change since the acute fight sometimes can make it hard to find the new join character. The last function is guide the player playing the game. When players lost in the game (it's pretty common since the scene in recent games are bigger and complicated than before), the sound can help and guide players to find the right way.

5 Discussion

By analyze the case of Onmyoji, we can see a trend to use sound in the game will be more popular and broad but not just a supporting role. Let's take the game "quaver[12]" (Fig. 4) as an example, this is a sound control game, player use their voice to control the character move, jump and dodge the obstacle. The game system is very similar to super Mario, but the sound control mode makes it become special and popular in the market. Different from traditional game, the control mode is changing from mechanized control and touch control to new kind of control. But how long the new way can lasting will need time to testify. The new interaction method is also has some problems. For instance, the player of "quaver" often has to pause the game since they want cough. On the other hand, environment and interactive method always affect each other. Phone is the platform of phone game. The size of phone screen, the way how to type the button, all of these are really limit the creation of interaction. In the last, for blind and visual disability, when visual interaction is not working, how to find a new to interact in the game will be another problem (Fig. 6).

Fig. 6. 休八分音符(Copyright ©http://www.gamersky.com/news)

6 Conclusion and Hope

Game brings people feeling that quite different from daily life. In this kind of experience, sound and picture together making player feel happy. Using sound is not only simulating the real situation, but also to transfer the information and stimulate player. When the picture can not transfer the information accurately or player feel tired to use their eyes, sound will take the responsibility to transfer the information. Sound can transfer information to player in a quiet and invisible way, guide player with necessary information without notice. This can assure the immersion and fluency in the same time. We can say sound is an invisible interactive method and an invisible assistant of player.

[12] A prevailing game http://www.gamersky.com/news.

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What Distinguishes a Traditional Gaming Experience from One in Virtual Reality? An Exploratory Study

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Abstract. Despite the rapid and significant growth of virtual reality based video games, scientific studies have not yet been conducted to highlight the outstanding differences of this kind of immersive video games as compared to the more traditional kind (i.e. not immersive, for instance tablet or console games). Peculiarly, very little information is provided about the players' experience during a virtual reality game. On the basis of these observations, the paper presents an exploratory study aimed to compare the players' experience while performing a video game in an immersive (virtual reality) and in a non-immersive (tablet) condition. In order to address this objective, 10 participants, within the age range of 18 to 35 years old, were asked to play Smash Hit, a first person game in which the player is provided with an inventory of metallic spheres with which to aim and break glass obstacles. The video game was played by participants on to different display modalities: immersive (virtual reality) and non-immersive (tablet) condition. Psychometric (self-report questionnaires assessing emotional responses and usability of the video game) and physiological (heart rate) measures were used as quantitative dependent variables. The experimental design and results of this exploratory study will be presented and discussed.

Keywords: Virtual reality · Video games · Human factors · Game design

1 Introduction

During the course of last year, there has been an actual revolution in the gaming business thanks to the entry to the mass market of Virtual Reality (VR). Thanks to commercial Head Mounted Displays (HDMs) and their now reasonable cost (e.g., Oculus Rift $599, HTC's Vive $799, Sony's PlayStation VR $399), VR is becoming more and more present in the gaming market [5].

Video games have always required actions from the players. However, what could be defined as a single and simple action in the past (e.g., moving the bar at the right

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moment to hit and direct the ball while playing PONG), with the entry of VR it has turned into a multisensory experience (visual, auditory, proprioceptive), opening new possibilities for how video game itself cab be considered (Benedicuts [2]; Heineman [5]). Within the context of gaming experience, VR gives multiple interactive possibilities, differently from more traditional display modalities (e.g., desktop, console, tablet). As Andrew House (CEO of Sony Computer Entertainment) stated: "the most fascinating thing is how VR has rewritten the rulebook of what game design should be. It's levelled the playing field in terms of production values" [12].

While in the past most video game research has focused understanding outcomes of playing games (e.g., Anderson et al. [1]; Ferguson [4]), recently there has been a shift toward understanding how specific game features, especially display modalities (immersive; non immersive) and format (2D; 3D) can impact game playing [6, 7, 9, 13]. Previous studies comparing game-like situation (i.e., navigation and wayfinding tasks) in non-immersive (desktop) and immersive (VR) display modalities have shown that individuals tend to perform better when play in non-immersive setup [15, 17, 18]. In addition, VR has been reported has more emotion inducing that content that is experienced with less immersive technologies [8, 10, 12], suggesting that more graphically enhanced interfaces are more emotion-inducing than systems less advanced.

However, scientific studies conducted to highlight the outstanding differences of VR video games as compared to the more traditional kind (i.e. not immersive, for instance tablet or console games) are still very limited. Peculiarly, still no information is provided about the players' experience during a VR game in terms of emotional responses and usability.

On the basis of these observations, this exploratory study was aimed to compare the players' experience while performing a commercial video game in an immersive (VR) and in a non-immersive (tablet) condition.

2 Materials and Methods

2.1 Participants

The experimental sample included 10 participants (age: M = 26.1, SD = 3.72; years of education: M = 16.5, SD = 1.58), 4 women (36.4%) and 6 men (54.5%). Participants were chosen among students and personnel of the University of Milano-Bicocca and of other universities in Milan. No credits (ECTS) nor economic rewards have been provided during the research.

In order to be included in the study, individuals will have to meet the following criteria: (1) age between 18 and 35 years old; (2) no major medical disorders (heart disease or high blood pressure, neurological disorders, epilepsy); (3) no left-handed; (4) no presence of pharmacotherapy (psychoactive drugs, anti-hypertensive, anti-depressants); (5) no significant visual impairment (all with normal or corrected-to-normal visual acuity).

Before participating, all participants were provided with written information about the study and were required to give written consent in order to be included. The study received ethical approval by the Ethical Committee of the University of Milano-Bicocca.

2.2 Measures

A multimethod (i.e. focused on diverse aspects of the users' experience) and multilevel (i.e. based on the integrated use of different technical and methodological solutions) approach has been used, previously tested during a pilot study conducted by the researchers involved in this experimentation [11].

Psychometric Assessment
At the start of the experimental session, a self-report questionnaire was given to the participants in order to analyze their gaming habits (mean hours gaming per week) and technological knowledge (tablet usage skills and knowledge of VR system, in a 7-point Likert scale). In addition, in order to measure the subjective indexes concerning the game experience, the following self-administered questionnaires have been used:

- State-Trait Anxiety Inventory, Form - Y1 (STAI-Y1) [16]: a validated and widely used measure of state anxiety;
- System Usability Score (SUS) (Brooke [3]): a reliable tool for measuring the usability. It consists of a 10 item questionnaire with five response options for respondents (from "strongly agree" to "strongly disagree");
- Net Promoter Score: a customer loyalty metric [14]. NPS can be as low as −100 (everybody is a detractor) or as high as +100 (everybody is a promoter).

Psychophysiological Assessment
During the experimental sessions, the following psychophysiological data have been recorded Heartbeat (HR), measured with Electrocardiogram (ECG). In particular, HR mean value, measured in Beats per Minute (BMP), was calculated through R-to-R peak detection. The physiological signals were acquired using a ProComp Infiniti device from Thought Technology, including Biograph Infiniti 5.0.2 software to record and export all raw signals. Every signal was exported at a 256 Hz sampling rate.

2.3 Video Game

The videogame has been selected following two main criteria: (1) relevance in the world of gaming; (2) possibility to be played both in an immersive (VR) and in a not-immersive (tablet) display modality. Videogame tested in the study was the following:

- Smash Hit: a first person shooter game developed in 2014 by Mediocre AB. It includes a continuously moving perspective along a colorful hallway. The player has an inventory of metallic spheres with which to aim and shoot at glass obstacles. In order to proceed in the game, the player must hit pyramids and polyhedral objects in order to obtain more spheres with which to shoot to obstacles. If the player misses the target, he/she will lose one sphere. The game is over when the player has no more spheres to shoot.

The total time played and the final level reached by the player was evaluated.

2.4 Experimental Design

A within-subjects design was used to compare emotional responses and usability of the two experimental conditions. Specifically, the study compared the following conditions:

- *Non-immersive Condition:* Tablet (TB). During the TB condition, individuals were seated at a desk on which an Ipad was positioned. Participants were asked to play the game until they lost.
- *Immersive Condition:* Virtual Reality (VR). In the VR condition participants were seated at a desk and asked to wear a HDM (Samsung Gear VR with Samsung S6 smartphone) on which they were asked to play the selected game (Smash Hit). After a brief training about the HDM's controls, participants were asked to play the video game until they lost.

2.5 Procedure

Participants were randomly assigned to the order in which the conditions were presented, counterbalanced for each subject through an established randomization scheme obtained from http://www.randomizer.org/. At the start of the experimental session, participants were asked to complete a self-report questionnaire about their gaming habits and technological knowledge, and the STAY-Y1. Participants were then connected with biosensors for recording their HR. A baseline measure of this signals was registered for 3 min in rest condition, with eyes opened. Once the physiological baseline was recorded, the experimental session started, beginning with the first assigned condition, and psychophysiological signals were recorded while the participants completed the game. After each condition participants completed the following self-reported questionnaires: STAY-Y1, SUS, and the Net Promoter Score. The complete experience was about an hour long.

3 Results

Data were entered into Microsoft Excel and analyzed using SPSS. Change in psychometric and physiological measures within-subjects were calculated using paired t-tests.

