SCIENCE AND SKIING

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First International Congress on Skiing and Science
St. Chrisoph a. Arlberg, Austria
January 7–13, 1996

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Introduction

The first International Congress on Skiing and Science was held at St. Christoph a.Arlberg, Austria, from 7–13 January, 1996. This event was organized by the Austrian Association of Sports Sciences (ÖSG), the Universities of Salzburg and Innsbruck and the Österreichischer Arbeitskreis für Skilauf an Schulen und Hochschulen. It was also part of the programmes of the World Commission of Sports Biomechanics.

The scientific programme offered a broad spectrum of current research work in Nordic and Alpine skiing. In addition to the six keynote papers, for which we were able to secure some of the most renowned experts in the relevant fields, 47 oral and 41 poster presentations stimulated fruitful discussion. Apart from the scientific programme, numerous social activities provided many opportunities to make friends and to enjoy the best that winter has to offer in this region.

In the Proceedings of this congress, the six keynotes and forty-four of the oral presentations are published. The manuscripts were subject to peer review and editorial judgement prior to acceptance. The volume is organized into five parts based on scientific disciplines. Each part is introduced by one of the keynotes.

We hope that this congress report will stimulate many of our colleges throughout the world to research the field of skiing so that at the Second International Congress on Skiing and Science, which will also be held in St. Christoph a. Arlberg in the year 2000, as many research papers as possible may be enjoyed by the participants.

Erich Müller, Chair
Hermann Schwameder
Elmar Kornexl
Christian Raschner

We would like to express our cordial thanks to Ingrid and Andreas Sandmayr for the time and energy which they invested in the editting of this book.

Part One

Biomechanics of Skiing

1

SKI-JUMPING TAKE-OFF PERFORMANCE: DETERMINING FACTORS AND METHODOLOGICAL ADVANCES

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Keywords: ski-jumping, force measurements, neuromuscular function, kinematics, electromyography.

1 Introduction

Ski-jumping is a very complex skill involving several phases—in-run, takeoff, flight and preparation for landing-, each of which has importance to the length of the jump. In general the skill includes both ballistic and aerodynamic factors. The ballistic factors refer to release velocity and release position from the take-off table, whereas the gliding properties of the jumper/ skis system (velocity, suit design, surface area, posture of the jumper/skis system, turbulance and resisting and lifting forces) belong to the aerodynamic factors during the flight. It is important to realize that both ballistic and aerodynamic factors place special demands on the jumper so that he could optimally maximize the vertical lift and minimize the drag forces.

Take-off is probably the most crucial phase for the entire ski-jumping performance. The purpose of the take-off is to increase the vertical lift and simultaneously maintain or even increase the horizontal release velocities. It is therefore important to emphasize that it is the jumper and his ability to perform a skillful take-off and the subsequent flight phase, which finally determines the length of the jump. For this reason much is required from the jumper's neuromuscular system, especially because of the unusually short time available for execution of the take-off performance.

The present article makes an attempt to review factors which are involved in take-off performance. Special efforts will be made to characterize the take-off action and link this to the relevant neuromuscular functions of the jumper. Techiques of measurement of the actual take-off forces have improved considerably during the last two decades. These aspects are also described both methodologically and with respect to the neuromuscular requirements and especially how they are related to the length of the jump. Integration of muscle activation patterns with take-off technique is also relevant for the understanding of the ski-jumping performance. These aspects will be highlighted also with prospects for future measurement techniques.

2 Important take-off parameters and their characteristics

Ski-jumping take-off is performed from a crouch position (Fig. 7) during a very short time, ranging from 0.25 to 0.30s [1] [2]. This time period covers on the average 7.1 m from the take-off table. Thus the first take-off movements are initiated during the transition phase from the end of the inrun curve to the flat table. This phase is very crucial for the timing and coordination of the movements due to sudden disappearance of the centrifugal force at the end of the in-run curve. Kinematically the rapid take-off movement can then be characterized by changes in two major angles: hip and knee. The hip angle displacement is, on the average, from 40° to 140° [2] [3] emphasizing that the hip extension continues in the air after the take-off edge has been passed (Fig. 1). Similarly the knee-joint extension (from 70° to 140°) is not complete during the take-off table. However, the knee-extension velocity reaches a very high value of over 12 rad$\times s^{-1}$ [4], which is usually reached a few ms before passing the take-off edge. In the optimal take-off, the hip extension velocity is also relatively high ($\approx$10 rad $\times s^{-1}$)[4], and it is caused mainly by the thigh movement, but with a smaller upper body extension [3]. Thus the upper body is maintained in a lower position to reduce the drag forces [5] (see also Fig. 16). This adds to the lift forces with resulting reduction in the load for the extension movement. According to the force-velocity relationships of the muscle, the light load can be moved with higher movement velocity [6] [7]. The knee-extension velocity is reportedly the highest correlating factor of all take-off parameters to the distance jumped [3]. The powerful knee-extension movement therefore results in a suprisingly high vertical velocity (Vv, normal to the take-off table) of the center of mass of the jumper/ski system. Velocities, such as between 2.3 and 3.2 m$\times s^{-1}$ are not unusual [1] [2] [5].

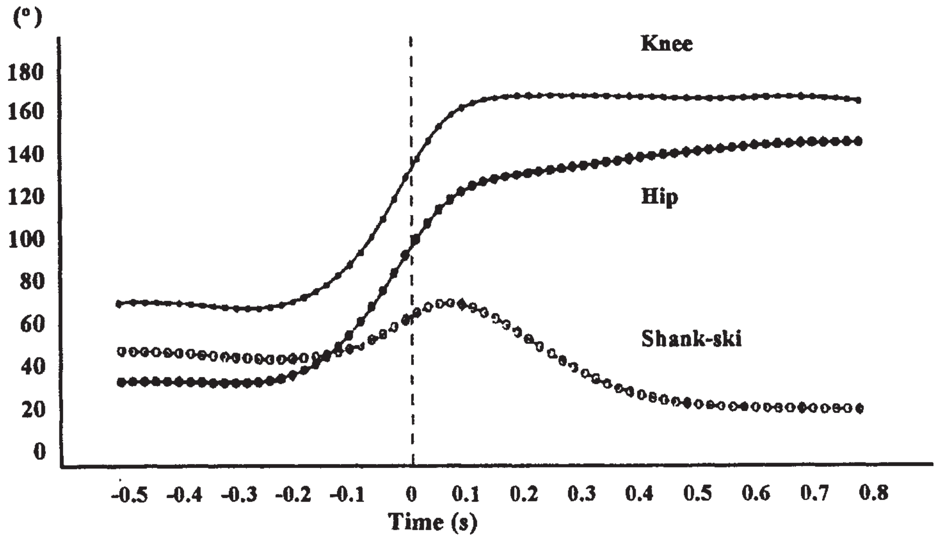

Fig. 1. Progession of the knee, hip and shank ski angles before and after the take-off instant. The take-off movement begins, on the average, 0.28 s before the release instant (dashed vertical line) [2].

In addition to high vertical and horizontal velocities, the purpose of the take-off movement is also to produce angular momentum. The somersault angle, defined as an angle between a line connecting the knee and shoulder joint center to the global longitudinal axis has been used to describe the production of forward momentum in ski-jumping take-off [3]. A greater angular velocity enables the jumper to prepare for and subsequently assume the flight position as rapidly as possible from the take-off. There may therefore be a slight contradiction in that the impulse at take-off is necessary to achieve height and to generate angular momentum.

To obtain maximal height the jumper's center of mass (CM) must be located along the line of action of the vertical ground-reaction force, whereas the production of angular momentum requires the CM to be located anterior to this line. Evidence has been presented that the more succesful jumps are characterized by higher knee extension velocities and simultaneously by a more rapidly decreasing somersault angle towards the take-off edge [3].

3 Limiting neuromuscular factors in ski-jumping take-off

The preceeding description of the take-off parameters is naturally selective and somewhat simplified. Its purpose was, however, to highlight those factors which can then be related to and interpreted by the function to the jumper's neuromuscular system. Short take-off time, high knee angular velocity and low upper body position are special requirements and very specific to ski-jumping. Clarifications to the problems from the point of view of neuromuscular limiting factors can be derived from the well-known curves describing the force-time, force-velocity, as well as force-length relationships of the isolated human skeletal muscles and muscle groups. The possibility of utilization of muscle elasticity for the maximization of take-off potential must also be examined.

3.1 Force-time curve

In isometric conditions, when the muscle is maximally activated the force production to the highest level requires in human leg extension 600–1200 ms (Fig. 2). When this is compared to the time available for the take-off movement (28 ms), one can understand that the time to produce force is indeed a limiting factor in ski-jumping.

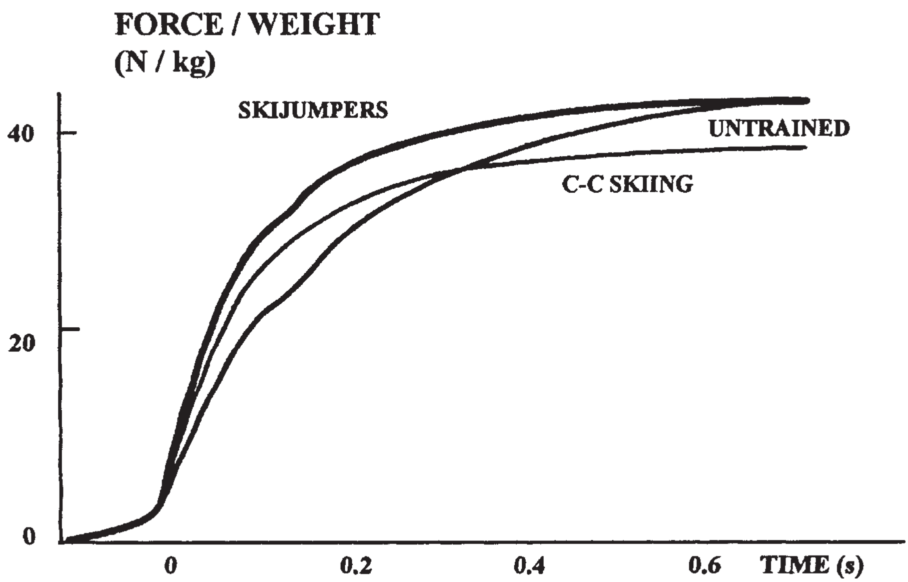

Fig. 2. Force-time characteristics of the bilateral isometric leg extension among ski-jumpers, untrained controls (policemen) and cross-country skiers [8].

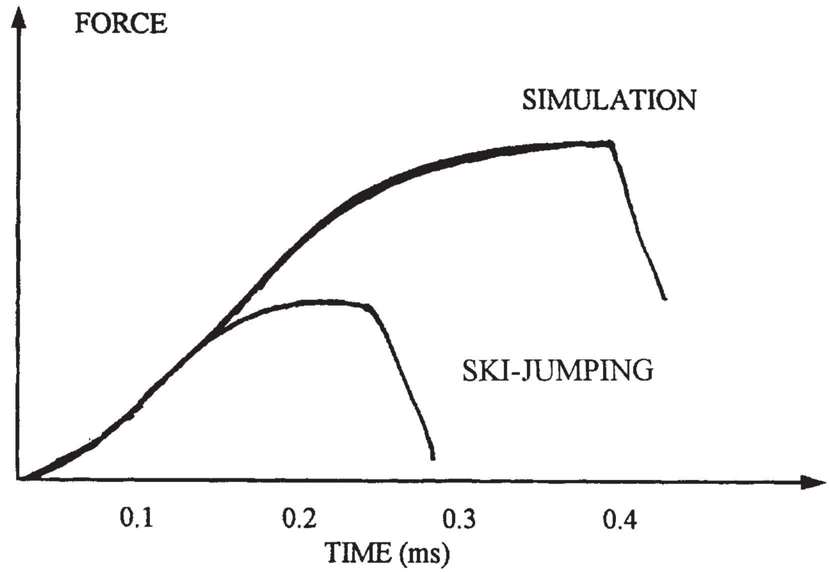

Fig. 3. Schematic presentation of the vertical force-time relationships in actual ski-jumping take off and in a simulated ski-jumping take-off in the laboratory. Please note that the time is a limiting factor in actual ski-jumping take-off.

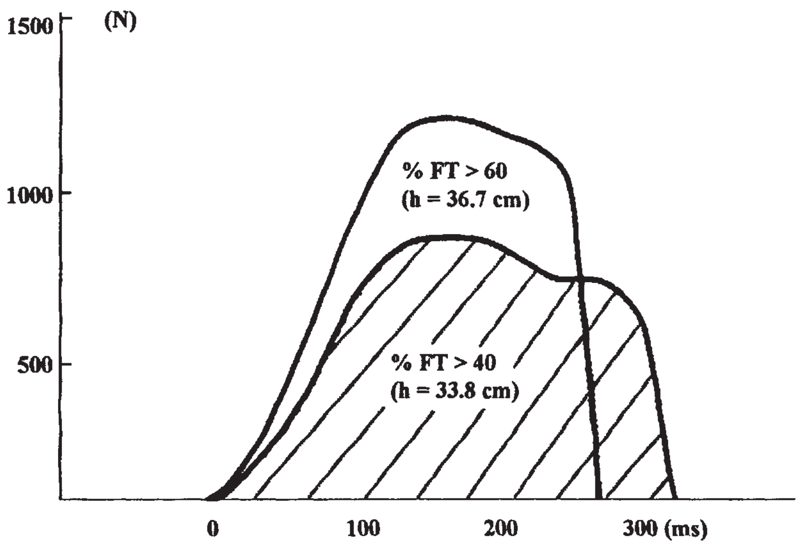

Fig. 4. Average vertical force-time curves for vertical jumps made by two groups of subjects with different muscle-fiber composition on a force platform. The jumps were performed from a starting position with relatively extended knee angle [11].

The importance of the short take-off time can be characterized by comparing schematically the take-off forces between actual ski-jumping and the simulated ski-jumping take-off (Fig. 4). It is interesting to note that ski-jumpers have more favourable isometric-force time curves than the controls (Fig. 2) or, for example, endurance athletes. This may be due to the adaptation to training per se and/or due to the more favorable muscle-fiber compositon of the ski-jumpers. It is well-known that the skeletal muscle contains muscle fibers which have different mechanical characteristics. Fast-twitch (or type II) fibers increase force in a shorter period of time [9] and if a majority of the fiber population of a specific muscle is of this fiber type, it is very likely that the force-time characteristics favour rapid force production. Ski-jumpers are reportedly of fast type as judged by their muscle-fiber composition [10]. In a vertical jump test those subjects having more FT fibers are superior to those having a majority of slow-twitch (type I) fibers in their vastus lateralis muscle (Fig. 5).