3.1 Participants Characteristics and Video Game Performance

The gaming habits and technological knowledge of the sample included were the following: mean hours gaming per week ($M = 17.4$, $SD = 13.5$); tablet usage skills ($M = 5.8$, $SD = 1.22$), knowledge of VR system ($M = 2.9$, $SD = 1.52$). Regarding video game performance no different between conditions emerged (Table 1).

Table 1. Mean and standard deviation of video game performance and SUS and Net Promoter Score scores in the two experimental conditions.

Condition	Virtual reality	Tablet	*t*	*gl*	*p*
Time (tot sec)	429.8 (297.1)	407.5 (190.2)	−2.38	9	.817
Game level	2.5 (1.17)	2.5 (1.08)	.000	9	1
SUS	75.75 (12.69)	80.75 (11.6)	.951	9	.366
Net Promoter Score	8.2 (1.75)	6.2 (2.89)	−2.739	9	.023**

3.2 Psychometric Variables

In order to test if self-report emotional measures changed depending on the specific condition, the mean difference of STAI-Y1 (score at the baseline minus score after condition) was calculated for each condition. A paired t-tests showed that the mean difference in STAI-Y1 was significantly higher in the VR condition (M = −7.6, SD = 9.58) than in the TB condition (M = −2, SD = 8.45), t(9) = −2.32, p < .05.

Then, in order to evaluate differences between conditions in self-report measures of usability paired t-tests were conducted on the mean scores of SUS and Net Promoter Score assessed after each condition. Analyses showed significant differences only in the Net Promoter Score (Table 1).

3.3 Psychophysiological Variables

In order to test whether psychophysiological indexes changed depending on the specific experimental condition, the mean difference of HR (BPM at the baseline minus BPM after condition) was calculated for each condition. A paired t-test showed that the mean difference in HR was not statistically siginificative different between conditions: VR condition (M = −5.97, SD = 8.69); TB condition (M = −1.27, SD = 11.26), t (9) = −1.282, p = .231.

4 Discussion

The first main results of this exploratory study is that players showed the same video game performance in the immersive (VR) and in the non-immersive (TB) condition. Results showed, in fact, no significative differences in terms of total time of played and in the final level reached by players between conditions. This results seems different from what have been observed in previous studies comparing non-immersive (desktop) to immersive (VR) display modalities in game-like situations, which reported a a global tendency of individuals to perform better when using non-immersive systems (Sousa Santos et al. [15]; Swindells et al. [17]; Yeh et al. [18]). One of the possible explanation could be the different type of game adopted (i.e., a first person shooter game versus navigation and wayfinding tasks).

Secondly, from this explorative study emerged that players reported a higher self-report anxiety after the immersive (VR) condition compared to the non-immersive

(TB) condition. This results could be related to participants' low knowledge of VR technology and to the anxiety generated by using a not well-known device when compared to one more familiar such as the tablet.

Finally, the third main result of this study is that VR was perceived by participants more appealing than the tablet, as revealed by analysis on the Net Promoter Score, but not more usable, as results on the SUS suggest. This appears very interesting, since seems in contrast to the fact that participants reported higher level of self-report anxiety after playing in VR compared to tablet.

Although are interesting for their possible applications in the video game research and design field, this study has some important limitations that could affect the generalizability of the results or that may have influenced the findings. The main issues are related to the small sample size and the specific sample included in the study (who were young adults, played often per week and had a low knowledge of VR system). Another limitation is that we did not assess interesting variables such as cybersickness and presence experienced by players.

Despite this limitations, the present exploratory study found that: (a) to play a video game in VR was not more difficult than play through non-immersive devices, such as tablet; (b) players showed higher anxiety after playing in VR than after playing through the tablet; (c) VR was perceived by players to be more appealing than the tablet.

Future studies are needed to investigate the differences in players' experience between video game presented through VR compared to non-immersive devices. In particular, the relationship between interactivity, the intensity of emotional response, and players' performance should be deeply investigated.

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Voice-Control as a New Trend in Games Applications

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Abstract. Nowadays, we're moving to a new world of technology and input devices designed to fit specific times and places, such like voice activation for computer games and app games. Automatic speech recognition systems are not a new concept in modern app games. Developers believe gesture-based technology, along with voice-activation technology, will inspire entirely new kinds of games. This paper aims at find a new trend of app games, and that can be universally applied for designing inclusive games. Voice-control app games involve a variety of play types, They increase the playing more interesting and interactive.

Keywords: Human factors · Voice-control · App games

1 Introduction

As the mobile Internet technologies continue improving, the app market in China is rapidly growing with the rise of smartphone users. Games are bigger than any other app category and both for the social web and for mobile devices. Today, many game manufacturers are racking their brains to create some very attractive games. And such as Gameloft and other large manufacturers, They are easy to forget that in the development process, the greatest sense of pleasure is more important than techniques.

Don't stop! Eighth note, a game which took off in early 2017. Overnight, it became the talk of the town. Compare with the other app games, a simple voice command captured this game.

The Voice-control app game is only one step towards inclusiveness and thereby universal design. It is convenient to play and simple operation. The Voice-control app game will help the player pick it up and figure it out quickly, it is intuitive, it's easy to play, doesn't require a ton of time to play and can be enjoyed by a wide range of people. People derive such great enjoyment from these simple games. It making us relaxed and naive again in the world of adults. Users are willing to share their game videos, which makes spread like wild-fire. This will make app games more interactive than ever. While these games are growing their audiences, it is a nice way of unwinding.

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2 Literature Review

In fact, most of the electronic entertainment equipments are more or less with voice recognition function. Other voice commands that Google is introducing will let users dictate notes to their phones, navigate straight to websites, see maps and send email or text messages. Nintendo DS developers have been able to add phonetic elements to the game in NDS, and offer a good gaming experience for the majority of game players.

Game is an art. The most successful part of the game is it share a common fate for players, also providing a better interaction experience and emotion experience. For example, a lot of players will feel sorrow because of the death of game character; At the same time, even the player only make a little success, it will still gives them a sense of achievement.

As we all know, most game vendors support only a few operating systems for their applications. We usually play app games by clicking and sliding. At the same time, is complicated to call the camera, microphone, and G-Sensor modules. More important, the trade-off is one of convenience versus compatibility.

Voice Actions are a series of spoken commands that let you control your phone using your voice. Speech recognition is technology that uses desired equipment and a service which can be controlled through voice without touching the screen of the android smart phone [1].

3 Description of the Game

3.1 Don’t Stop! Eighth Note

Don’t stop! Eighth note is a interesting but ridiculous game. In this game, people control the Eighth Note via the duration and amplitude of their voice. Honestly, the game had no imaginative storyline and characters, challenging gameplay, or superb graphics. This is a very interesting game, the rules are very simple. But like so many simple games, this one seems highly addictive. Players can only manipulate the game through the level of the sound., they need move and avoid obstacles by shouting (Fig. 1).

Fig. 1. Adjust the volume during the game

When you speak through a microphone, the sound of your voice turns into an electrical signal, which is passed into the computer and stored in a pile of data. Based on the physical characteristics of the amplitude and other factors, the value is not the same. Through playing it, players can released the pressure, tediousness and anguish in their real life, to meet the emotional satisfaction (Fig. 2).

Fig. 2. The screen of *Don't stop! Eighth note*.

3.2 Game Method

In the game, the Eighth Note can move, small jump, big jump with different sound levels. First of all, please allow microphone when you first launch the app. If you shout loudly, then the notes will jump up. On the one hand, when it was louder, the notes will jump higher; but if you just make some faint sound, then notes only slowly moving forward. On the other hand, the length of the sound is also very important. If the sound suddenly broke when the player was in the air, then the note will drop from an upright position. In response to this need, Eighth note replaces touch input with a speech detection algorithm that allows users to control the game with the duration and intensity of their voice [2]. So don't stop shouting during jumping. And only the eighth note touches the▲ will you succeed! Players can adjust the sensitivity of the sound for different situations (Figs. 3 and 4).

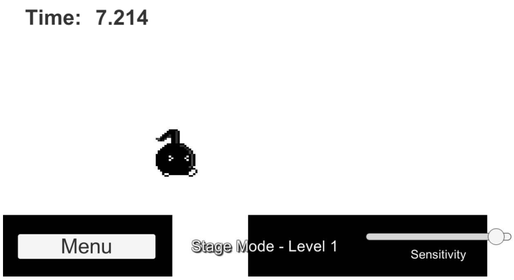

Fig. 3. The sensitivity of sound.

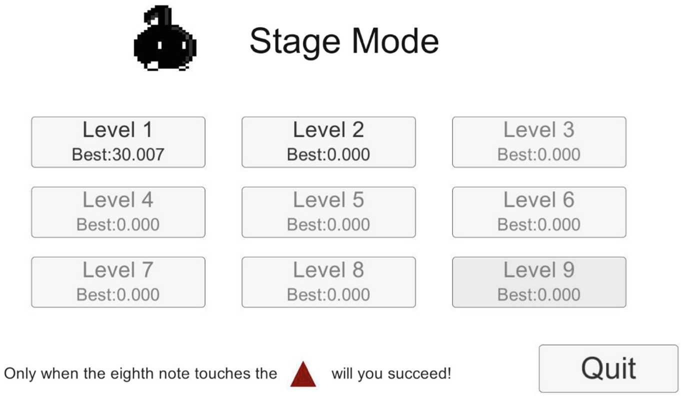

Fig. 4. The stage mode of the game.

3.3 Program Code

We can develop this game by using the cocos2d-python and pyaudio modules. Making the game in this paper, and uses a relatively simple mechanism for collision detection algorithm to simplify a lot of code, which makes the game run smoothly on the phone (Fig. 5 and Table 1).

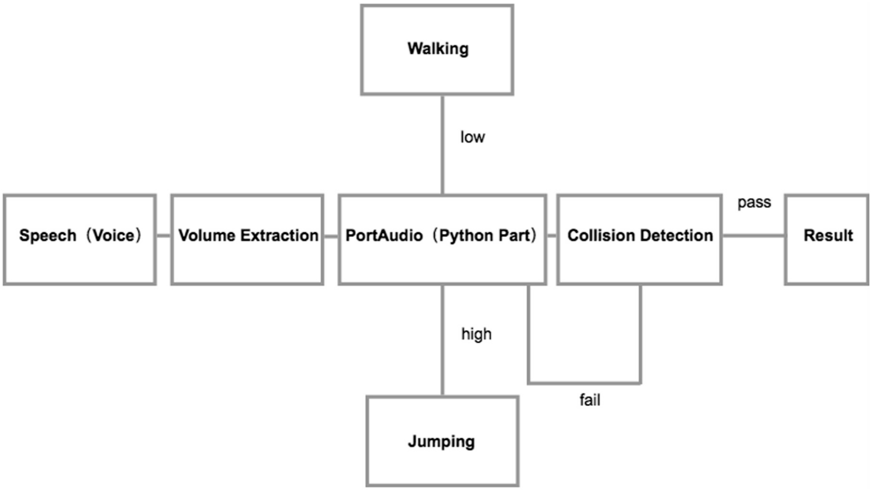

Fig. 5. Converting Speech signal into a set parameters suitable for game.

Table 1. Different kind of Voice-control app games.

APP Games	Kind	Difficulty index
≪Mayday! Deep Space≫	Maze game	Very difficult
≪Pah≫	Shooting game	Difficult
≪Don't stop! Eight note≫	2D action game	Easy

Step 01——Sprite. Sprite is the protagonist of the game. First of all, we define roles and add to the scene, and rename the role to PKQ.

```
class PKQ(cocos.sprite.Sprite):
    def __init__(self):
        super(PKQ, self).__init__('pkq.png')

self.pkq = PKQ()
self.add(self.pkq)
```

Step 02——Increase the effect of gravity to the character

```
def update(self, dt):
    self.speed += 10 * dt
    self.y -= self.speed
    if self.y < -80:
        self.reset()
```

Step 03——Recorded the sound of microphones

```
  pa = PyAudio()
  SAMPLING_RATE                                                    =
int(pa.get_device_info_by_index(0)['defaultSampleRate'])
  self.stream    =    pa.open(format=paInt16,    channels=1,
rate=SAMPLING_RATE,                                input=True,
frames_per_buffer=self.NUM_SAMPLES)

string_audio_data = self.stream.read(self.NUM_SAMPLES) k
= max(struct.unpack('1000h', string_audio_data))
```

Step 04——Judge walking or jumping by volume

```
if k > 3000:
    self.floor.x -= min((k / 20.0), 150) * dt
if k > 8000:
    self.ppx.jump((k - 8000) / 1000.0)
```

Step 05——Uncomplicated collision detection

```
def collide(self):
    px = self.pkq.x - self.floor.x
    for b in self.floor.get_children():
        if b.x <= px + self.pkq.width * 0.8 and px +
self.pkq.width * 0.2 <= b.x + b.width:
            if self.pkq.y < b.height:
                self.pkq.land(b.height)
                break
end.
```

4 Competitor Analysis

4.1 Mayday! Deep Space

Mayday! Deep Space is a science fiction maze game created by developer Daniel Wilson [3]. It has ambitious goals as a piece of interactive sci-fi. Players owe it to yourself to explore Mayday! Mayday! will have you hooked, from the first "Affirmative" til' the closing credits. More than once, hearing everything it has to offer. In the game, the player must use simple voice commands to instruct a man who is stuck on a spaceship full of monsters. It has Ingeniously simple concept with pitch perfect execution (Fig. 6).

Fig. 6. The screen of Mayday! Deep Space.

Mayday! is a wholly unique experience that takes place entirely within the confines of a radio call made from the USS Appaloosa — a spacecraft set adrift after an unknown incident leaves the crew massacred, save for one lone survivor. Having answered their communiqué entirely by chance, it's your job to use your view of their onboard radar to guide the poor soul to safety using only a stable of rudimentary voice commands ("go left," "run forward," "faster," etc.), all the while uncovering the realities of what happened on the doomed vessel in the first place. these voice commands are actually very simple, but it is enough to allow players to combine into a variety of walking routes. And when you first boot up Mayday! Deep Space, it tells you to find somewhere quiet to play it, presumably out of practical concern for interference with your voice commands.

But don't underestimate the difficulty of the game, as the story progresses, the map of the route will become extremely complex, and the number of zombies will rise. The player need to have patience in shouting. Many reviews found the use of voice commands to be unique and one of the highlights of the game as a whole.

4.2 Pah

Pah! is a very interesting voice-controlled game. The app has now hit the Windows Phone Marketplace for $1.99. It's amazing that over 350,000 downloads and 50,000,000 shouts of Pah! in 40 days! This voice-controlled game took the mobile world by storm. Players shout 'Pah!' at your Android or iPhone device and you can control a little blip-firing spaceship on the screen. A long 'Paaaaahhhh' moves the spaceship, and a short emphatic 'Pah!' fires the shooter [4]. The game uses both voice and gestures to guide your ship to the finish line. Of course, the word 'Pah!' can be replaced by any similar noise, and it doesn't matter what are you speak in the game. To an extent, Don't stop! Eighth note is similar as Pah (Fig. 7).

Fig. 7. The screen of Pah.

5 Limitations

Voice-control app game aims to create the experience of playing a game controlled by your voice. This new technology could make our lives more interesting and convenient. But some people, in fact, hold a different view. They think it was phenomenal. We really need discuss the limitations of the Voice-control app games and propose improvements for further development.

A quiet place would definitely provide you with the best gaming experience. However, most of voice recognition system can't offer you the freedom to play the game in any circumstance. It's difficult for each voice recognition system to distinguish your voice from any background noise, such as a noisy bus station or other places.

More importantly, most people are so ashamed to play the voice-control app game s in public. And players may feel tired if they keep shouting.

Voice-control app game has its shortcomings, but on the whole it brings joys and wonderful interactive experience. Based on the characteristics of the mobile phone game interaction, is bound to develop into a simple operation, interactive trend.

6 Voice-Control Game Future Direction

In addition to many different kinds of action games, players can find so many categories to choose from the puzzle games, dating simulation games, adventure games and lots more. Then it could make the voice-control game more entertaining and intriguing. The following examples illustrate this principle in the context of direction discussed in this chapter.

Love Plus is a very popular dating simulation game in Japan. In the chat session, there are many ways of interaction with girls. Players can talk to the girls, play games with them virtual girlfriend, ask her the next date time and place etc., and dialogue becomes closer that will help you to win her. There's an entire industry in Japan that helps men who eschew romantic lives cope with loneliness through relationship-simulating video games and even holiday retreats (Fig. 8).

Fig. 8. Love Plus voice-control game.

Another popular game is In Verbis Virtus. Cast spells using your voice! In Verbis Virtus is a game with voice control and with first person view in which you solve the enigmas and face the enemies using magic. It is developed with the Unreal Development Kit by Indomitus Games. It is a first person game where you use a microphone to cast spells by actually saying the magic words. It mixes action and puzzle elements in a fantasy setting [5].

7 Look Forward

In the past we have been seeing the typical mouse and game controllers to control games on different devices.. But with a sensitive sound recognition engine, Voice-control app game can immerse players in the world that react to them voice.

People nowadays can play games not only with their computers but also mobile phones, and there are thousands of games in the world and still more of them are created every day. It is getting more and more difficult to create a really unique game with the ability to attract huge masses of players [6]. App game makers and publishers are entering a period of uncertainty as technology alters the way consumers play. In recent years, the fast development of speech technology brings a new trend for app games.

There are many approaches to game control. The most usual devices are keyboard and mouse. But in the future, we will focus on providing a better gaming experience by new technologies. Voice-control, 3D & VR version would become a new trend. Multilingual intelligent human-machine interaction is a hot spot in the field of speech recognition.

In the past it is unclear whether voice-control app gaming is a promising new business model or a fad with only limited appeal. With the development of technology, excellent visuals and soundtrack could let them release pressure in the future voice-control game. They will temporarily forget the daily pressures and trouble in the life and get the freedom of the mind. This is the glamour of the voice-control app games. The purpose of this thesis is to provide a new trend of app games, based on analysis of voice-controlled games.

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Game Design for Students: Teaching as a Whole Context

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Abstract. In this article, we will present the importance of a game design pipeline that takes human factors into account when working with undergraduate students. To accomplish this goal, we have been working with game design students to see the impact of how a more streamlined production can help improve the quality of all projects done inside the university. Better projects during their time as students can help them becoming better professionals in the future.

Keywords: Game design · Teaching · 3D modelling · 3D artist

1 Introduction

Along the years, our university have taught Design students the basics to create a 3D game. Areas like modeling, shading and animation allowed them create assets for it. But lacking the full comprehension of a game design pipeline have led to some poor results.

The indecision and stress that most students go through in this phase make the professor's role even more important, since they are the ones who will support and guide the students in their progress. To help in this matter we developed a method to improve the students' performance in class, by connecting all the areas of knowledge - that are usually taught separately - and putting them into a context of a nearly real-life game design production line.