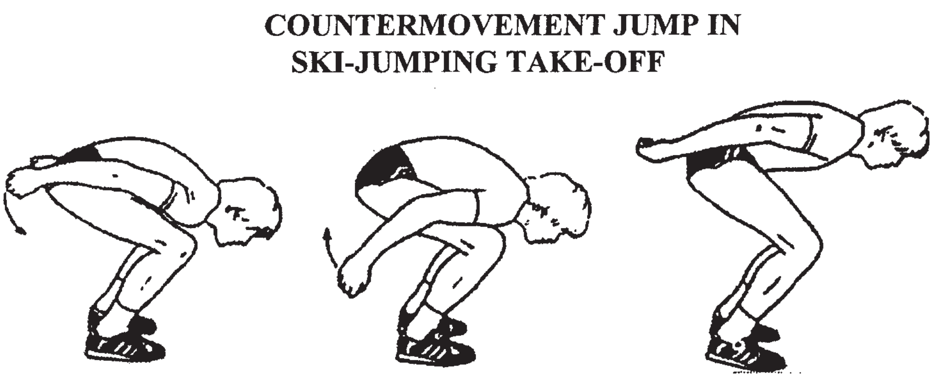

Fig. 5. A proposed arm action to produce sudden unweighing (and possible maximizaton of take-off potential) during ski-jumping take-off. The amplitude of the quick downward arm action is slightly exaggerated in this presentation [17].

3.2 Force-velocity relationship

The average knee extension velocity of over 12 rad×s^{-1} also implies also more favorable use of fast-twitch fiber population. Tihanyi et al [12] have studied the maximal knee-extension movement with varying loads, and discovered, in addition to the conventional force-velocity (F-V) dependence, a clear shift to the right and up of the F-V curve at higher velocities (and lighter loads) among subjects having a majority of FT fibers in the vastus lateralis muscle. Velocities over 12 rad×s^{-1} certainly rely on the contractile performance of the fast-twitch fibers. Thus it is very likely that good ski-jumping take-off action with high knee-extension velocity can be performed only if the jumper's knee-extension muscles have sufficient proportions of the fast-twitch muscle fibers.

3.3 Force-length (force-angle relationship)

Assuming again that the knee-extension muscles are mostly involved in powerful ski-jumping take-off performance, the performance of these muscles is also limited by the initial muscle lenghts (joint angle). If the inrun position is too deep (small knee angle), the force-production capability is drastically limited as compared to the more extended (e.g. 75–80°) knee angle [13]. The time is also critical here: a deep crouch position with small knee angle may finally produce high extension velocity [2] but to reach it may require more time than what is available on the take-off table.

3.4 Possible use of muscle elasticity

It is well-known that when an active muscle is stretched prior to its shortening, the final power (and velocity) can be higher than that attained in a pure shortening muscle action [14]. When applied to a vertical jump [15], the jumps performed with a preliminary countermovement will attain higher take-off velocity as compared to a jump performed without countermovement. This phomenom can be well demonstrated in a simulated ski-jumping take-off in the laboratory [16]. The take-off performed with a preparatory countermovement can reach a vertical take-off velocity of 10–20% higher than in jumps without countermovement. Despite these relatively clear differences in the laboratory tests, the use of the peliminary countermovement has not reached uniform acceptance among coaches and jumpers. The major poblem arises when the countermovement is performed too excessively and timed improperly with the transition from the in-run curve to the flat table. Succesful ski-jumpers often perform the countermovement intuitively with rapid arm movements. As proposed in Fig. 5 (see also Fig. 13) this very short but quick downward arm movement will cause a short but quick unweighing action with the resulting pre-stretch in the knee-extensor muscles. Sometimes it is also possible to see this phenomenon as a quick but short amplitude knee flexion movement. It must be emphasized, however, that any efforts to amplify the countermovement will very likely result in an uncontrolled take-off motion. This is probably the reason why some athletes and coaches have not favored the use of the countermovement.

4 Take-off forces and their characteristics in ski-jumping

As implied in the introduction, the incitement for the force measurements in ski-jumping has been a basic assumption that by measuring the take-off forces it is possible to explore factors which influence the final result (i.e. the length of the jump). Hochmuth [18] initiated investigations of the force production during the take-off simulation in ski-jumping. His estimation that a 3-degree rise of the take-off angle could increase the jumping length by 9–14 m with approach velocity of 22–24 ms^{-1} strengthened the need for research in this area.

4.1 Methodological attempts

The take-off forces during ski-jumping have been measured by several authors either during the take-off simulations in the laboratory [16] [18] [19] [20] [21] [22] [23] [24] [25] [26] [27] [28] or during actual ski-jumping conditions[2] [5] [21] [23] [26] [29] [30] [31] [32]. Measurements made in actual ski-jumping conditions are summarized in Table 1.

Table 1. Force measurements made in actual ski-jumping conditions.

Author	Year	Place	Transducer type	In-run conditions
Sobotka & Kastner	1977	Seefeld (AUT)	force plate	snow
Troxler & Rüegg	1979	St. Mortitz (SUI)	force plate	snow
Tveit & Pedersen	1981	Hurdal (NOR)	ski binding	snow
Virmavirta	1988	Jyväskylä (FIN)	force plate	snow
Vaverka (rev)	1987	Frenstat p.R. (TCH)	force plate	plastic
Virmavirta & Komi	1989	Calgary (CAN)	force plate	snow
Jost	1993	Oberwiesenthal (GER)	force plate	plastic
Virmavirta & Komi	1993	Jyväskylä (FIN)	force bar	frost rail
Schwameder & Müller	1995	Stams (AUT)	EMED insole	porcelain

In 1975 Sobotka & Kastner [29] made the first attempt to measure takeoff forces exerted by ski-jumpers by installing force plates under the snow. Due to the harmful effects of snow it proved to be difficult to keep the force measuring system working properly. However, based on their results, the authors concluded that the final phase of the take-off correlated to the length of jump. Troxler & Rüegg [30] used the idea of Sobotka & Kastner and developed a new system (for technical details, see Sägesser [33], which measured the perpendicular reaction forces from the last six meters on the take-off table. The correlations between the length of the jump and different force variables were evident in individual examination and especially clear for good jumpers (Fig. 6).

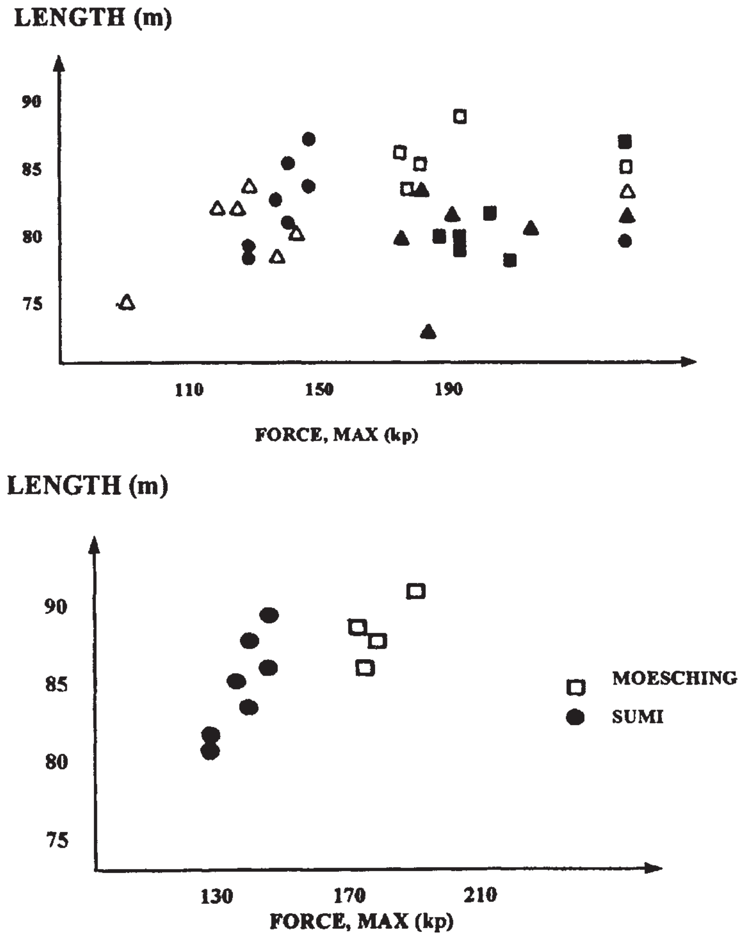

Fig. 6. Correlations between maximum force and the length of the jump for the group of jumpers (upper) and for the individual jumpers (below) [30].

Tveit & Pedersen [21] measured the take-off forces by equipping one of the skis with force transducers under the heel and toe. The authors found that the total force was far less in the 70 m hill than in the take-off simulations.

In 1988 Winter Olympics Virmavirta & Komi [32] also faced the harmful effects of changing snow conditions around the force plates and they had to use a correction program to restore the original signals to a more applicable form. In this study the high relative force production at the take-off seemed to have a weak correlation with the length of the jump.

Due to the aforementioned problems occurring primarily in winter conditions, it has been reasonable to develop a force measuring system for plastic summer jumping hills. Vaverka & Salinger [34] have measured take-off forces in Frestát p.R. plastic jumping hill (K-92 m) regularly since 1977 (Fig. 7). They have studied yearly about 70–90 competitors and 200–300 take-offs, which means more than 650 subjects and 2500 take-offs in total.

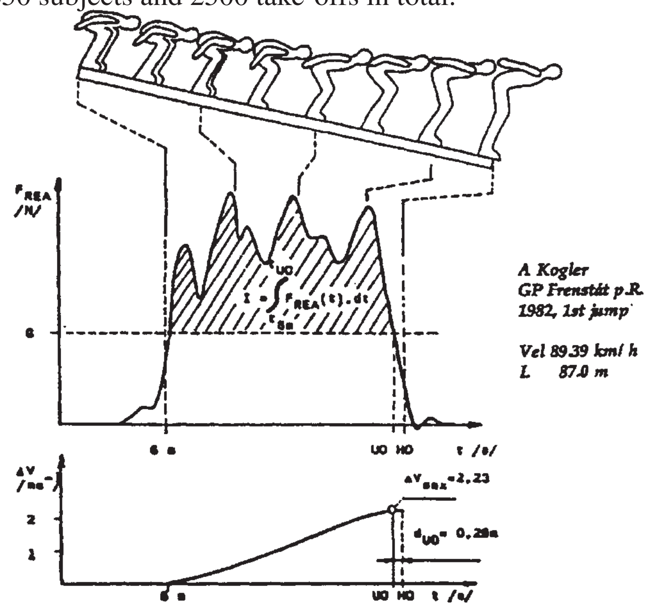

Fig. 7. Normal force curve during the last six meters on ski-jumping take-off table and the corresponding calculation of the perpendicular velocity for the jumper AK [23].

The explanation and description of this method has been presented by Vaverka et al. [35]; for review, see [23] and the technical problems of the system discussed by Salinger [36]. One example of the direct comparison between the take-off measured under laboratory and jumping-hill conditions was made by Vaverka et al. [37].

Jost [26] calculated jumpers' vertical take-off velocity from the force impulse and he concluded that for a successful jump only optimal take-off speed is necessary, and that exceeding this optimum leads to a non-linear correlation and destroys the performance of a jump.

Schwameder & Müller [2] used two EMED-insoles (40 Hz) with 85 capacitive sensors each. The force values were determined by the interpolation method. A-team jumpers showed significantly higher (p=0.015) relative forces compared to B-team jumpers.

4.2 Jyväskylä studies on ski-jumping take-off

The first attempt to measure the ski-jumping take-off forces in Jyväskylä was made in 1986 [31] by installing force plates originally designed for cross-country skiing [38] under the snow. The avoidance of the harmful effects of snow was almost impossible in these measurements as well because of the change in air temperature (-25-+2°C) and the preparation of the hill after the snow fall during the time period when the force plates were under snow. Calibrations made before, during and after the measurements showed quite large differences between the different places of the total measuring area (last 9 m on the take-off table). In actual measurements the mean value for the measured maximum normal force (Fmax) was 1742 N±391 (range from 1405 N to 2368 N, five subjects, 43 jumps). A weak correlation between Fmax and the length of the jump was found for one individual jumper (Fig. 8).

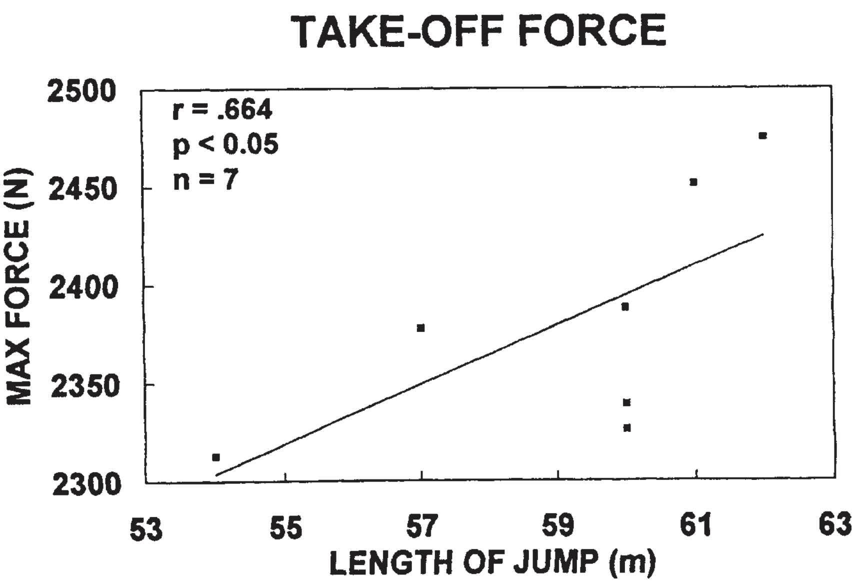

Fig. 8. Relationship between the maximum normal force and the length of the jump for one individual jumper [31].