This method is an adaptation from the Jim Wallman's paper "It's Only A Game". We adapted it in a way that the students have a set of steps to go through. By following this methodology, we intend to prevent the problems that may appear later in the development of the project, by giving the students plenty of opportunity to test their work and providing them the necessary space to try things out. By the end of the project, a more confident and prepared student will be considerably more aware of their own capacity, which will certainly lead to a better result.

2 The Design Course in UFSC

To a better understanding of the process used in this paper, it can be useful to have some context about the environment where it was applied: The Design Course in the Federal University of Santa Catarina (UFSC).

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2.1 UFSC

Located in southern Brazil, in the state of Santa Catarina, UFSC has its headquarter in the city of Florianópolis and, as the name implies, it is controlled by the federal government. As a public university, it's completely free and there is also a grant for people in low-income situation to help them stay in the city during the courses (Fig. 1).

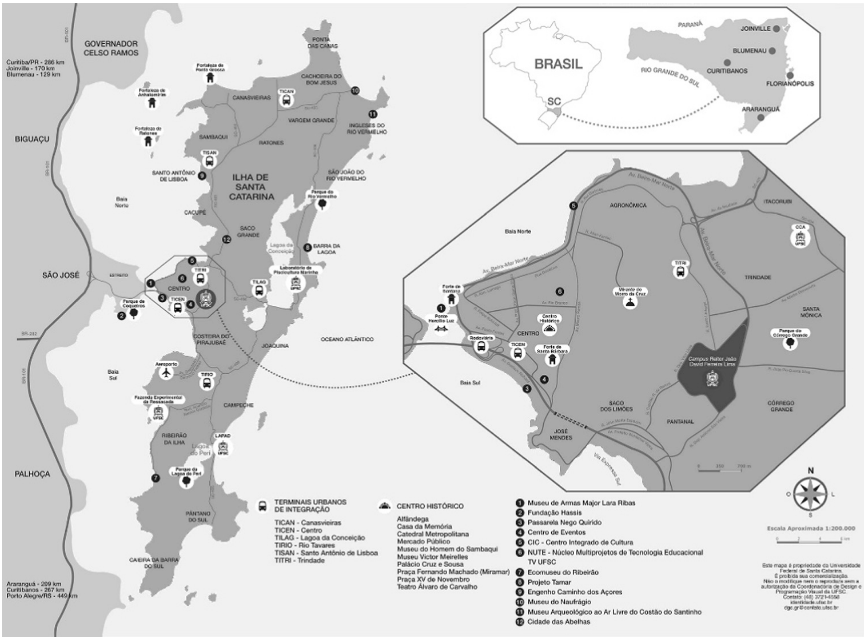

Fig. 1. Map showing UFSC location. Source: http://estrutura.ufsc.br/mapa/

To put in some numbers, there are around 50,000 people in the university, divided in students, staff and teachers, being around 5,500 employees working there. Besides the headquarter, it also has campus in other four cities, all located in the same state of Santa Catarina: Araranguá, Curitibanos, Joinville e Blumenau. In 2016 UFSC has reached number 25 in the QS Rank for universities in South America and number 9 in Brazil, with 83 undergraduate Classroom Learning programs with "19,660 students enrolled, and 13 undergraduate Distance Learning programs in all areas of knowledge with 5,389 students enrolled". It also "offers 56 graduate programs and the figures for 2010 showed 3,882 students enrolled at the Masters level, 2,360 at the Doctoral level and 2,693 at its several Postgraduate Diploma programs. Ranked among the 10 best overall Brazilian universities in Latin America by the Webometrics Ranking of World Universities, it is one of the leading Latin-American research universities" [1].

2.2 The Design Course

The Design course, located in Florianópolis, UFSC main campus, is a 4-year undergraduate program. Starting as a generic course in the first year, when they take introductory disciplines, and then, in the second year, the student may choose which of these areas to specialize: Graphic Design, Product Design, Fashion Design, Advertising and Animation. For each of these areas, there is a group of projects they can take on each semester. They need to complete four projects to move on to the final one, meaning it will be two years in total. Then there is one semester when they do internship and another one for the final project. Besides this, there is also a group of disciplines that they are obliged to take, separated as a general mandatory and inclusive disciplines. They may also take some elective disciplines that are not necessary to finish the course, but all these disciplines need to be taken before doing the final project. The whole structure of the course can be seen in Table 1 separated by semesters.

Table 1. UFSC design 4-year course structure.

Semester	Main content	Parallel content
1	Introductory disciplines	
2	Introductory disciplines	Mandatory/Elective disciplines
3	Projects	Mandatory/Elective disciplines
4	Projects	Mandatory/Elective disciplines
5	Projects	Mandatory/Elective disciplines
6	Projects	Mandatory/Elective disciplines
7	Internship	Inclusive disciplines
8	Final project	

The students need to complete 2925 h of class time to graduate, divided by the introductory disciplines, mandatory disciplines, inclusive disciplines, projects and internship as shown in the Table 2. In this structure the final project in considered part of the inclusive disciplines.

Table 2. UFSC design minimum disciplines class time to graduate.

Discipline	Class time
Introductory disciplines	720
Projects	960
Mandatory disciplines	420
Inclusive disciplines	525
Internship	300
Elective disciplines	0
Total	**2925**

The students that want to work with game design take the animation projects, starting when they reach the second year. There are 4 different projects for each semester and they all have 4 disciplines: one for the project and the other three to complement it, so they have a total of 16 when they finish all the projects. They are not obliged to follow the projects in any particular order, but in order to take the project discipline they must also take the other 3 to complement it. Following, there is a list with the name of the disciplines that compose each project, in the order that they are supposed to take:

- Project 17 – 2D I, Scenery, Sound, Introduction do 2D Animation.
- Project 18 – 2D II, Advanced 2D Animation, Character Concept, Semantic Research and Scenary.
- Project 19 – 3D I, 3D Animation I, 3D Modelling I, Character Modelling.
- Project 20–3D II, Post-Production, 3D Animation II, 3D Modelling II.

As showed above, they are separated in 2D and 3D and each of it is made of part I and part II, one introductory, where they learn the basics on each area, while the other is more advanced where they can learn by practicing their skills. The students are also free to choose if the final product is going to be an animation for a movie or a game cinematic or either creating assets for a game. There are also some elective disciplines available, some of them to give some specific skills, like Motion Capture, while others improve the ones they have already learned, like Post-Production II. Then, to finish the course, they create a final project where they are free to choose what to do. This final project is called PCC, that are the initials in Portuguese for Course Completion Project (*Projeto de Conclusão de Curso*) and is divided in two semesters: PCC 1 and PCC 2. This means that they have one year to complete this final project. In the first half, they usually create the story, concepts and improve the skills. Then, they use the second semester for the production itself. They also must write a report about it, but the most important thing is the final product they create in the area they chose to work.

To help them during the whole course, our university provides a complete infrastructure like classroom with computers and also laboratories equipped with powerful computers, render farm, 4K RED video cameras, 3D Printer and the largest motion capture studio in Latin America. It started in a small room when it was first created in August 2013 but since December 2015 it has moved to a new building with a 15 by 25 m large and ceiling placed 9 meters above for a real big volume space. It uses Vicon equipment, starting with 6 T40 4 megapixels 515 fps camera. Later on, it was acquired 8 more of these cameras, totaling 14 cameras by the time of this paper. This amount of cameras is not able to cover the whole area so for the moment we have 12 by 8 by 4 meters capture volume as shown in the picture below, but we are in the process of acquiring 32 more cameras to start covering the whole area. This system is modular, so it's easy to expand it from time to time as we get funds from projects and we aim for a total of approximately 80 cameras in the future. But with the 14 cameras we have now, the system is fully capable of capture with the students and researchers producing some nice animations with it (Fig. 2).

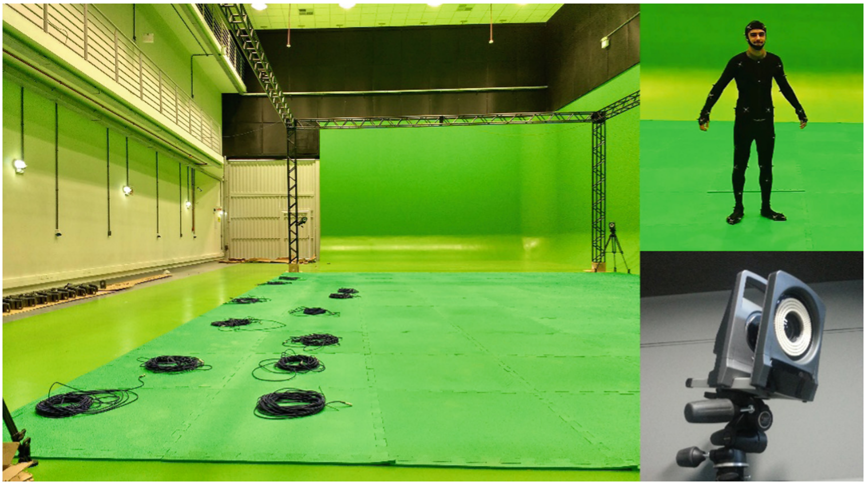

Fig. 2. UFSC motion capture studio, student wearing a motion capture suit and a motion capture camera. Source: Author.

3 Identifying the Problem

Some of the students decide to take the skills they learned in the 3D animation projects to work with game design in their final projects, and here is where we found some problems. The students couldn't achieve the whole extension of the project like they have planned. Then, we decided to do some research to help them out and that was the main motivation of this paper. The cases we analyzed to identify the problem are the ones related to the researcher's area of expertise: 3D games. Since the final project is an individual project that must be completed within one year, it's highly unlikely being able to create a complete 3D game in this timeframe, so they plan the main idea of the game, produce some assets and test them in a game engine.

Even though students could create whatever they wanted in the final project, the ones who chose 3D games always had the same idea: developing characters for a game. And they all have the same approach: creating the story, the persona, sketching the characters, modeling, texturing, shading, rigging, applying some motion and then sending it to a game engine. Since they have already learned the skills to complete all these tasks, the students were expected to have around 3 to 4 finished characters in one year of project. In the end, most of them designed and create the concept for 4 characters on average but only finished one. In other cases, some of them didn't finish the project in one year and had to extend into another semester but also finishing only one character. There were also cases where 4 characters where modelled and textured but didn't had a rig or a game engine test. After analyzing each of the projects, we conclude that they lack a full comprehension of a game development pipeline, they were too focused on each of the tasks but not on the entire project. This led to indecision during the creation phase that reflected on the production phase. We then decided to take one student that was planning to work on 3D game for his final project and introduce some context of a nearly real-life game design production line.

4 Testing a Different Approach

In order to have a methodology to test, we choose to adapt the ideas of Jim Wallman's paper "It's Only a Game" [2]. Since it's a paper from 1995, we had to adapt it in a way that the students have a set of steps to go through. Firstly, they make design choices. Then, after each major decision, they collect feedback and, depending on the results, they may start the process over again, making the necessary corrections, or moving forward to the next phase. The constant feedback gives the students the support they need, and it comes not only from the main professor, but also from other students, other professors or even the target audience for that project, if possible.

We also introduced the students to some other game design authors, in this case they also used some ideas from Jesse Schell second edition of "The Art of Game Design: A Book of Lenses" [3] and Robin Hunicke, Marc LeBlanc and Robert Zubek approach presented on "MDA: A Formal Approach to Game Design and Game Research" [4].

To put this in practice, we pick a student about to start his final project with the intention to create something for a 3D game to follow the authors' methodology. Contrary to we've seen so far, this student didn't want to create characters but instead a game scenario. After some debate, he decided that it would be a new map for a game like Rocket League, a popular awarded game that "combines soccer with driving in an unbelievable physics-based multiplayer-focused" [5]. Even though it could be a custom map for this game, there were some problems with doing it so. The biggest problem is that Rocket League, released in 2015, is a sequel do the game Supersonic Acrobatic Rocket-Powered Battle-Cars, released in 2008. And, as such, it uses the same Unreal Engine in version 3 as the prequel, forcing anyone that creates custom map for this game to use this version, now considered outdated. First released in 2004 the last update came in February 2015 (2 years ago, by the time of this paper). The lack of updates is because in May 2012 version 4 came out as a complete new engine and it's being constantly updated since then. So, from the academic point of view, makes no sense to teach a program to a student with an outdated version.

After deciding that it wouldn't be a custom map for the game, it would be an arena like scenario where the cars would battle and would use the latest Unreal Engine 4 that already have a car simulation that can be used to test the map in a game like situation. And instead of just moving forward to the production, the student was told to read and follow the authors here cited, working in a loop going back and forward on each stage, moving forward just when it was tested and seems to be working. This helped avoiding doubts and not taking something deficient to the next stage. Also, the student doesn't work just based on skills of modeling, shading etc., they have the whole vision of the game design instead of just working on individual parts. The result is being finished by the time of this article but have already made great progress and will be showed at AHFE 2017 in July.

5 Creating a New Animation Course

Another thing that we noticed during the years as teachers in UFSC Design Course is that the students that wants to work with animation and game design are much different from those who choose graphics or product design. We even had a past experience of having a separate Animation Design for two years but then it was merged with Graphics Design and Product Design creating a unified course where the students may choose an area to specialize. Then in 2015 we started the process to create a new course apart from Design but using the experience we gather through the years. We also had to rely with the existing teachers and infrastructure because we didn't received funds for the new course, resulting in some cuts on the what we were planning. On the other hand, we already have classrooms and complete laboratory as shown before.

The structure of the course is similar to the Design course presented before but with some changes: the first year is also dedicated to the basic disciplines but with an extra emphasis on drawing. Then in the second year they start the projects but divided in 3 semesters instead of 4 on the Design course and finishing in 3 and a half year instead of 4 years. We decided to create a more compact course so that they take less time to complete and can go on to specialize in some area after that. To accomplish it the projects are now made of 5 disciplines instead of 4 and, based on the experience we have presented in this paper, we created some complementary disciplines focused on game design. Another difference is that the final project is meant to be created in group instead of individual like before, so that they can create bigger projects.

The course was already approved by the university in 2015, still being located in the same place as the design course: UFSC, campus of Florianópolis, in the Center of Communication and Expression (CCE) and the Graphics Expression Department (EGR). The course receive 20 students each semester and the first class started in March 2016. To enter the course the candidates can choose two tests they can take: one similar to the SAT that is the same in the whole country, who receive 30% of the vacancies; or a test from UFSC that receive the other 70% and there is no specific test for the animation course.

6 Conclusion

After identifying the problems the students were having when choosing 3D game as the theme for the final project, we found out that having the skills to concept, create, model, texture, shade and animate are not enough to work with game design.

To help them we proposed a methodology shown in this paper based on 3 references [2–4], and the first project we implemented it have given great results so far, preventing some of the problems that used to appear in the development of the project. By giving the students plenty of opportunity to test their work and providing them the necessary space to try things out, we've seen, by the end of the project, a more confident and prepared student and considerably more aware of their own capacity, leading to a better result.

Following the schedule we plan for the new Animation Course, the first class will work in first final project in 2019. We expect that the students that decide that the theme is Game Design to follow the idea proposed in this paper to make it go smoothly by being less stressful and giving assurance to the choices made, consequently improving the performance of both the student and the professors involved in the projects.

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Evaluating the UX of a VR Game Using a Mixed Methodology

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Abstract. The current paper aims to present the process used for validating a VR game in its two modes: single and co-op. Through the combination of qualitative and quantitative approaches, it was possible to map the users' initial perceptions, points of improvements, and expectations for the information assessment. Ultimately, it was possible to observe that although both single and co-op modes were introduced to participants, the latter created a greater level of engagement and motivation, increasing the participants' interest.

Keywords: Virtual reality · Game design · Playtesting · Game evaluation

1 Introduction

Virtual Reality (VR) is continuously contributing to the creation of new challenges regarding the way content is visualized and accessed. In terms of inputs, it goes beyond interactions mediated by a single click or computer peripherals – body gestures and head movements are examples of interaction alternatives within this technology [1, 2]. From games to military use, the technology is presenting a variety of possibilities that can be explored by different users for distinct purposes.

However, due to factors like equipment price and a limited array of existent applications [3], it is possible to say that this technology still has a low access rate with only 47 million of users [4], particularly when compared to smartphone users (approximately 2,1 billion in total [7]). On the other hand, with the support and push from companies like Sony, HTC, Oculus and Samsung, it is possible to recognize a boost in experience consumption on VR, mainly related to the game industry. According to a recent market study, 2.9 billion dollars of revenue share was expected for it in 2016 [5, 6], transforming this industry into the technology's main segment currently.

In this scenario, it is possible to say that the UX evaluation of games has been a challenge for the UX community for a while now [1] and, in this sense, VR technology brings even more difficulties for this process. Researchers are facing new paradigms of UX evaluation and methodologies: How to conduct UX studies for VR games? How to assess UX in VR games without compromising the UX itself? On one hand, researchers must be careful with the topics that involve a gamer profile, such as: gender, age, favorite platforms, gamer style (i.e. casual, mid-core, hardcore), single player or multiplayer

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preference and, within the multiplayer scope, collaborative or competitive preference. Conversely, they also need to consider virtual reality challenges like cybersickness during and after VR usage and which research techniques seem to be proper to measure the aspects of learning, satisfaction, and usability in the game environment.

Considering these challenges, the current paper presents an UX evaluation using a VR game. *Rock & Rails* is a rock and roll-themed game that has two modes: single and cooperative (often abbreviated as co-op). A cooperative game consists of two elements: (i) a set of players, and (ii) a characteristic function specifying the value created by different subsets of the players in the game [2]. The experiment was planned in a way to make it possible to identify points of improvement for aspects related to usability, gameplay and multiplayer. Through a mixed UX methodology that included an online survey, interviews and participative observation, 96 users were interviewed. The study's outcomes and learned lessons will help in the definition and application of future studies in this field of knowledge.

2 Game Design Process

In regard to the process of designing an experience for games, game designers tend to cover much more interaction than the designers of more linear experiences (e.g. folders, mobile applications, editorial design). They must deliver to the player control over the sequence of actions and events in the experience as a whole [8].

Although the game development process has stages that can vary according to the game type and the game development's complexity, in general the steps to create a game are similar, independently of technology. Three major stages can define the game design process: concept, elaboration, and tuning. The concept stage refers to the phase in which you perform first and whose results do not change; Elaboration phase is the stage in which you add most of the design details and refine your decisions through prototyping and playtesting; the tuning stage is related to the phase when no new features may be added, but you can make small adjustments to polish the game [9].

Even though slightly different, SIDIA's Black River Studios also uses three stages for the game development process: Concept, Prototyping and Playtesting. During the concept phase, requirements like market segment, innovation level, available technology, and game goals are presented to the team. With this information, a sequence of brainstormings and co-creation methods are used in order to create concepts.