The next step in this development was to create and install a new force measuring system to the ski-jumping take-off platform under the frost rail in-run track element of Porkka Co., (Lahti, Finland). The system consisted of 11 transverse force bars with strain gauge transducers at both ends placed 1 m apart along the last 10 m on the platform (Fig. 9).

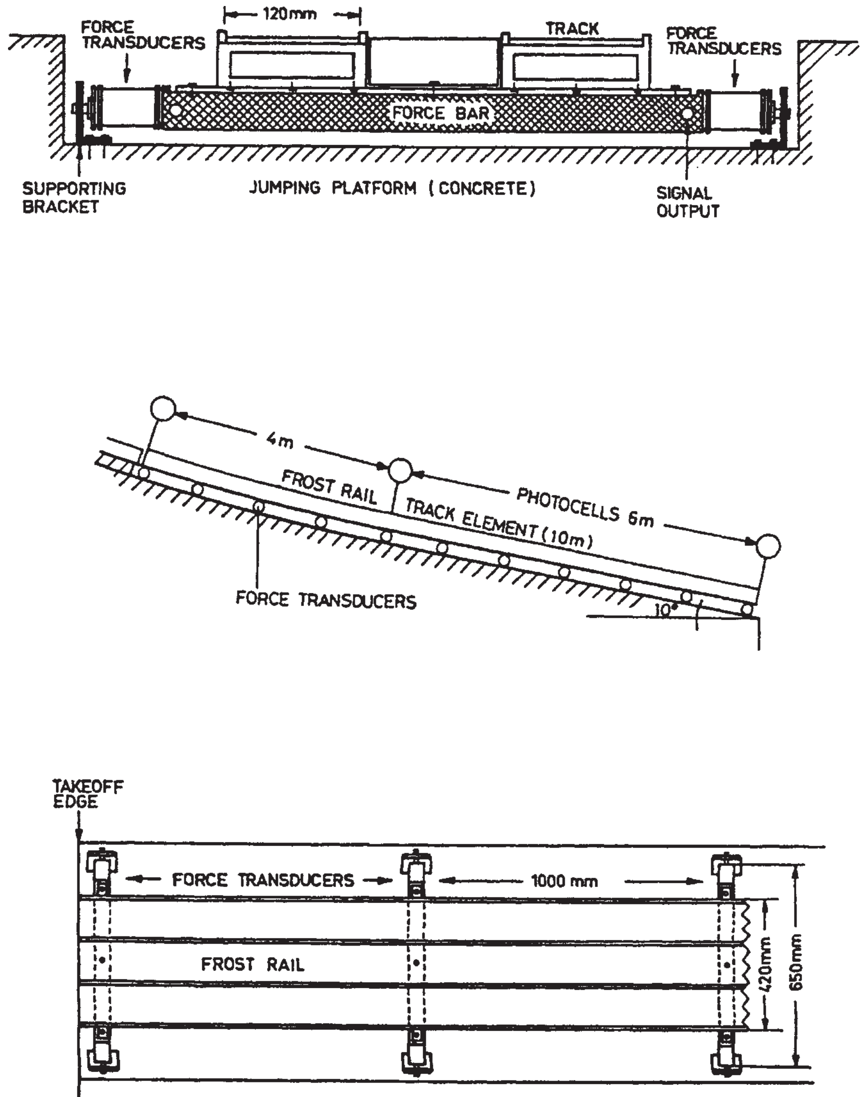

Fig. 9. Schematic presentation of the frontal (above), lateral (middle) and overhead (below) views of the force platform construction at the ski-jumping take-off table [5].

This system makes it possible to record ground-reaction forces perpendicular to the take-off table (normal force) and parallel to it. However, parallel forces were not considered reliable enough, because the length change of the aluminium frost rail element due to the temperature variations caused additional tension to the system and made the calibration of these forces difficult. The normal forces were recorded in different situations (training and competition) in 1988. Due to the problems in the calibration of the parallel forces, the 10 m long frost rail element was cut into 5 pieces (2 m each). The attachment of the lower force bar (closer to the edge of the take-off table) of each track element allowed the lower bar to move in the direction of the tracks but not in a perpendicular direction (Fig. 10).

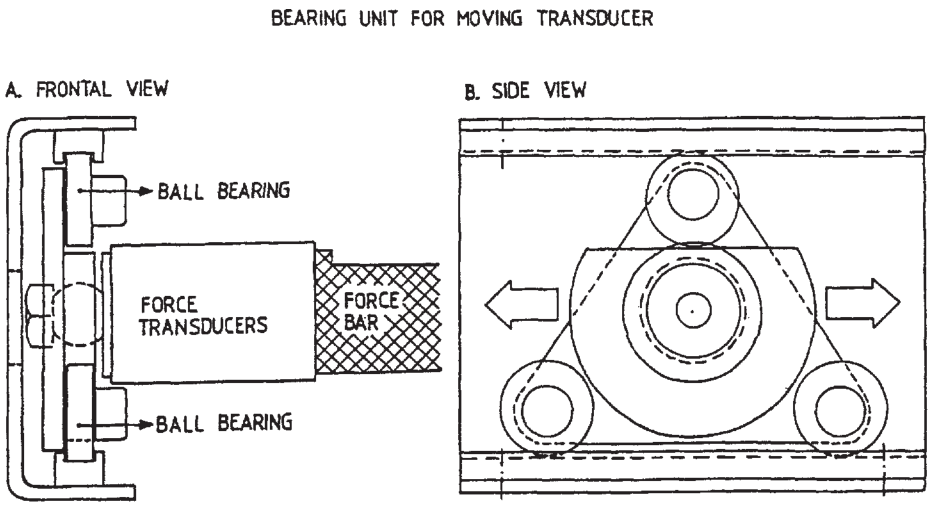

Fig. 10. Frontal (A) and side (B) view of the force-bar construction with a bearing unit for moving transducer [39].

It was assumed that with this procedure, the harmful effects of length changes in track elements could be avoided. Even though the calibration showed that some improvement was achieved, the forces in this direction could notbe measured accurately enough. Thus, only the normal forces were again recorded with this new system (cut track elements) in 1991. Fig. 11 shows that the pattern of the force production of one jumper remained quite constant over a three-year period (1988–1991) between the two experiments. More distinct peaks in the force curves of 1991 were probably due to the small gaps between the short frost rail elements used in this experiment.

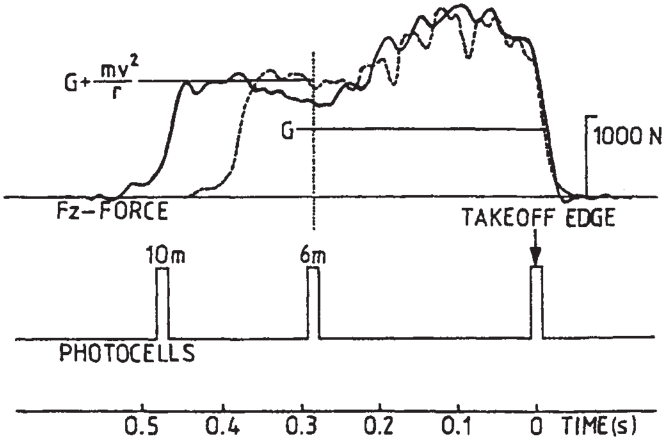

Fig. 11. Two force curves from two different experiments (1988=solid line, 1991=dotted line) for the same athlete. G refers to the jumper's body weight and mv^2/r to centrifugal force. Please note that the force sensing elements were longer in 1988 (10m) as compared to 1991 (8m) [39].

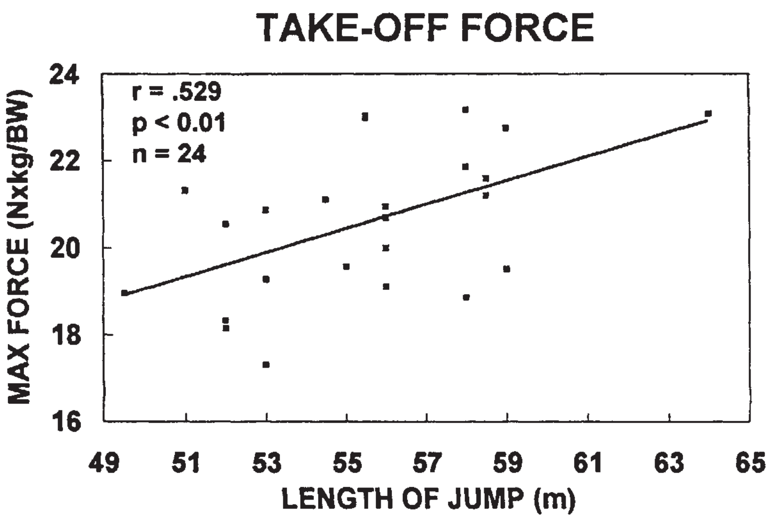

Fig. 12. Relationship between the relative maximum normal force (Fmax2) and the length of the jump among the ski-jumpers [4].

On the basis of the performed calibrations (made several times on several days before and after the measurements), the take-off forces exerted perpendicular to the take-off table could be measured very accurately with this system. Loading the different places of the frost rail track element showed differences of less than 5% between the places for the total 10 m distance and less than 3% for the straight take-off table. The force system's validity was roughly estimated by comparing the recorded force values during the in-run curve to the calculated centrifugal forces. The measured values seemed to match fairly well the calculated forces. Significant correlations between the maximum normal force and the length of the jump was found for individual jumpers as well as for a certain group of jumpers (Fig. 12).

Results from the studies of the take-off forces exerted by ski-jumpers in the past years clearly show that the force perpendicular to the take-off table influences the length of the jump. Most of those force measurements have been made before the overall change took place from a classical flight style to V-style. V-style may emphasize more the role of the flight phase for the entire performance, and thus the results in the force measurements do not necessarily give a true view of the situation during the transition to a new technique. However, it is assumed that after the certain adaptation period to the new flight technique has passed, the take-off forces would be of great importance also in V-style ski-jumping.

5 Take-off of a champion ski-jumper

Virmavirta & Komi [40] were able to examine the uniqueness of the take-off of Matti Nykänen (MN) in 1988 when he mastered the ski-jumping circuit by winning three gold medals at the Calgary Winter Olympics. In that study the take-off of MN was compared to the other jumpers in ski-jumping competition by using both force measurements (for methods see [5]) and the film analysis. Fig. 13 shows the comparison of the force curves of two jumpers (MN and JH) with corresponding stick figures. In Fig. 14 it can be seen that MN had significantly higher second force peak (Fmax2) and average force ($NxBW^{-1}$) at the end of the take-off than the group of other jumpers. The progressive force production toward the take-off edge seemed to be the major advantage of MN as compared to the other jumpers. By keeping his shank from moving backwards too much during the take-off, MN could move his upper body forwards as can be seen in Fig. 15 and 16. The high angular velocity and small angle of the hip joint at the release instant demonstrates the smooth upper body action of MN in Fig. 17. These variables show that the superiority of the take-off of Nykänen was not due to only one or two attributes but it was a sum of many take-off factors which influence ski-jumping performance.

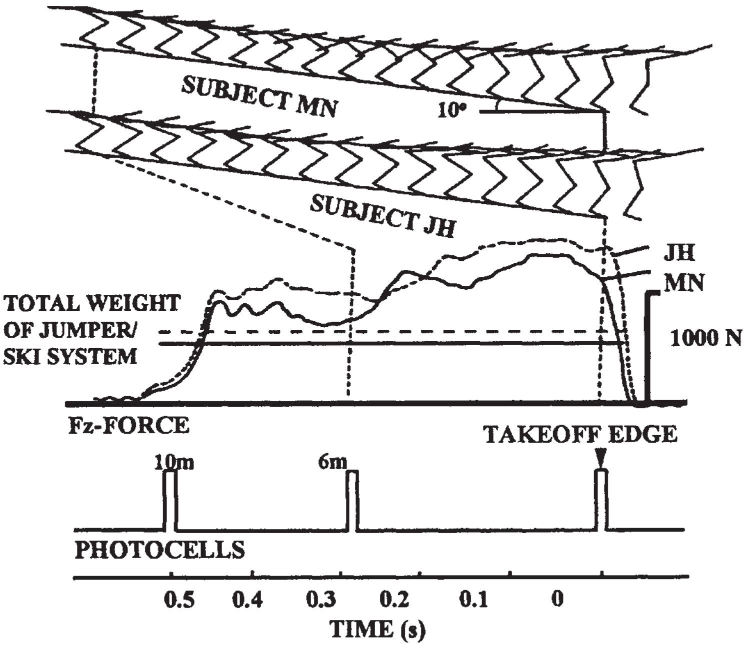

Fig. 13. The take-off techniques and force curves of the jumpers MN and JH [5].

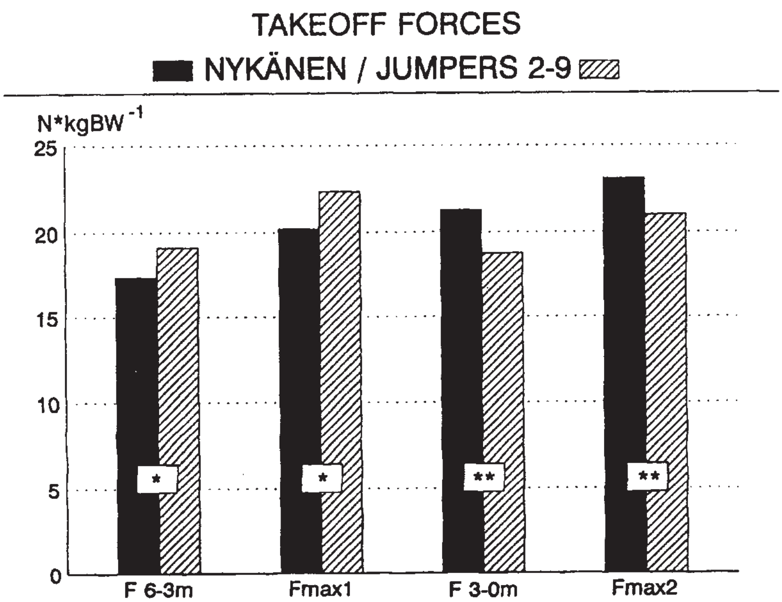

Fig. 14. Relative maximum take-off forces of MN compared to the other jumpers [40].