After choosing which concepts have the most potential, the prototyping phase is initiated. The team studies and performs experiments with technologies and then creates the prototypes in order to test the game theory and choose the appropriate concept design according to the defined requirements. This phase ends when, after the experimentation, the team is ready to initiate the development of the alpha version of the game (first build).

At this stage, the story is well defined so it is possible to investigate attributes like fun and engagement using simple processes like cards and storyboards, confirming if the game is fun and interesting. The main features of the game compose the alpha version and, despite the fact that some of these will be in a poor stage of polishing, they will have enough information to be comprehended and evaluated by players. This playtesting phase aims to confirm hypothesis and check doubts related to the overall experience of the game. It is the moment to detect points of improvements and check if other features are expected or required (e.g. feedback, guns).

The playtest outcomes are used to improve the Beta version. This version can be considered the first official release of the game. Few adjustments (in general, problems categorized as cosmetics) are done after the Beta version is ready.

2.1 Game Elements

In order to create a great user experience, some game elements are necessary for delivering a gradual increase in challenge and engagement. Some of these elements are listed bellow [8]:

- Mechanics: related to the goal of the game and how players can and can not try to achieve it, and what happens when they try. Game Mechanics require technology to support it, aesthetics components and a story that allows actions and flows that make sense to the players.
- Story: can be defined as the element that connects all events in a game. For this reason, game designers must choose mechanics that will both strengthen the story and let that story develop.
- Aesthetics: these elements must reinforce the ideas of the story. Colors and textures are very important to stimulate the relationship between the game and the player.
- Technology: refers to the interaction process that makes the game useful and possible to be played. It can be a paper, a pencil, plastic cards or a sound systems – it is the way in which the mechanics will occur.

3 Games for VR

A reality system is the hardware and operating system that full sensory experiences are built upon, and it is composed of 4 primary stages: tracking (input), application, rendering, and display (output). Input collects data from the user such as where the user's eyes are located, where the hands are located, button presses, etc. The application includes non-rendering aspects of the virtual world including user-interaction, physics simulation, etc. Rendering is the transformation of a computer-friendly format to a user-friendly format that gives the illusion of some form of reality, through auditory and haptic rendering. Output is the physical representation directly perceived by the user (e.g. a display with pixel or headphones with sound waves) [10].

Virtual Reality simulates the reality using three-dimensional environments to create sensorial experiences. It can be applied individually or to groups, in first or third-person view, and with some options of accessories.

It is a promise in continuous development, which has not reached its maturity stage. This can be observed through the series of adverse effects arising during or after its use (e.g. motion sickness). Motion sickness refers to the symptoms that are associated with exposure to real or apparent motion [11] – nausea, headaches, disorientation and sweating are not uncommon after using a VR device.

In regard to the game development process, VR games do not have a completely different approach. However, the content naturally brings challenges and differences, mainly during the development of mechanics and the definition of the set of activities that will compose the fun experience. This means that a game in VR will probably have a different gameplay when created for a gaming console or handheld device due to the different ways of interaction with the content.

4 *Rock & Rails* Game

The game used during the experiment, named *Rock & Rails*, can be defined as a casual game. Compatible with Samsung Gear VR[1] headset, the game can be played in both single and co-op (limited to 2 players) modes and it was made as third-person shooter gamer. The player can use head movements, taps, gaze and swipes for controlling the game.

The story of the game is based on the fact that the world of Rock and Roll has been fully silenced – *Silence Beasts* are now roaming around and dominating everything. It is the player's goal to reclaim the world back (in the name of Rock and Roll) with the help of other friends/band members. Players must "get loud" while using guitars and basses to blow up the beasts while riding on rails all over the cities.

The main features of the game's final version include:

- Characters: users can choose to play as the bassist Groove or as the guitarist Mischa. There is also an unlockable third character: Steve, the keyboard player.
- World: 9 stages with unlocks, power ups and collectibles to find were build.
- Local co-op: using a Wi-Fi connection and 2 separate devices with the game installed, it is possible for the user to play with a friend. The idea is to make it possible for these users to face challenges together while competing for best scores.
- Metal mode: a more difficult game mode for advanced players.
- Boss fights: the player can fight the commander of the invading creatures in a final boss fight.

5 UX Evaluation

The study was performed with the game's alpha version (first build) and was divided into two main sessions – in the first users would play the game's single mode and in the second users would play the co-op mode. The setup was prepared in a way to make it possible to evaluate 4 pairs of users simultaneously. As a consequence, all materials and proceedings were prepared to attend 4 pairs of mediators. At the end of two days, a total of 126 participants were interviewed.

Interviews between sessions represented the study's qualitative approach, which had two focuses: game usability and game playability.

[1] Samsung Gear VR is a virtual reality device developed and manufactured by Samsung in partnership with Oculus.

The quantitative data was collected through an online survey – that was filled during the interviews – and had its core questions structured in 4 sections: personal data, technology knowledge (including Virtual Reality), gaming experience information and overall game-related questions.

The decision of having interviews and form filling tasks between sessions was done in order to have a more honest and unaffected (by the whole experience) opinion from each user.

6 Results

6.1 Online Survey

The participants were invited to fill out the online survey into three moments:

1. Before playing they completed the questions related to personal data, technology knowledge.
2. After playing the single mode they evaluated the playability, fun and usability of the game.
3. After playing the co-op mode they evaluated the overall experience and also questions related to usability and playability.

Regarding gender, 93 participants were male and 33 female. Regarding age, 94 participants were in the *18 to 24* category, 18 participants were in the *25 to 34* category, 7 were in the *Under 18* category, 5 were in the *35 to 55* category, and only 2 were in the *45 to 54* category (Fig. 1). The average age categories were defined according to a previous survey study conducted to map the game possible target audience.

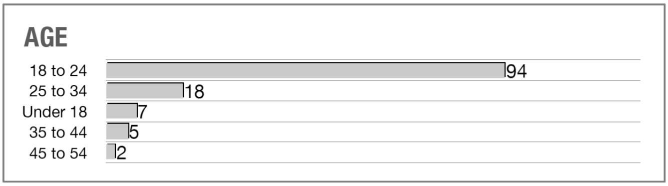

Fig. 1. Number of respondents for each age category

When asked about education and employment status, 67 participants said that they only study (undergraduates or high school students), 39 participants answered they were studying and working at the same time and 20 participants said that they only work. About VR technology, results can be observed in the following picture (Fig. 2):

When asked about gaming style, 71 participants classified themselves as casual gamers, 48 as core/mid-core gamers and only 7 said they are hardcore gamers. Casual Gamers can be defined as people who like playing games but in short sessions and/or infrequently; Core/Mid-core Gamers are the ones who play various types of games regularly, but without the amount of time spent and sense of competition of Hardcore

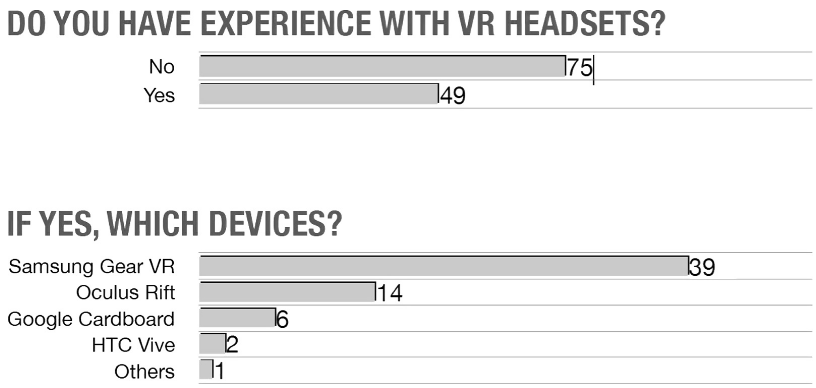

Fig. 2. Online survey outcomes for VR technology usage

Gamers; Hardcore Gamers play seriously or competitively, investing in gaming devices, and also participating in gaming communities[2].

Regarding gaming platform preferences and gaming frequency the results can be observed in the following pictures (Figs. 3 and 4).

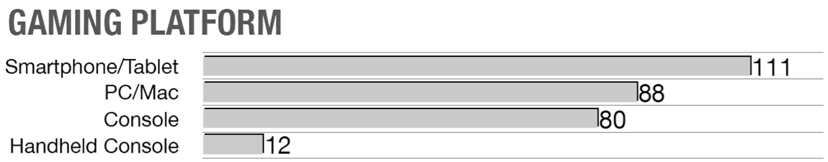

Fig. 3. Online survey outcomes for Gaming platform

In regard to playability, the most expressive results were related to the difficulty that the user felt while playing with a friend in co-op mode. During the interviews, it was possible to comprehend that those aspects of dissatisfaction were mainly because of the lack of communication to and/or visibility of a friend due to connectivity issues.

Although all the topics related to usability were well evaluated on the survey, many users demonstrated some level of discomfort when directly asked if the game was monotonous during the interview. Some of them said that they expected more challenges and components, mainly in single mode.

6.2 Interviews Findings

It was possible to observe that after playing single and co-op mode, users had a preference for the latter as a whole, mostly saying that they found it to be more fun and

[2] The definition of styles was built based on responses from a previous online study that had 158 respondents from 14 countries, and was focused on gaming preferences and attitudes.

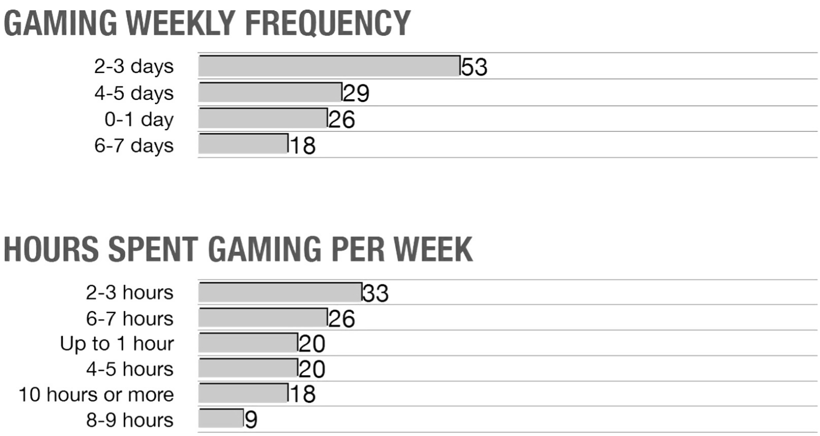

Fig. 4. Online survey outcomes for Gaming frequency (weekly and per week)

enjoyable. Some of them said that after playing the co-op mode they did not feel stimulated to play in Single mode again. The lack of actions and components to increase the challenge, fun and enjoyability were the main factors that influenced their verbal opinions.

The main findings from this process were: (a) the instructions are not clear nor visible – the player gets confused while playing (especially during first use); (b) Limited Fun, Enjoyability and Control elements are available. In regard to game context, (c) users have high expectations for challenges and fun, so these factors are even more expected when the game is introduced on VR – some of these users also thought that the co-op version of phases was supposed to be harder than single mode; The (d) connectivity for co-op mode was not how users expected it to happen, which compromised the overall UX and user satisfaction. Furthermore, there were technical problems with the connection during the playtest.

In the end, it was also possible to observe that although both modes, single and co-op, were introduced to participants, the second one created a higher level of engagement and motivation. None of the participants had troubles in using the game controls, even those without previous VR experience. Furthermore, only one user felt motion sickness effects after playing. From the obtained results, it was possible to define the subjects for the study's following phase, a qualitative approach focusing on playability and on people with experience in VR games.

7 Conclusions

Although the results indicate a high level of acceptance of the game, it must be considered that 76 participants were identified as casual/beginner-level gamers, without any previous experience with virtual reality gadgets. During their first contact with VR technology, participants became extremely impressed by it, even though they were facing issues related to player action and fun. This factor tends to influence their opinions positively as well as minimize their level of critical analysis.

Through the study's mixed methodology and aiming to comprehend the aspects that influenced the quantitative results, the facilitators observed and asked the users about their overall impressions. In several moments, it was possible to observe some level of discordance between the participants' choices in the survey and what they really felt about the game concept (mainly related to the game's single mode).

Users were also unfazed by the game's sound/music quality, which was directly affected by our choice of not using headphones in the experiment. According to some authors, when considering games for virtual reality the sound tends to influence more than 50% of the experience, positively or negatively [12]. Because of this, next steps will consider including a specific approach for evaluating this element.

Furthermore, since most participants were unfamiliar with the technology and VR applications, it was not possible to map expectations for interaction aspects. What does the user expects to do? Questions like this can guide an investigation about relations between 2D (mobile) and 3D (VR) experiences in a way that improves the state of VR environments and that can minimize challenges like motion sickness and other adverse effects.

Finally, after each session, mediators would write the main findings of the interviews' collected data. By the end of the study's second day, after interviewing 126 participants, all collected data was quickly gathered and tabulated. This process made a 5-day time frame possible for conducting the playtesting phase and delivering a full report, becoming a highly recommended process for our Usability Lab.

Acknowledgments. The conception of this essay was the result of the combined efforts from SIDIA's UX & Design Team and Black River Studios. It is also important to highlight the company's performance in supporting and promoting research and development for systems that are present in the domestic market's leading technology products. Our sincere appreciation for all those people involved in the game's project and related experiments.

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Gaming as a Driver for Social Behaviour Change for Sustainability

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Abstract. Social interventions emerging from the field of social psychology have drawn attention to the social dimension of behaviour change for meeting sustainability objectives. Gamified Behaviour Change Programmes (GBCPs) are one such example, which have been quite effective in stimulating a positive change in behaviour and in establishing a culture of sustainability within the targeted groups. Gaming is an integral part of GBCPs as it adds fun and excitement to the process and motivates the players to adopt sustainable actions in a playful way. By investigating some of the effectively implemented cases of GBCPs, the study intends to develop a deeper understanding of the process of social behaviour change, particularly of the role that elements of game mechanics play in engaging and motivating the participants and in facilitating an influential social environment for behaviour change. This understanding would provide some essential touchpoints for applying game mechanics to the process of social behaviour change for environmental benefit.

Keywords: Social behaviour change · Gaming · Social innovation · Sustainable behaviour

1 Introduction

A positive change in consumption behaviour is required to strive towards the concept of a sustainable society [1]. Recent recognition of the importance of behaviour change in achieving sustainability objectives has led to the emergence of several interventions targeting behaviour change. Most of these interventions have targeted behaviour change at an individual level. For instance, design-led interventions, which draw heavily on cognitive and environmental psychology, have mainly focused on the design of specific products and their interactions to reduce product-related environmental impacts [2–4]. Thus, design-led approaches have been both product-specific and action-specific. Although some of these interventions have been quite effective in encouraging more efficient usage of products and resources, they seldom consider the social context in which behaviour evolves, persists, spreads and defects [5, 6]. They consider that individuals' behaviour is not influenced by their social surroundings [5, 7, 8].

On the other hand, some of the interventions based on social psychology have focused on a well-defined social group to induce collective change. Instead of targeting

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behaviour change at the individual level, they intend to 'achieve long-term social transformation by encouraging a collective social movement of good choices' [9]. They consider that human behaviour is socially grounded and deeply embedded in the social context; therefore, targeting a unified social group can lead to long-term social transformation and can establish a culture of sustainability [10–13].

Gamified Behaviour Change Programmes (GBCPs) are one example of such a social behaviour change intervention, making use of elements of game mechanics to engage the participants in a common objective and stimulate them to adopt sustainable actions under the influence of the social game. Gaming plays a vital role in these programmes as it adds fun and excitement to the process, makes the players compete, either individually or in teams, and stimulates them to perform a range of sustainable actions in a playful way. Elements of game mechanics such as rewards, recognition, engagement model, play space, progress path, triggers, feedback and social comparison make the programme highly compelling and immersive, driving the players to perform the sustainable actions inscribed by the developers in the game [14]. GBCPs target the social and systemic nature of behaviour by providing an influential social environment for learning and practising sustainable actions that eventually replace (unsustainable) habitual behaviour over time [6]. Through social games, GBCPs encourage the participants to perform the desired behaviour consistently, which eventually establishes social norms and a culture of sustainability within the social group. GBCPs have promoted a wide range of sustainable actions in various organizations, university campuses and online social groups. Some of these programmes have been quite effective in establishing a culture of sustainability within these social groups. By investigating some of the effectively implemented cases of GBCPs, this paper intends to develop a deeper understanding of the role of game elements in the process of social behaviour change. It intends to identify how game elements in GBCPs help to develop an influential social environment that encourages the participants to adopt sustainable actions in a playful way and instigates long-term social change by establishing a culture of sustainability.

2 Method of Study

Three diverse cases of GBCPs were analysed using a document analysis method. This method was particularly chosen because documents provide neutral and unbiased information about a case [15]. Several published documents pertaining to these cases were collected from different sources. These documents included case studies, journal articles, annual business reports, magazines and newspaper articles, customer feedback reports, manuals, websites, mobile applications and official blogs. To gain insight into the cases, a detailed analysis of documents was conducted by using open and axial coding procedures [16].

3 Cases

3.1 JouleBug

JouleBug is a playful mobile application that helps the participants make their everyday habits more sustainable. It engages the players in a challenge and makes them compete with their friends. Participants can win rewards by performing sustainable actions and can share their achievements with friends on social networks. JouleBug encourages a wide range of sustainable actions related to minimizing energy, water and fuel consumption. JouleBug uses game elements, such as an engagement model, points and badges, that add fun and excitement to the process and encourage the participants to perform sustainable actions in a playful way. JouleBug claims that each of its players saved an average of US$200. I-cubed and Wesleyan University reported that JouleBug resulted in significant behaviour change as it triggered intense competition among the participants. JouleBug established a culture of sustainability within the organizations where it was implemented [14, 17].

3.2 Big Energy Race

Big Energy Race was a programme developed by Global Action Plan to encourage 4,000 households to reduce their energy consumption by engaging them in an interesting challenge. The challenge involved well-known behaviour-change techniques that encouraged the participants to adopt certain sustainable actions such as turning off lights and appliances when not in use. Big Energy Race used game elements such as challenges, progress path, rewards, comparative feedback and goal-setting to engage and motivate the participants. The programme on average saved participants £117 each on their energy bills [18].

3.3 Operation TLC

Operation TLC programme is implemented at the Barts Health NHS Trust to help the staff teams reduce energy consumption. It encourages the staff to adopt three 'TLC' actions: turn off equipment when not in use (T), switch off the lights (L) and close doors and windows (C). Staff members were grouped into teams, who competed against each other to reduce energy consumption. The programme used game elements such as competitions, goal-setting, rewards, triggers and prompts to engage and motivate the participants. The programme resulted in savings of £428,000 annually and a long-term cost benefit to the organization [19].