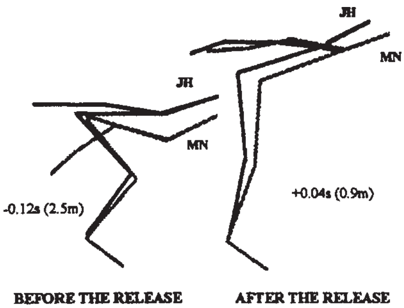

Fig. 15. The body positions of the jumpers MN and JH at different phases of the take-off [5].

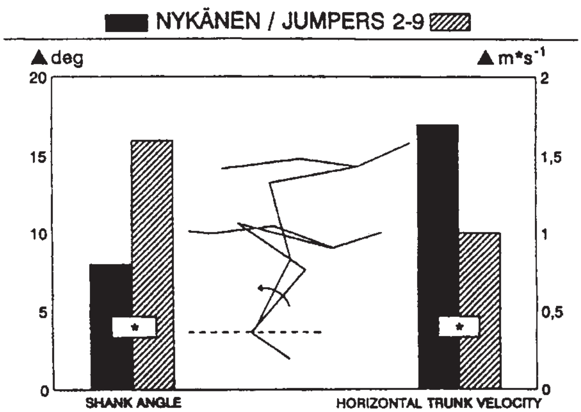

Fig. 16. The action of the shank and trunk segments of MN compared to the other jumpers [40].

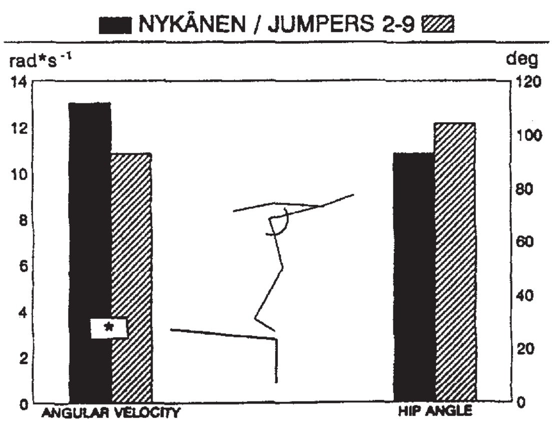

Fig. 17. The action of the hip joint of MN compared to the other jumpers [40].

6 Use of electromyography during ski-jumping

Only a few electromyographic (EMG) studies in ski-jumping have been reported [41] [42] [43]. In these measurements the main concern has been to describe the behaviour of certain muscle activities during the ski-jumping performance. Fig. 18 presents examples of the rectified EMG activities for one jumper during ski-jumping performance.

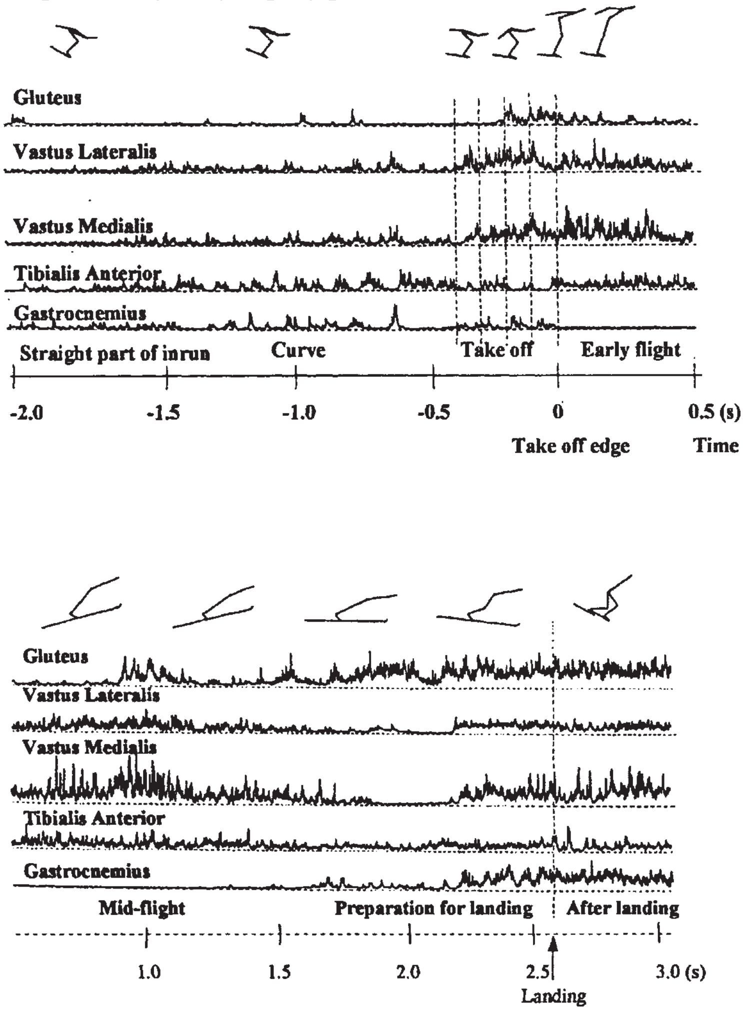

Fig. 18. EMG activities of the gluteus, vastus lateralis and medialis, tibialis anterior, and gastrocnemius muscles with corresponding positions of one jumper during the entire ski-jumping performance starting from the preparation of take-off (above) and ending at landing (below) [41].

Fig. 19 shows the mean integrated EMG activities for the group of jumpers from the different phases of the jump.

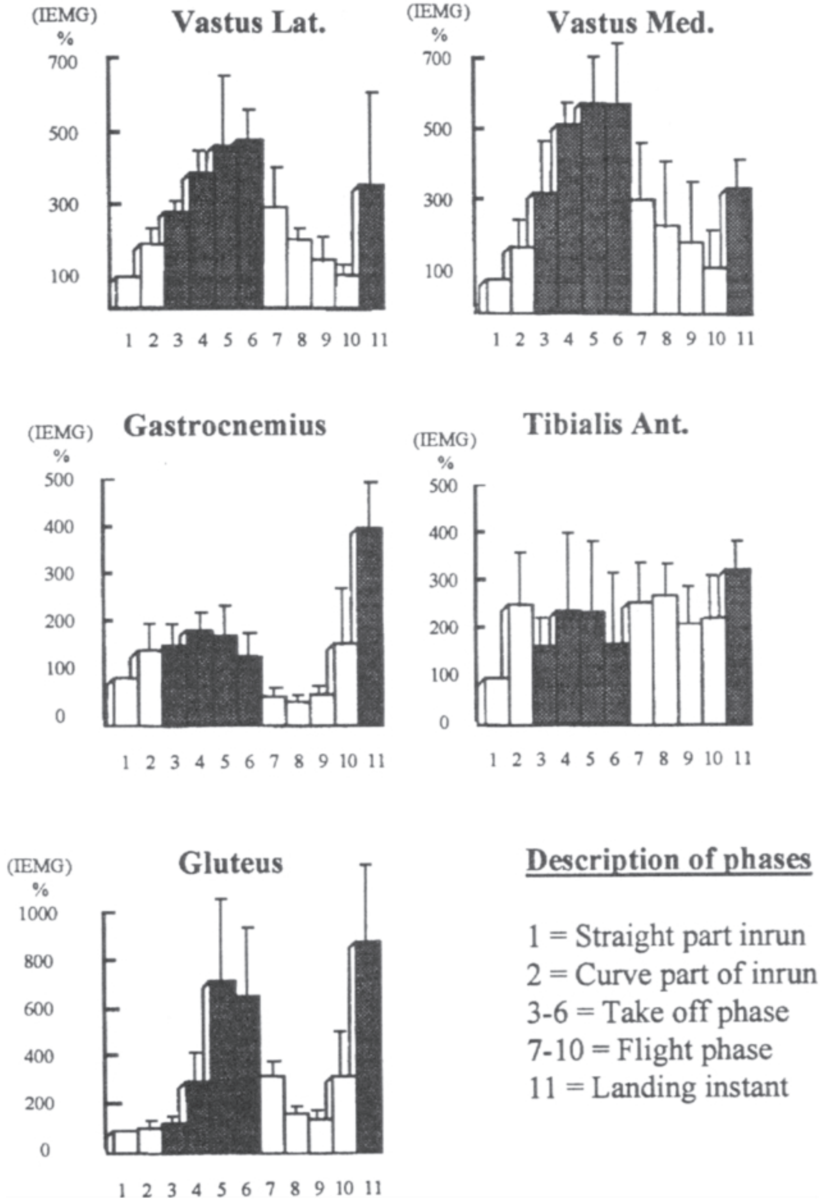

Fig. 19. Mean integrated EMG (IEMG) activities of different muscles for the group of jumpers from different phases of the ski-jumping performance [41].

From these illustrations it can be observed that the leg-extensor muscles are mainly responsible for the execution of the take-off. Strong action in the hip joint is demonstrated by the increase in the activity of gluteus muscle at the end of the take-off. Characteristic to jumping take-off, the gastrocnemius muscle (GA) is only weakly active. Utilization of GA especially during the last phase of take-off is much different from the take-off action in vertical jumps, where plantar flexion is of importance. The quick lifting of the skis does not allow effective use of GA (i.e. plantar flexion) and thus the take-off is performed more with the knee-extensor muscles. On the other hand, the structure of the ski boots limits the possibility for efficient plantar flexion during the take-off. On the basis of the aforementioned facts, the use of simulation take-offs with training shoes may have a negative transfer to the real performance. More information about the muscle activation (EMG) of the jumping take-off is, however, needed.

7 Future trends

Although much is known about the take-off action in ski-jumping, the ideal and individually most optimal take-off performance has not yet been developed. Research can help in this process, and the comprehensive use of kinematic, kinetic and EMG techniques may prove useful in this regard. Fig. 20 shows, schematically, our latest attempts (in progress) to utilize this principle and collect a great number of different parameters with modern recording techniques (e.g. 40-channel data logger).

Take-off action can be regarded successful only if it, in addition to the high vertical and horizontal velocities, produces optimal aerodynamic position. Future research should therefore concentrate also in this transition phase from the take-off to the early flight. Isolated studies with flight aerodynamics are not always useful unless they are combined with take-off kinetics and the associated requirements of the jumper's neuromuscular function.

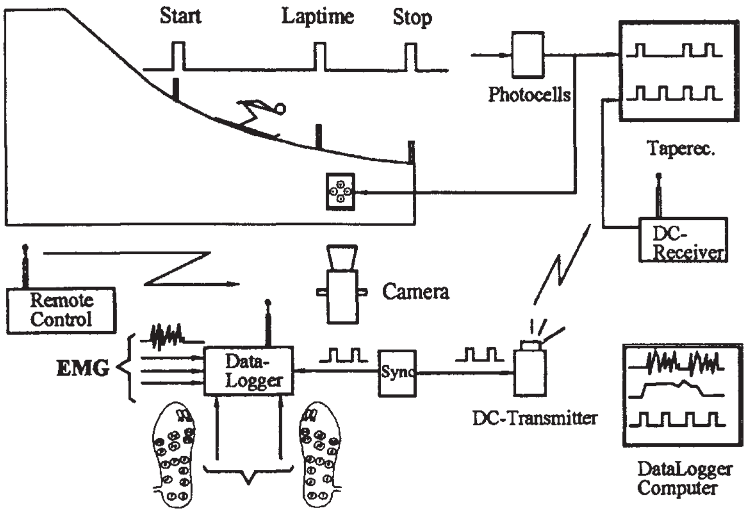

Fig. 20. Schematic presentation of the various methods currently used by the authors to study ski-jumping take-off and early flight phase. The kinematic methods usually employ several video cameras simultaneously.

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2
LOAD ON THE LOCOMOTOR SYSTEM DURING SKIING. A BIOMECHANICAL PERSPECTIVE

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Keywords: load, locomotor system, ACL ruptures, hip joint loading, hip replacement, biomechanics, alpine skiing, cross country skiing.

1 Introduction

Skiing has developed from an exotic sport of a few eccentric fanatics at the turn of the twentieth century into a popular leisure time activity in countries with mountains and snow. Parallel to this development, skiing equipment has made advances from simple wooden skis and rather soft ski boots to hightech ski constructions and sophisticated ski boot and release bindings for alpine and cross-country skiing, using modern materials and forms. Despite this development (or maybe partially because of it) ski injuries are rather frequent, have changed due to equipment [10] and there is concern about the loading of the locomotor system during specific skiing activities. Kuriyama and Fujimaki [17] found in a 28 year retrospective study that with the introduction of safety bindings in Japan in 1959 the relative proportion of ankle sprains, knee sprains and ankle fractures started to decrease. However, with the increase of the stiffness of the ski boots and with the higher back-spoilers in the early 1970's the fractures to the lower leg and knee sprains began to increase with respect to their relative proportion of injuries. Johnson et al. [11] reported for a period between 1972 and 1990 a significant reduction of the incidence of injuries of the ankle and tibia from 28 to 9% of all reported injuries. Knee sprains, involving minor to moderate damage (usually of the MCL) dropped by 70%. However, serious knee damage (grade III) involving complete rupture of one of the knee ligaments increased by 209%. These changes were typically attributed to changes in the boot-binding-system. Forces are transmitted from the binding to the knee if the binding does not release [6] [8] and these typically torsional forces are often the reason for excessive forces in knee ligaments. Despite these injuries and those publications, skiing is still a very popular activity and whoever started once getting involved in skiing activities attempts to continue these activities as long as possible. Specifically, skiers with major surgery and with artificial joints would like to return to their favourite activity of skiing.

The purpose of this paper is to summarize and synthesize knowledge of mechanical loading of the locomotor system during various skiing activities. Specifically, external loading during various forms of cross country and alpine skiing, possible injury mechanisms for isolated ACL ruptures during alpine skiing and loading of the hip joint during various skiing and daily activities are discussed.

2 External loading

External forces acting on the skier's body in relation to the strength of typically injured structures have been described in details previously [2] [23]. Maximal external forces acting on the athlete's feet for cross country skiing were reported for relatively slow speeds (5.5 m/s) in the order of magnitude of 1.5 to 2 times body weight (BW) for both, horizontal and vertical components [14] [28]. Forces in the cross country ski poles were only a fraction of BW (about 0.2 to 0.4 BW). The forces on the athletes feet and in the ski poles increased substantially with increasing speed and/or slope [13] [15]. Differences in force magnitudes between classical and skating techniques were not substantial [19].