4 Role of Game Elements

4.1 Play Space

GBCPs are practical and action-oriented interventions, which encourage the participants to perform the actions in the real world. Unlike videogames, which take place solely in a virtual world, the play space for GBCPs is largely the real world. Nevertheless, some GBCPs do make use of a virtual platform for various activities and processes. Two of the cases (Big Energy Race and JouleBug) used a virtual platform to train, engage and motivate the participants, but they encouraged the participants to perform the actions in the real world. This is what distinguishes GBCPs from other digital games. It was observed across these two cases that the virtual component also played an important role in the process of change. It helped in various activities and processes such as keeping the scores, sharing useful information, social networking, team building, online feedback, training, motivating and communicating the comparative information. Although, the players played the game in the virtual world as much as the real world, the desired actions were always performed in the real world. Furthermore, the interface between the virtual and the real world was so smooth that the participants felt as if the they were playing in the virtual world.

4.2 Progress Path and Levels

In order to change behaviour, the GBCPs took the participants on a journey (through various stages) from first step to final goal. The objective was to maintain the interest of the participants throughout the process and avoid defection from the programme. Therefore, various challenges and complex tasks were broken down into smaller achievable steps that participants could easily perform and adopt in their daily routine. The stepwise process made the actions suitable for all participants with different expertise and capacities to perform. Although there was only one fundamental challenge, the stepwise process and increasing difficulty levels marked a clear upward path. The progress path was seen as one of the most essential constituents of GBCPs as it kept the participants engaged and motivated so that they consistently performed one challenge after another until the desired behaviour became part of their daily routine.

The programmes maintained a ‘moderate’ difficulty level throughout the challenge. The challenges were difficult enough to maintain the interest of the participants, but not so difficult that they led to frustration or defection from the programme. Players were asked to start with very simple tasks in the beginning and were made to progress from one level to another. They were rewarded at various stages, which encouraged them to progress from one level to another and undertake even more difficult challenges. The easiest level in this process was ‘onboarding’, when the players were introduced to the game, and the later stages became increasingly demanding.

4.3 Player Engagement Model

The engagement model was at the heart of the GBCPs. It involved a number of activities and processes such as setting up challenges, defining goals and targets, player-to-player interaction, competition, monitoring and cross-referencing, collaboration and teamwork. Engagement was important because it played multiple roles in the entire process of social behaviour change. It made the overall process fun and interesting, which kept the participants engrossed and active over a longer period. Active participants performed the desired behaviour consistently, which eventually developed into a new habit. Besides this, engagement created an influential social environment and circumstances in which participants were motivated to comply with the expected behaviour (social norms) and match their performance with that of other competitors.

The observed cases involved both dimensions of engagement – competition and collaboration – in their process. They involved both individual-level as well as team-level challenges, which sparked competition and comparison between the teams and the individual participants. Social comparison encouraged the racking up of personal achievements, which created a friendly rivalry between the participants, and, when performances were compared, they implicitly communicated the expected behaviour (social norms) within the social group. This created social pressure, which pressed the participants to learn to adopt socially acceptable behaviour and match their performances with that of their opponents.

On the other hand, team-level challenges engaged the players on multiple levels, as they involved both dimensions of engagement. These team-level challenges encouraged the participants to connect and bond with fellow team members and work for the benefit of the team they belonged to. They encouraged social interaction, sharing, team work and friendly competition between the teams. Team-level challenges also motivated the participants to work as a cohesive unit to accomplish the set goals. The pressure of not being seen as the weakest link in the team stimulated the participants to adopt and perform sustainable actions. Teamwork and social interaction between the team members nurtured a sense of belonging in the team, and helped to communicate the social norms within the group.

4.4 Triggers

GBCPs used different types of triggers, which worked as a call to action, provoking an immediate response. These triggers were timely reminders that informed the participants of exactly when the actions must be performed to ensure consistent performance. These reminders were either sent by the programme or by fellow team members. Besides reminders, prompts in the form of posters, stickers, post-it notes and text on white boards were also used to remind the participants. The programme also used personalized tips, based on the past behaviour and context of the participant. These tips helped the participants to incorporate actions into their daily routines and communicated the anticipated benefits and impact of their actions. Overall, triggers in the form of reminders, alerts and prompts encouraged consistent performance, which helped in adopting and nurturing the new behaviour.

4.5 Rewards and Recognition

GBCPs rewarded the participants for learning, adopting and performing sustainable actions. Besides this, they also rewarded the participants for extending the outreach of the programme, raising sustainability awareness, sharing new ideas and strategies with fellow participants, organizing team meetings, escalating social interaction and sharing achievements on social media. The reward mechanism was thoughtfully planned across all of the cases. It consisted of various levels and types of rewards matching the complexity of the actions. Symbolic (rather than economic) rewards such as points and badges were used in all the cases. Symbolic rewards used in GBCPs characterized self-esteem and social capital (enhanced social image). GBCPs deliberately associated various social meanings and images with these rewards. For instance, the image associated these rewards were responsible, environmentally aware, environmentally concerned consumer, best performer and inspiring figure. When rewards were announced publicly or shared on social media, they enhanced the social image of the participants. This enhancement of social image was one of the key motivations for participants to learn, adopt and perform sustainable actions.

Rewards and recognition played a central role in stimulating the participants to learn, adopt and perform the desired behaviour consistently. They not only added fun and excitement to the process, but also sustained the engagement of the participants with the programme for a longer duration. Anticipated rewards, personal and environmental benefits and enhanced social image were the key motivations for the participants to associate with the programme. Rewards such as points and badges informed the participants of their progress and provided a means to measure and compare their performance against that of others. This comparison of achievements was important in the process because participants wanted to know their performance in relation to others', which encouraged them to perform better than other participants. Rewards were also useful in communicating clear milestones and targets to the participants. They indirectly communicated the importance of their actions and were useful in prioritizing them. Although the properties and dimensions of rewards differed from case to case, rewards played an indispensable role in the process of social behaviour change.

4.6 Feedback

Primarily, there were two types of feedback used in GBCPs. These were (1) data-based feedback and (2) post-performance feedback. Data-based feedback or 'monitoring' is a real-time feedback that allows the participants to monitor their own, as well as other competitors', real-time performances. It includes the monitoring of real-time resource consumption, performance and comparative scores throughout the process. Data-based feedback played a significant role in GBCPs as it sparked competition and comparison, which stimulated the participants to learn and adopt new behaviours. Participants monitored the performances of their neighbours, opponents and team members through websites, apps, weekly updates, scoreboards and points-table. This real-time feedback kept the players engaged, energized and motivated throughout their journey. Besides this, real-time monitoring of top performances encouraged the participants to cross-reference their own actions and set new benchmarks. Real-time monitoring made the process interesting and encouraged the participants to perform consistently. Comparative performances also helped in implicitly communicating the expected behaviour (social norms) within the social group.

Post-performance feedback was usually positive and constructive in nature. It communicated the immediate impact of their actions to the participants. Feedback informed the participants how well the action was conducted and the scope for further improvement. The purpose of the feedback was to encourage the participants to repeat the behaviour and to help them to improve their performance and accommodate positive actions in daily routine. Feedback often comprised of behaviour-based suggestions and personalized tips for improvement. Participants felt more connected to personalized feedback, as it helped them in enhancing their performance. Feedback often included a progression track, which informed the participants how far they had come. Such feedback helped in re-energizing the participants. Feedback was particularly useful in motivating the beginners and slow performers. Overall, feedback played a key role in the process as it encouraged the participants to repeat the desired behaviour and boost their performance.

4.7 Social Comparison

Social comparison refers to the comparison of performances of the participants and the teams. Social comparison was observed as one of the most essential activities because social standing was just as important to people as their individual achievements. When performance was compared, it sparked social image concerns, which led to social pressure (peer pressure). It also intensified competition, which prompted the participants to learn and perform sustainable actions. Comparison implicitly communicated the expected behaviour (social norms), which generated social pressure and encouraged the participants to perform well in order to comply with the social norms.

Performance data was constantly collected from the participants' end and was measured in terms of common parameters such as monetary savings and environmental contribution (measured in terms of CO_2, KWh, litres of water, kilograms of waste). This comparative data was analysed and translated into a meaningful and understandable format such as graphs, scoreboards, points-tables, rankings, leader-boards etc., which communicated their relative performance to the players. Participants also shared their comparative scores on social media in order to enhance their social image.

Although social comparison is one of the most powerful motivators in the process, it can also demotivate the underperformers. GBCPs used a number of strategies to deal with such situations and to handle discouragement and thereby avoid defection. For instance, they provided progression tracking, personalized tips and encouraging feedback that helped the participants improve their performance. By keeping the participants engaged and motivated throughout the process, social comparison played a key role in the process of social behaviour change. Figure 1 shows the game elements involved in GBCPs and the resultant driving factors induced by these game elements.

Fig. 1. Game elements in GBCPs and the resultant factors that drive social behaviour change

5 Conclusion

The paper provides useful insights into the role of game elements in GBCPs and highlights how game elements assist in the process of social behaviour change. It indicates the potential of gaming in driving social behaviour change to meet sustainability objectives. In particular, it demonstrates how game elements create an influential social environment that motivates the participants to perform sustainable actions in a playful way, and how these elements contribute to the process of creating a culture of sustainability within a social group. For designers and game developers engaged in sustainability and behaviour change, this provides some essential touchpoints to consider while devising such gamified solutions for meeting sustainability objectives. The study adds another dimension to how gaming can contribute more towards building a sustainable society. The paper also serves as groundwork for further research on more structured tools and processes, which could help in methodically designing such game-based solutions for fostering a culture of sustainability.

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