Maximal loading (forces and moments) during alpine skiing were reported as about 270 Nm for hip extensor moments, 150 Nm for varus/valgus knee moments, 60 Nm for torsion knee moments, and 1300 N for anterior shear forces at the knee joint [9] [16] [20] [22] [23] [25]. External forces reported in the literature are not excessive in alpine skiing if compared to other sport activities but ski specific force applications may create high internal local stresses (for specific data see section 4). The internal forces, however, are the forces which are of importance when deciding whether a specific skiing activity is "safe" and can be recommended to a specific person.

3 Mechanisms for isolated ACL ruptures

Epidemiological studies reported the MCL injuries as the most frequent knee injury in recreational skiers [1] [18]. However, one of the most surprising developments in the injury characteristics for elite and competitive skiers was the substantial increase in isolated ACL injuries. In elite skiers this injury etiology has been proposed to be associated with a hyperflexed, seated position after an airborne phase [12]. It has been proposed that injury occurs during a backward fall or in the attempt to avoid it. In the attempt to recover into a balanced position, the skier may contract the quadriceps muscles to extend the knee and to accelerate the upper body forward. It has been suggested that the quadriceps force, without co-contraction of the hamstrings, produces a large strain in the ACL [7] [21]. However, it has been correctly demonstrated that contraction of the quadriceps muscles at knee flexion angles greater than 45 degrees does not cause an anterior shift of the tibia [26]. Instead, a posterior force is applied to the tibia, reducing the possible strain in the ACL.

Another mechanism which has been proposed to explain the etiology of the isolated ACL injuries is the so-called “boot induced” mechanism. In the unbalanced back-seated position, it is proposed that the skis accelerate forward with respect to the upper body. The tibia, in high backed stiff ski boots, is also accelerated forward. This results in an anterior drawer effect which may be large enough to overload the ACL [3]. However, it is not obvious why the skis and boots should be accelerated more than the rest of the body since an additional decelerating force, the frictional force between snow and ski, decelerates the speed of the ski.

From the remaining proposed mechanisms to explain isolated ACL injuries in skiing, two seem to explain, in the view of the authors, the mechanical situation most appropriately. The first one has been proposed by Nachbauer et al. [24]. When landing after a jump with the ski tips high in the air the ski rotates quickly into a position parallel to the slope. The posterior part of the shoe (the spoiler), which follows the movement of the ski, pushes the tibia forwards and may produce excessive loading of the ACL. Consequently, isolated ACL injuries should be more frequent with stiff boot-spoilers if this proposed etiology is correct. It is, therefore, proposed to analyse the existing injury data for this proposed phenomenon.

A second proposed possible mechanism is associated with the recovery from an extreme backward position after landing. Simulation of this recovery using a simulation model with muscle specific information showed high forces in the ACL during the recovery movement. Appropriate landing technique was, consequently, proposed to minimize the frequency of these injuries.

4 Loading of the hip joint during skiing activities

Degenerative diseases in the hip joint, such as osteoarthritis, are painful and may limit the range of motion to an extent that daily activities are no longer possible. Total hip replacement is a common surgical procedure to regain a normal range of motion at the hip and to allow pain-free movements. The success rate of such surgical interventions is relatively high. Nevertheless, the implant has the tendency to loosen up after several years and this may require another surgical intervention.

Controversial opinion exists whether a patient with hip arthroplasty should participate in sports activities [29]. It is generally believed, also not proven, that high impact activities accelerate the loosening process of the implant. However, the opinions of the medical profession are divided as to whether low impact activities might actually be beneficial for the fixation of hip arthroplasties.

Dubs et al. [5] and Widhalm et al. [30] compared the loosening of the total hip replacement between physically active and physically non active patients. Both studies found that the rate of loosening was considerably lower in the physically active group. Low impact activities were, consequently, proposed as having a bio-positive effect on the stability of hip arthroplasties [5]. However, both studies had methodological shortcomings. They did not randomly assign patients to the physically active or the physically non active group. Thus, it may be argued that other factors than physical activity, such as positive attitude or better following the prescribed physiotherapy, were the reason for the better outcome. Furthermore, the follow-up time was in the average 5.8 years after surgery, which is relatively short considering that the loosening usually starts ten years after surgery.

However, these and other studies underline the interest in objective criteria to help to decide whether specific sport activities should be recommended/ allowed after hip arthroplasty. Objective criteria would presuppose the knowledge of the actual loading situation at the hip joint during defined physical activities. Measurements and estimations of actual hip joint forces have been presented for walking and running. However, this information was not available until recently.

In a recent study, loading of the hip joint has been quantified during various alpine and cross country skiing activities and was compared to heel-toe running [4]. A method was developed to determine the 3-dimensional resultant hip joint forces and moments and intersegmental (contact) hip joint forces using accelerometer data from the trunk (top-bottom method). The method was applied to an analysis of hip joint loading during the single support phase of walking and running and compared to similar calculations using an inverse dynamics approach (bottom-top method) using force and kinematic data. The loading patterns obtained with these two different methods were similar. However, the top-bottom approach provided joint loading which was in general about 20% lower than the results from the bottom-top approach, a result which was defined as acceptable.

The method was used for a study with nine subjects in which the hip joint loading for several physical activities were compared (Table 1).

Table 1. Summary of activities and conditions included in this study.

ACTIVITY	CONDITION	COMMENT
walking	1.5 m/s	
running	3.5 m/s	
alpine skiing	flat slope	large radius turns
	flat slope	short radius turns
	steep slope	large radius turns
	steep slope	short radius turns
cross-country skiing	classic technique	
	skating technique	

Additionally, data were collected for two subjects skiing in steep moguls. Further details regarding the methodology are described elsewhere [5]. In this text the discussion will concentrate on the most important results.

Absolute values of forces in the hip joint during specific activities can not be used at this point in time to decide whether a specific activity should or should not be recommended for patients with hip arthroplasty. The basic knowledge for such a decision is not available yet. However, since running is generally not recommended for patients with hip arthroplasty, the following recommendations use the loading results for running as a criterion to decide whether a specific physical activity is recommendable for this specific group of patients. Since the running speed was only 3.5 m/s the hip joint loading quantified during running was rather low and the recommendations are on the conservative side.

The results are summarized in Fig. 1. They will be discussed with respect to three aspects: the magnitude of the hip joint loading, the presence of impact forces at the hip joint and the direction of the hip joint loading.

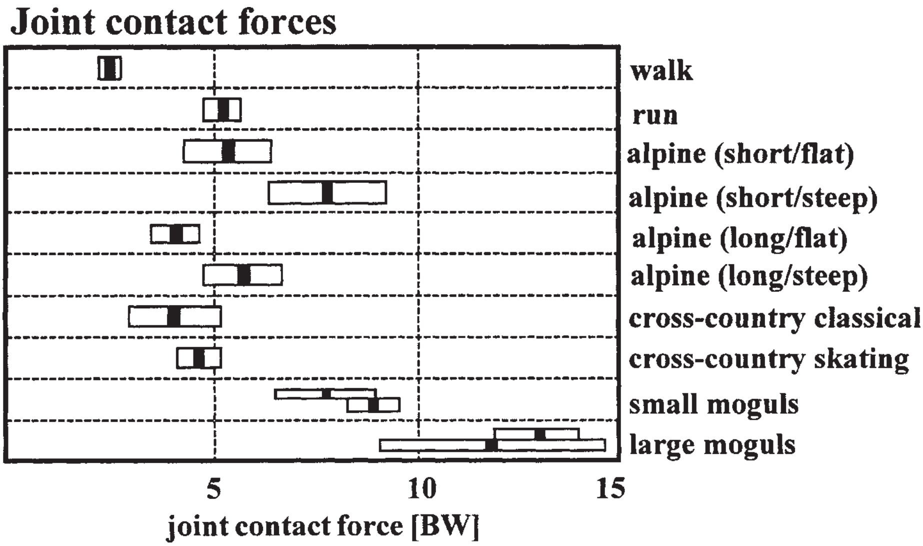

Fig. 1. Summary of the joint contact forces (in units of body weight) during various forms of physical activities, including walking (1.5 m/s), heel-toe running (3.5 m/s) and various forms of alpine and cross-country skiing.

(a) Magnitude of loading

Cross country skiing was reported to have slightly smaller hip joint loading than heel-toe running. Hip joint loading in alpine skiing was reported to be smaller than for heel-toe running for skiing long turns on flat slopes, slightly higher than heel-toe running for skiing short turns on flat slopes and long turns on steep slopes. However, the loading of the hip joint was substantially higher than for heel-toe running for skiing short turns on steep slopes and for skiing small moguls. The hip joint loading was extremely high when skiing large moguls.

(b) Impact forces

Impact forces at the hip joint were only observed during heel-toe running, but not during the various alpine and cross country skiing activities tested. This result may support the commonly assumed notion that patients with hip arthroplasties should not run since high impact forces are assumed to be one major reason for the loosening of the prosthesis.

(c) Direction of loading

The direction of loading showed large a-p and m-l components during alpine skiing. The magnitude of these components were in the same order of magnitude as the magnitude of the vertical component. This finding may be of importance for the protocols for the testing of hip prostheses since they suggest not primarily vertical (axial) loading of the prosthesis.

Based on these results, it was concluded that controlled alpine and cross country skiing should not create excessive loading for patients with hip arthroplasties. However, based on these results, alpine skiing on steep slopes, skiing in moguls and skiing with short turns are not recommended for patients with hip arthroplasties since during those activities the hip loading was clearly higher than in heel-toe running.

5 Final comments

External and internal load on and in structures of the locomotor system during alpine and cross-country skiing activities follows a typical pattern for load during sports activities. The external and internal forces are within reasonable limits for non excessive skiing activities and one should expect biopositive effects due to these skiing activities as long as they are executed within reasonable limits. However, as with most other sports activities, the loading of the locomotor system increases substantially when extreme situations are created. Extreme situations may occur due to the selection of the activity (e.g. excessive mogul skiing) or due to the loss of control during the skiing activity (e.g. a fall). For those situations the forces may be excessive and reason for injury. However, biomechanical or epidemiological studies provide only information about the controlled situations.

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3
BIOMECHANICS OF SKI-JUMPING—SCIENTIFIC JUMPING HILL DESIGN

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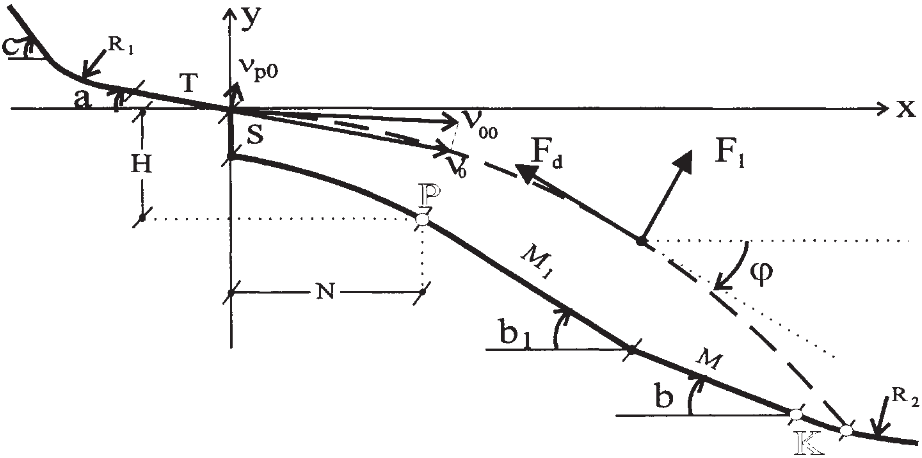
Keywords: biomechanics, ski-jumping, jumping hill design.

1 Introduction and methods

The simulation results shown here start out from a highly realistic reference jump based on the mean position angles of 15 excellent jumps (mean jump length: 186.6 m) measured during the World Championship 1994 in Planica. The corresponding sets of wind-tunnel-lift (L) and drag (D) areas (in m^2) are: 0.2 and 0.4 (at t=0 s, i.e. at take-off), 0.65 and 0.60 (0.2 s), 0.68 and 0.58 (0.4 s), 0.77 and 0.64 (2.3 s), 0.79 and 0.73 (4.0 s), 0.78 and 0.77 (4.6 s), 0.78 and 0.79 (from 5.0 s on until landing). Linear interpolation was used in between. The mass of the athlete (including the equipment) was 70 kg and the air density was 1.15 kgm^{-3}. The reference jump and simulation results concerning questions of safety in ski jumping, as well as technical aspects of the measuring methods used have already been described in detail [1] [2], Additional aspects and results from investigations of today's ski jumping can be found in some recently published papers [3] [4] [5].

The following study focuses on the flight phase. Fig. 1 shows the schematics of a jumping hill and the flight path in the x - y plane. The approach velocity V_0 and the velocity component perpendicular to the ramp V_{p0} (due to the athlete's jumping force) are initial values for the equations of motion:



$$\dot{\upsilon}_x = \left(-F_d \cdot \cos\varphi - F_l \cdot \sin\varphi\right)\tfrac{1}{m} \qquad (1)$$

$$\dot{\upsilon}_y = \left(-F_d \cdot \sin\varphi + F_l \cdot \cos\varphi\right)\tfrac{1}{m} - g$$

$$\dot{x} = \upsilon_x$$

$$\dot{y} = \upsilon_y$$

$$F_l = \tfrac{\rho}{2} \cdot w^2 \cdot L$$

$$F_d = \tfrac{\rho}{2} \cdot w^2 \cdot D$$

$$w = v_g - v$$

x, y, u_x, u_y, time t
state variables
w ... wind-speed vector
υ_g ... velocity of a gust
υ ... velocity of motion along the path

F_l ... lift force
F_d ... drag force
ρ ... air density
m ... mass
(athlete with equipment)

Fig. 1. Schematics of the flight path and a jumping hill. Values for the ski-flying hill in Planica, surveyed immediately before the World Championships 1994 by H.H.Gasser, FIS: a=-11.6°, b=-38.1°, b_1=-40.1°, c=-38.5 °, H=58.38 m, N=107.33 m, R_1=125 m, R_2=228 m (until 1=210 m), M=24.40 m, M_1=37.35 m, T= 10 m, S=5 m. Angles counted negatively in clockwise direction. In competition (as in the computer model), the jump length l is determined according to a defined length at the K-point (185 m in Planica).

Although these coupled and nonlinear differential equations do not cause major numerical problems and have already been used by several authors (e.g. compare with [6] or [7]), it is not possible to estimate the effect of initial value or parameter changes without the help of a computer model. This is particularly the case when comparing different or changing aerodynamic values (lift area L, drag area D) during the flight. During the flight phase, the athlete's position changes; our modelling concept considers the dependency of L and D values to the actual flight position and allows one to simulate flights with any sequence of position angles imaginable. Tabulated functions give the according wind-tunnel data. A preceding experimental determination of L and D values in a wind tunnel is necessary, because the general equations of motion for fluids (Navier-Stokes eq., [8] [9]) are complicated due to chaotic motion in such spatially coupled nonlinear systems [10]. In many cases, even for simple structures, mathematical predictions of aerodynamic forces are possible with only limited precision. In order to obtain precise wind-tunnel data, we used the large (5×5 m^2 cross section) wind tunnel of the *Bundesforschungs- und Prüfungszentrum* ARSENAL in Vienna (blocking corrections were between 3.5% and 6.5% only, depending on the actual position).

Analyses of the physical background of ski jumping can provide a reliable basis for changes to be made to the regulations and for new jumping-hill designs. In a first step, in order to stop the development towards steadily increasing aerodynamic forces and to reduce the hazards of this sport, two changes to the regulations have recently been made by the FIS: the maximum thickness of the athlete's dress has been reduced to 8mm and the front ski to total ski length relation has been limited to 0.57. The latter reduces the tension between skis and athlete and leads to less extreme postures in flight. Both regulations are based on our investigations [1] [2].

Although these changes to the regulations also contribute to matching the flight paths to the existing jumping-hill profiles, there is still an alarming discrepancy. We should not follow a backward track to lower aerodynamic forces too far, owing to the associated higher flight velocities [2] [11]. The work introduced here describes the existing discrepancies between the flight paths obtained by today's athletes and the profiles of jumping hills. A modern jumping-hill design will have to take into account the results that are presented here.

2 Results and discussion

2.1 Analysis of the jumping hill in Planica (K=185 m) and dependency of the equivalent landing hight on altered landing slope angles.

Varying the approach velocity V_0 between 26 and 30 ms^{-1} (V_0 of the reference jump is 28.6 ms^{-1}, i.e. the mean value from the field) and keeping all other initial values and parameters unchanged, results in the curve families of Figs. 2a and b. Even from such a simple simulation, protocol-interesting information can be gathered: characteristic landing values are given in Table 1. Fig. 3 shows the dependency of the equivalent landing height h_1 with increasing jump length l. The equivalent landing height corresponds to a jump onto a horizontal plane from height h_1. It is less than 0.3 m from l=120 m to 150 m and less than 0.8 m until l=185 m, from here on h_1 increases dramatically. This sudden increase is very dangerous for the athletes.

Table 1. Simulation results obtained using different approach velocities V_0.

υ_0 [ms^{-1}]	26.0	26.5	27.0	27.5	28.0	28.5	28.6	29.0	29.5	30.0
h_l [m]	0.41	0.23	0.22	0.32	0.74	0.80	0.90	1.53	2.31	3.10
v_l [ms^{-1}]	29.34	29.94	30.54	30.95	31.19	31.37	31.41	31.51	31.58	31.64
t_l [s]	3.85	4.32	5.01	5.64	6.10	6.51	6.59	6.86	7.12	7.35
a_l [°]	5.53	4.10	3.90	4.67	7.03	7.27	7.69	10.03	12.31	14.28
l [m]	98.9	113.9	135.6	155.8	170.6	184.0	186.6	195.6	204.3	212.0

υ_0 .... approach velocity; h_l .... equivalent landing height; v_l .... landing velocity; t_l .... flight duration;
$a_l = b - \varphi$ (piste angle - flight path angle at landing); l .... jump length

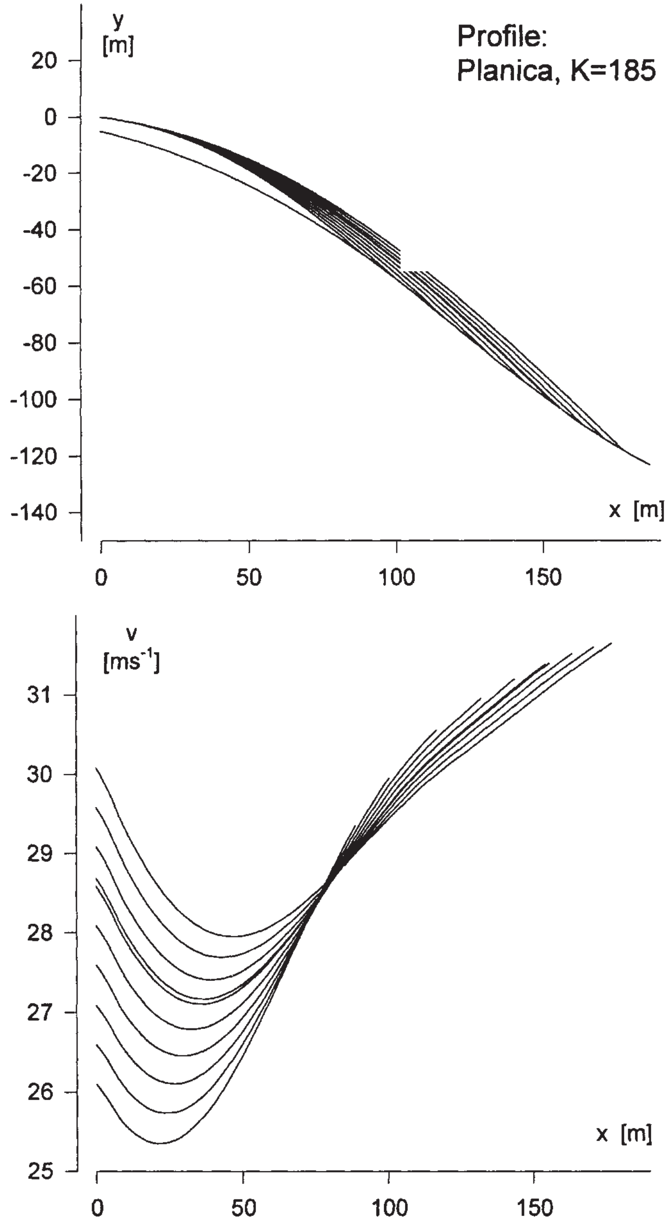


Fig. 2a and b. Flight paths y=y(x) and velocities v=v(x) according to different approach velocities V_0 (compare with Table 1). The velocity immediately after take off is given by $v(0)=\sqrt{v_0^2+v_{p0}^2}$

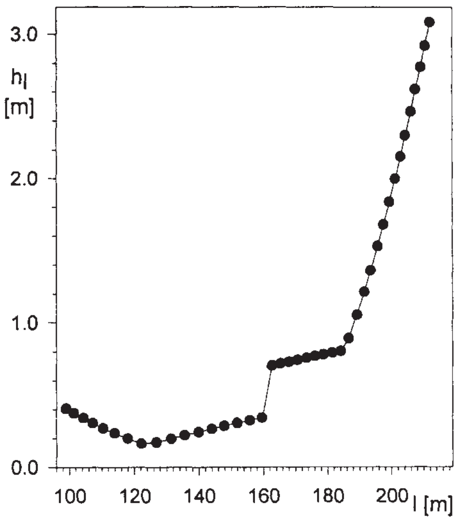


Fig. 3. Shows the dependency of the equivalent landing height h_1 on the jump length l. Here the approach velocity V_0 has been varied between 26 ms^{-1} and 30 ms^{-1} in order to obtain different jump lengths (compare with Table 1 and Fig. 4). The sudden increase of h1 at 1=160.6 m is due to the transition from M_1 to M (compare with Fig. 1).

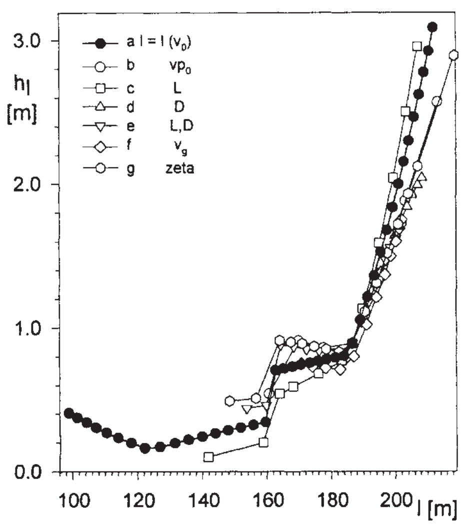


Fig. 4. Dependency of the equivalent landing height h_1 on the jump length l. The jump length was varied using different simulations protocols: a: l=1 (V_0); b: l=1 (V_{p0}); c: l=1 (L); d: l=1 (D); e: l=1 (L, D); f: l=1 ($|\vec{v}_g|$); g: $l = l\,(\zeta)$.

We have made similar simulations varying other parameters or initial values in order to obtain sets of jumps with different lengths (compare with [1] [2]). The jump length 1 also increases when the velocity v_{po} (due to the athlete's take-off jump) or the lift area L or both, the lift (L) and drag area (D) increase. We also obtain longer jumps when a gust (gust velocity $\bar{v}_g$) blows from an advantageous angle (gust angle ζ) up the hill. A decrease of D also increases the jump length. Using a constant gust velocity $(|\bar{v}_g| = const.)$ and altering the gust direction in the plane containing the trajectory (gust direction ζ measured from the x-axis, negatively in clockwise direction) also results in an alteration in jump length. The equivalent landing height at a given jump length depends on the parameters and initial values used. Fig. 4 shows these results for the simulation protocols described above. Of course, combinations of two or more of these changes can also be combined in order to vary the jump length.

The sudden increase of h_1 at l>185 m can be found with all simulation protocols. There is no acceptable buffer zone between low and very high h_1 values, h_1 also increases for extremely short jumps in an alarming way (not shown). Most jumping-hill profiles are not well matched with the flight paths obtained today.

In order to obtain the set of simulation data shown in Table 2, we varied the slope of the M-part of the jumping hill between -40° and -30°. This is just an heuristical example for the modification of one part of a jumping hill.

For the optimum design of a new and modern jumping hill, or for the redesign of a given one, a large set of simulation protocols are necessary. Imaginable influences from gusts as well as from changing equipment or flight styles (including uncontrolled descents) have to be taken into account in order to develop improved jumping-hill profiles, which are as safe as possible. Using our data and this computer model, we can optimize jumping-hill profiles considering a manifold of imaginable flight paths.

Table 2. Dependency of the equivalent landing height h_l on the slope (angle b; M infinite). Here the lengths of the trajectories d_l are compared; d_l=191.1 m corresponds to the reference jump in Planica with a jump length of l=186.6 m at b=-38.1.

b [deg]	h_l	d_l [m]
-40	0.50	200.0
-39	0.65	194.8
-38.1	0.81	191.1
-37	1.04	187.6
-36	1.28	185.3
-35	1.54	183.2
-34	1.83	181.5
-33	2.15	180.1
-32	2.49	179.0
-31	2.86	177.9
-30	3.25	177.0

2.2 Ski-flying utopia

The reference jump described above (A) and a modified version (B), which considers a landing phase (pronounced increase of D) from t=6 s onwards (L=0.79 and D=0.86, compare with [1]) have been used for the simulation of long-time duration (up to 20 s), i.e. long-distance flights.

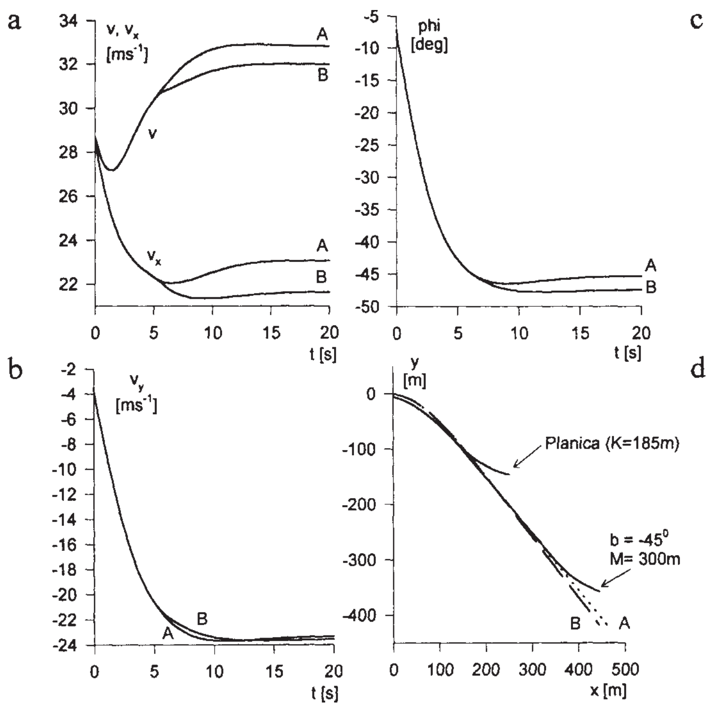


Fig. 5. Flights lasting 20 seconds have been studied in these simulations using the lift- and drag- area functions corresponding to the reference jumps A and B. In both cases v_0 was 28.6 ms^{-1}, v_{p0} was 2.24 ms^{-1}, ramp angle a was -11.6°, the athlete's mass (including equipment) was 70 kg, the air density ρ was 1.15 kgm^{-3}. 5a shows the velocity of motion along the path v and its component v_x; b shows the v_y component of the velocity, and c shows the angle of the tangent to the path φ (measured from x-axis, negative in clockwise direction). In d the trajectories y=y(x) are plotted as well as the profiles of the ski-flying hill in Planica and a utopic jumping hill. The trajectory lengths obtained at this utopic hill are d_l=423.5 m (A) d_l=323.5 m (B) and the landings occured at t_l=13.7 s and t_l=10.8 s, respectively.

Fig. 5a shows the velocities v=v(x) and their horizontal com-ponents v_x(t), b the vertical component v_y(t). During such long-duration flights, the angles of the tangents to the path f level out (c) and the trajectories y=y(x) develop toward a straight line (d). Compared to the velocities obtained at today's ski-flying hills, where record jumps last approximately 7 s, the velocity v increases only slightly from this time on. The flight path angle φ (Fig. 5c) shows a maximum steepness of φ=-46.4° at t=9.3 s (ref. jump A) and of φ=-47.8° at t=11.8 s (ref. jump B). The final values of φ (at t=20 s) are -45.3° (A) and -47.4° (B). The (stabilized) final velocities are 32.8 ms^{-1} (A) and 32.0 ms^{-1} (B), respectively. The trajectory lengths after 20 s are 629.7 m (A) and 617.1 m (B). The areodynamic forces reach final (constant) values of F_l=483 N, F_d=489 N (ref. jump A) and F_l=465 N, F_d=506 N (B). After 20 s flight time, the aerodynamic force vector compensates the weight of the athlete. This is shown in Fig. 6 for ref. jump A.

Fig. 5d shows the trajectories for both cases A (dotted line) and B (dashed line), the profile of the jumping hill in Planica (K=185 m) and a (utopic) modification of this profile, using M=300 and b=-45°. Using the lift and drag functions of reference jump A, the athlete in the model lands after t_l=13.7 s with a speed of v_l=32.9 ms^{-1}. The length of this trajectory d_l is 423.5 m, thus the mean velocity en route is 30.9 ms^{-1}. In this case, the athlete would hardly feel the touch down at all, because of an equivalent landing height h1 of only 0.01 m. For reference jump B we obtain t_l=10.8 s, v_l=31.8 ms^{-1}, d_l=323.5 m, and h_l=0.12 m.

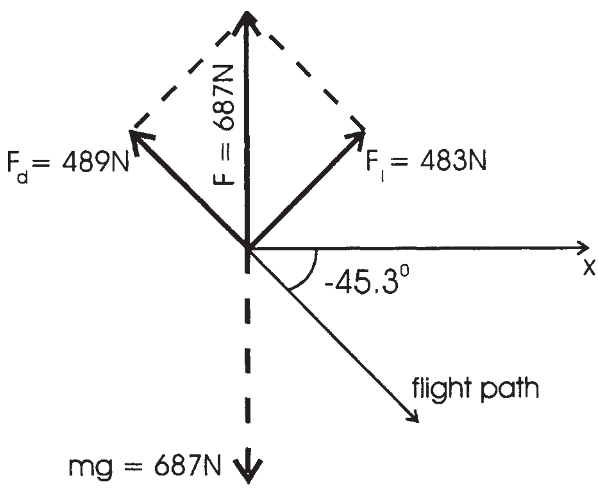


Fig. 6. Shows the aerodynamic force vectors F_l and F_d after 20 s. The resultant force F compensates for the weight of the athlete (m= 70 kg).

We have shown above that the velocity v would not increase much during flights far beyond 200 m (present record being 209 m by E.Bredesen) and also that the landing even after flights of 300 m and more would occur in a very smooth manner using today's flight style (V-style, introduced by J. Bokloev) and equipment at adequate jumping hills. Nevertheless, this cannot at all be interpreted as a recommendation to build such jumping hills and to perform competitions there. The above utopia ramp profile has only been used to give a brief insight into the physical background of utopic jumps and, of course, is far from being a detailed design that could be used to construct long distance jumping hills in reality. Within the framework of this article, it is not possible to present detailed designs and analyses of a complete set of imaginable flight paths including uncontrolled descents at different locations.

Although profile optimization for all sizes of jumping hills can be performed following the heuristic examples given above, we urgently recommend not to bring what is called here 'ski-flying utopia' into reality for several reasons: the hazards of ski jumping are not at all described sufficiently by the velocity during the flight (and the aerodynamic forces and torques associated with the velocity) and by the equivalent landing height and landing velocity. These are only crucial parameters for well performed flights under regular conditions. But what would happen if the athlete descends in an uncontrolled way, let's say a few seconds after take off, having an approximately -45° landing hill of several hundred meters ahead? Suddenly occuring gusts could cause instable flights and crashs. Who would be responsible and disposed to carry the consequences of such severe accidents?

3 Conclusions

Based on the heuristic simulation examples shown above, far-reaching consequences can be drawn concerning the safety and also the attractivity of ski-jumping competitions:

1. A dangerous landing impact does not result from an increased landing velocity at the end of long-distance jumps, but mainly from the mismatch of the glide paths obtainable with today's equipment and flight style and the existing jumping-hill profiles.
2. Almost all existing hill profiles have a curvature after the K-point which causes a dramatic increase of the equivalent landing height within a few meters. This inadequately shaped part of the landing hill always worries those responsible for ski-jumping competitions, because a wrongly chosen approach velocity or suddenly occuring gusts can lead to extreme and

unintended jump lengths followed by uncontrollable landings. A computer-aided design of a buffer zone at the final part of the landing hill could eliminate this problem and would increase the attractivity of this sport, because the athletes could always jump as far as they are really able to and would not have to interrupt the flight because of the severe risk associated with extremely high equivalent landing heights.
3. It is well known to the coaches and athletes that landings in the upper part of the hill (adjacent to the ramp) are extremely difficult and dangerous. This is a particularly an apparent problem with respect to poor or juvenile ski jumpers, because they are often confronted with this situation. Therefore, particular care should be taken over the curvature design of the hill adjacent to the ramp.
4. Over a large part of the landing slope (e.g. M_1-section in Planica from 1=123.3 m to 1=160.6 m) the flight paths obtained today are almost parallel to the piste, which could be flatter here. In this section the equivalent landing heights correspond to jumps from less than half a meter and the corresponding forces do not afford athletic training at all.
5. Optimization strategies for the calculation and design of landing hills must use iterative methods, because a change in one part of the piste will lead to necessary changes in the other parts.
6. In the efforts to improve today's jumping-hill profiles, one must also take into account the site of the piste as well as financial possibilities.
7. The attractivity of this sport can be increased without a negative influence on safety aspects. This is to be expected, because a meaningfully designed piste with an adequate buffer zone at the end would allow for extreme jump lengths of outstanding athletes without an irresponsible increase in the risks at landing.
8. Some of the problems discussed here can be reduced by influencing the glide path through altering the equipment regulations. Glide path modifications due to changes in equipment have to correspond to regulations concerning jumping-hill design and cannot be made independently from each other.

An extensive analysis would be urgently needed for existing jumping hills and for those being planned for future competitions. Such investigations would also have to consider extreme situations (uncontrolled descents, gusts from different directions, accidents occuring at take-off, wrong choice of the approach velocity v_0, outstanding performances of the best athletes, as well as the very poor jumps of inexperienced ones) in order to maximize both the safety and the attractivity of ski-jumping competitions. The computer simulation based on according wind-tunnel and field-study data provides a highly reliable basis for improvements and new developments of jumping-hill profiles.

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4

JOINT POWER PRODUCTION IN TAKE-OFF ACTION DURING SKI-JUMPING

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Keywords: ski jumping, biomechanics, segment model, joint power, joint energy, classification of jump skill.

1 Introduction

In ski jumping, take-off action is the most important factor for having ascent force (1). Ascent force acts on the ground (2) and is required for a jumper to obtain initial velocity and angular momentum. These kinetic parameters can be determined by video analysis (3). Virmavirta et al. directly measured the take-off forces of jumpers in ski-jumping competitions (2) (4) (5) (6). They showed that take-off force affected the flight length. Their study suggested the importance of the utilization of an appropriate take-off technique (6). Take-off force is produced by joint movement (2) (5). In take-off technique, appropriate movements of the joints and body segments should be aimed for, because reaction force is the result of the integrated kinetic parameters of each joint or segment. Those kinetic parameters can be determined by the analysis of jump action (7).

Generally, body action is the summation of the movements of each joint. For ski jumping, energy in each joint is produced in an orderly manner from upper body to lower body (8). Most of the power from initial action until take-off is produced by two joints, the hip and knee (9). When jump action produces force, the body is affected by ground reaction force. Reaction force makes the jumper revolve. In our previous research, jump action was characterized by two techniques that joint power contributes. One of the techniques had a higher contribution from the hip joint and another had a higher contribution from the knee joint (7). Reaction force gives the body both translational and rotational momentum at take-off. Sasaki et al. found that there is an exponential relationship between joint power and the rectified EMG of the hip and knee muscles (10). Power production in joints can be represented by joint muscle activity. Understanding joint power production is important to develop muscle training for individual jumpers. In laboratory conditions, there is no wind or sliding speed of skis. In an actual jump, wind resistance will affect a jumper as well as sliding speed (11). Therefore it is important that coaches and jumpers recognize how each joint action affects jump performance under conditions of wind resistance with skis sliding. The purpose of this study is to clarify the role that joint power and energy play in ski jumping for world class jumpers.

2 Methodology

The take-off action of six jumpers was analyzed from video taken at worldcup competitions at Okura ski-jump hill from 1994 to 1995. Camera speed was 240 frames per second (made by FOR'A co.). We observed moment force and joint power resulting from actual ski jumps, using six segment linkage models of four degrees of freedom. The segments were foot, lower leg, thigh, trunk (including head), upper arm and forearm segments. Data was obtained from ski-jump performances for each jumper.

Before calculation, we took anthropometric data of the segment lengths for each jumper from a control frame of two square meters on the take off ground. The body weight was fixed for calculation as 65 kg in each jumper. We calculated the torque, energy, and power produced by each joint. The momentum of inertia was obtained using Winter's method (8).

2.1 Data Processing and Definition of Joint Power

The data from video was collected by computer. All the data was filtered to decrease noise using a weighted moving average calculation of 21 digital points as a low-pass filter. Cut-off frequencies were 6 Hz for video data. An inverse kinematics solution was applied to video analysis. The data analysis system was developed for an NEC computer.

2.1.1 Definition of Joint Power

The joint is a medium for transferring mechanical quantity, but the joint is not able to produce force or energy. Torque (Nm), energy (J), and power (watts) in the joints are produced within the upper segment and then transferred downward through the joint (8). We considered this when we defined joint torque, joint energy and power. Joint torque and power were calculated using the link segment model. Joint power was calculated by the product of joint momentum and angular velocity.

2.1.2 Manner of Calculation

In the following equations (ωi) represents the angular velocity (rad/sec), and (Ni) represents joint torque. Here, (ωi) is defined as the ratio of a joint angle that is made up of two segments. The power produced by a joint (Pi) can be calculated by the outer product of torque (Ni) and angular velocity (ωi). Joint power and energy (Ei) can be described by the following equations.

Joint power (Pi) $$Pi = Ni \times \omega i \quad (1)$$

Total power (P) $$P = \Sigma\ Pi \quad (2)$$

Joint power (Pi) $$Pi = Ni \times \omega i \quad (3)$$

The total energy (E) can be calculated in the same manner as joint energy:

$$E = \int_{t1}^{t2} P\,dt \quad (4)$$

The kinetic calculation (E) by the Newton-Eular method is demonstrated in the appendix.

Table 1. Peak values of joint power and the intervals from peak to take-off.

Kinetic Parameters Max. Joint power, Interval, Energy & Calculated Force		Unit	Jumpers A.G.	M.H.	K.F.	J.N.	Y.A.	T.O.	Mean
Knee power	Positive	W	4614	1812	6499	7192	4907	3730	4792.4
Interval		sec.	-0.042	-0.054	-0.033	-0.054	-0.075	-0.071	-0.0548
	Negative	W	-	-	-2241	-2346	-	-	-2293.3
Interval		sec.	-	-	-0.075	-0.113	-	-	-0.0938
Hip power	Positive	W	2472	2236	3891	1879	3786	2194	2743.0
Interval		sec.	-0.100	-0.096	-0.092	-0.117	-0.071	-0.113	-0.0980
Knee energy		J	290	166	432	424	225	228	294.1
Hip energy		J	142	163	397	251	239	130	220.2
Total energy		J	437	350	855	678	498	373	531.8
Knee/Total		%	66.4	47.3	50.5	62.5	45.2	61.2	55.5
Max. Vertical Force		N	2183	1844	3141	2265	1759	2415	2268.0
Interval		sec.	-0.104	-0.096	-0.096	-0.121	-0.129	-0.129	-0.1125
Flight length		m	109.5	106.0	108.0	98.0	106.5	117.0	107.5

3 Results

Most of the power, from initial action until take-off, is produced by two joints, the hip and the knee joint. Peak values of joint power and the intervals from peak to take-off are indicated in Table 1. The knee joints were the major energy and power producers in all jumpers. The mean of the maximum values of vertical force can be observed -0.112 sec. before take-off. The value is 2268 N. Power production in each joint took place in regular order except in the performance of jumper Y.A. and T.O. The interval from peak to peak between hip and knee joints was utilized for classification of jump techniques.

3.1 Classification of Jumping Techniques

Jump performances were classified into three techniques according to the production of joint power. The first technique showed the tendency of the hip joint, and after some delay the knee joint, to produce power. The values were positive until maximum power. This technique was named the "Phase Shift Power Generation Technique". The second technique had the same tendency of power generation as the previous, but the power of the knee entered a negative level before peak power production. This technique included a remarkable action which was the forward rotation of the leg at the ankle joint. It was named the "Phase Shift and Leg Rotation Technique". The last technique had a tendency in which both hip- and knee-joint power rose at almost the same time, and the values were positive until maximum. It was named the "Close Power Generation Technique".

3.2 Phase Shift Power Generation Technique (PSPG)

The Phase Shift Power Generation Technique had no forward rotation as seen in the stick diagram in Fig. 1. Joint power contrasted with stick diagrams as indicated in Fig. 1 for jumper (A.G.), who received the first prize in the 1994 world-cup series. Joint power was produced in regular order. The hip joint, and after some delay the knee joint, produced power. In a comparison of the mean values of hip and knee power, larger power is recognized in the knee than in the hip joint. Changes in knee-joint power had positive values until maximum power production. The interval from initial power occurrence to maximum value was different in each joint.

The maximum value of total knee-joint power was observed 0.042 sec. before take-off. The values were almost the same and exceeded 4600 watts. The maximum power of the hip exceeded 2400 watts and the interval from peak to take-off was 0.1 sec. The interval from peak to peak of hip- and knee-joint power was 0.058 sec. Power production in each joint took place in a regular order. Each joint's power was produced in an orderly manner from upper body to lower body.

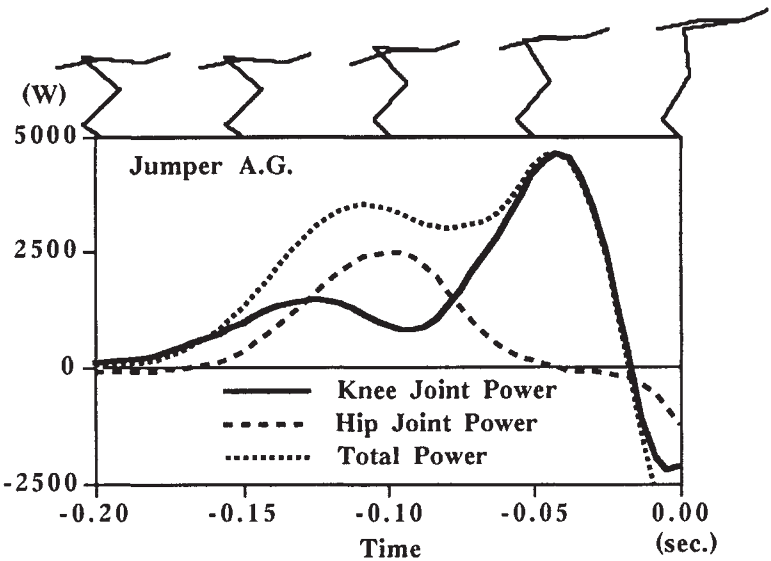

Fig. 1. Joint power contrasted with stickdiagrams in the Phase shift Power Generation Technique (PSPG). Jumper (A.G.), received the first prize in 1994 world cup series.

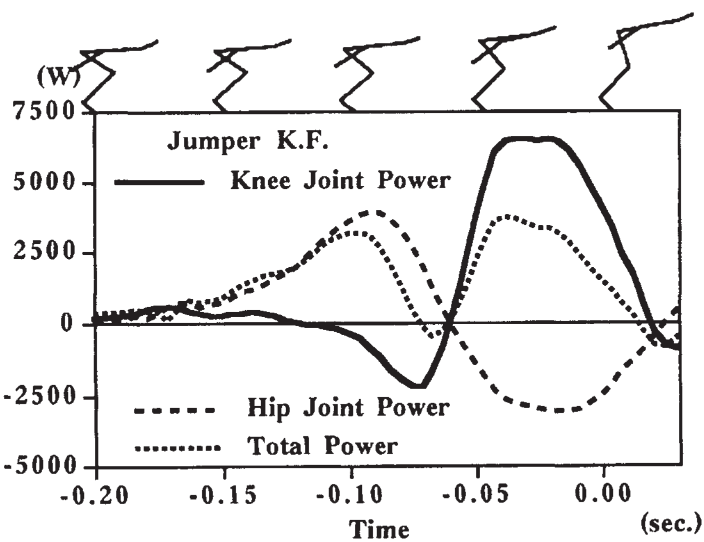

Fig. 2. Joint power contrasted with stick diagrams in the Phase Shift and Leg Rotation Technique (PSLR). Jumper (K.F.).

3.3 Phase Shift and Leg Rotation Technique (PSLR)

The performance of the jumper who had a remarkable forward rotation of the leg at the ankle is indicated by Fig. 2. Changes in knee-joint power had negative values until maximum power production. Particularly in jumper (K.F.), there was a phase resonance when the hip joint, and after some delay the knee joint, produced power. Minimum knee-joint power and maximum hip-joint power were produced at close intervals, as was the minimum hip-joint power and maximum knee-joint power. This technique is characterized by a phase resonance such as a 90-degree phase shift. Therefore, it was named the “Phase Shift and Leg Rotation Technique”.

The maximum value of knee-joint power exceeded 6400 watts. The total power exceeded 3100 watts. Maximum knee and total power could be observed at almost the same time, 0.033 sec. before take-off. The maximum power of the hip exceeded 3800 watts and the interval from the peak to take-off was 0.092 sec. The interval from the peak of hip to peak of knee-joint power was 0.059 sec. The power production in each joint took place in a regular order.

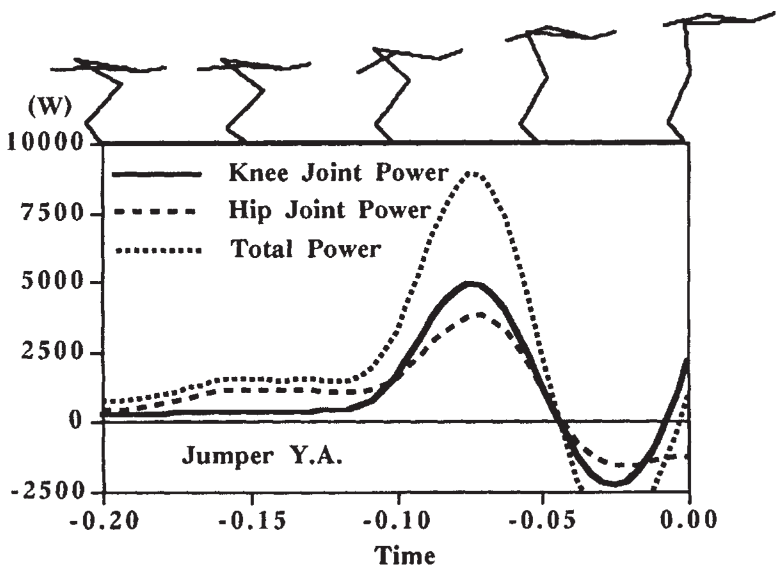

Fig. 3. Joint power contrasted with stick diagrams in the Close Power Generation Technique (CPG). Jumper (Y.A.).

3.4 Close Power Generation Technique (CPG)

Fig. 3 shows an example in which the maximum knee- and hip-joint power was produced at approximately the same time. For that reason, the total power was very large. The maximum power of the hip exceeded 3700 watts, the knee exceeded 4900 watts, and the total exceeded 8600 watts. The interval from peak power production to take-off for both hip and knee was almost the same (see Table 1). Most of the power during take-off action was produced by two joints, the hip and knee. Therefore, this technique is characterized by the close power generation of the two joints. It was named the "Close Power Generation Technique".

3.5 Joint energy

The proportion of joint energy is shown in Fig. 4. This figure demonstrates the relative energy balance among joints for all jumpers. It also indicates the effects of energy for all six body segments: foot, leg, thigh, trunk (including head segment), upper arm and forearm. The proportion of energy in the knee exceeded 50% for four jumpers. The knee joint as an energy producer particularly contributed to take-off action. In the PSPG and PSLR, the knee joint produced more energy than the hip joint.

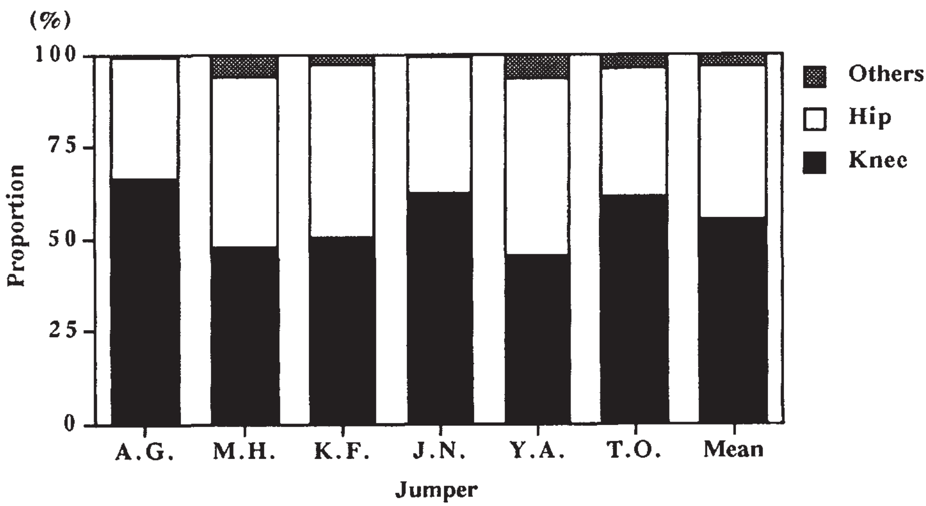

Fig. 4. Percentile of joint energy in hip and knee contrasted for six jumpers.

4 Discussion

Jumpers should have the potential to receive first prize using any technique. They also show individual characteristics in each jump performance. The jumpers in the world-cup series demonstrated individuality in their jumping skills. Therefore, it is important for jump-skill training that jump actions can be classified by manner of joint power generation. In this study, take-off action was classified into three techniques by the manner of power generation in the hip and knee joints.

4.1 Two Techniques: PSPG and PSLR

Power production in each joint took place in regular order in two techniques. The ascent power in the knee joint was produced later than in the hip joint. This orderly manner indicates energy transmission from upper body to lower body (8). This orderly manner of joint power production supports our previous study (7). Both PSPG and PSLR had variances that could be characterized by the presence or absence of phase resonance in the joint power production pattern. In laboratory tests, there is no wind and no speed of skis. Jumpers not only receive the effects of wind resistance and sliding speed, but they also will have to move and balance in actual ski jumps. That is a reason why in this study joint powers had larger values than the results of video analysis in simulation jumps.

Joint power is a mechanical concept which is calculated by the outer product of torque and angular velocity in that joint. Joint power ought to correlate to joint muscle activity. Sasaki, et al. found that there was a relationship between joint power and the EMG of associated muscles. EMG voltage indicated joint power production (10). This estimated difference of muscle activity can be used to analyze joint power. This has implications for the muscle training of ski jumpers.

4.1.1 Phase Shift Power Generation Technique (PSPG)

"The Phase Shift Power Generation Technique" had no forward leg rotation. The thigh segment rose up without any leg action. This technique is the simplest model of a ski jump.

4.1.2 Phase Shift and Leg Rotation Technique (PSLR)

Joint power was produced in an orderly manner from upper body to lower body as in the previous technique. However, the Phase Shift and Leg Rotation Technique was characterized by the forward rotation of the leg. Generally, forward rotation of the leg causes downward rotation of the thigh. Thus, jumpers have to make the thigh move forward on such occasions. Energy absorption also takes place in the knee joint. It can be forecast that knee-joint energy will be absorbed by leg forward rotation in this technique. Sanders and Allen found that a reduction of energy absorption was needed to increase jump height (12). This is a reason why the jumper should try to not move his leg so as not to loose joint energy. It has been common opinion among jump coaches that the jumper is not able to "throw" his own body without forward rotation of thigh. When the leg moved forward, the hip produced greater power with joint extension, as in the example of Fig. 2.

4.2 Close Power Generation Technique

In the Close Power Generation Technique, the maximum powers were produced at approximately the same time, and values were almost the same in the knee and hip joints. Thus, it can be considered that the action of each segment was produced synchronically. Using this technique, jumpers can obtain enough ascent force to increase jump height. Ascent force is very important for the accomplishment of longer flight distances. The time of maximum force generation is related to flight length (13) (14). Normal take-off forces affect the length of the jump (6). Large ascent force is one of the important factors for performing good jumps. Therefore, it can be recognized that this technique has an advantage in power generation. However, there might be difficulty in timing the initial ascent motion.

4.3 Joint energy

The lower segments bear momentum force in each joint when the body moves in a ski jump. In laboratory simulation jumps, Sasaki, et al. found that Japanese junior jumpers were characterized by larger knee-joint energy (3). However, most senior jumpers were characterized by larger hip-joint energy (7). The hip joint plays a very important role in ski jumping. However, for the senior jumpers in this study, the knee joints were the largest energy producers. The different conditions in laboratory and actual ski jump tests may account for the difference between these findings.

4.4 For future study

The values of joint power in this study were larger than the results of analysis in simulation jumps. Mechanical factors such as wind resistance, inertia force or effective force, act upon jumpers in actual ski jumps. Simulation jumps were performed without wind resistance or friction. However, the dynamic instability affecting jumpers sliding on the take-off ground should be considered. There are mechanical problems in model analysis. Therefore, we are not able to directly compare the joint power data of actual ski jumps and the data of simulation jumps. Future study will be necessary to solve such mechanical problems.

5 Conclusion

This study clarifies three important ski jumping techniques, based on an analysis of the patterns of joint power production. The manner of power generation is important for improving skills in each jumper. Our conclusions are as follows:

1. Actual ski jump action can be classified in three techniques according to joint-power production.
2. The power production in each joint takes place in a regular order in the Phasse Shift Power Generation Technique.
3. The Phase Shift and Leg Rotation Technique is characterized by forward rotational movement of the leg and phase resonance of the power generation pattern in the hip and knee joints.
4. The patterns of power generation in the knee and hip joint are produced without phase resonance in the Close Power Generation Technique.
5. The hip and knee joints play an important role for generating power and force in each jump technique.

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8 Appendix

Generally, when we calculate joint torque from video analysis, we used to apply inverse kinetic solution. Joint torque and power were calculated by Newton-Euler equation of motion in our study. This method was divided two manners by the Forward and Backward solution. In Forward solution, accelerations of each segment and whole body are calculated by using linkage segment models. In Backward solution, force and joint torque solved by using resultant of Forward solution. Joint power is defined by product of the joint torque and angular velocity in that joint. The orders of calculations are described follows:

8.1 Newton-Euler equations of motion

8.1.1 Forward solution

$$\mathbf{a}_0 = (0, 0) \qquad \mathbf{i} = 1\ldots n$$

$$\mathbf{a}_i = \mathbf{a}_{i-1} + \ddot{\theta}_i \times \mathbf{l}_i + \dot{\theta}_i \times (\dot{\theta}_i \times \mathbf{l}_i)$$

$$\mathbf{a}_{gi} = \mathbf{a}_{i-1} + \ddot{\theta}_i \times \mathbf{r}_i + \dot{\theta}_i \times (\dot{\theta}_i \times \mathbf{r}_i)$$

where,

n: Number of link
a_i: Acceleration of end of link i
a_{gi}: Acceleration of CG of link i
θ_i: Angle of link i
l_i: Position of end of link i
r_i: Position of CG of link i

8.1.2 Backward solution

$$\mathbf{F}_{n+1} = \mathbf{0}\ , \mathbf{N}_{n+1} = \mathbf{0}, \qquad \mathbf{i} = \mathbf{n}\ldots\mathbf{1}$$

$$\mathbf{F}_i = \mathbf{F}_{i-1} + \mathbf{m}_i(\mathbf{a}_i + \mathbf{g})$$

$$\mathbf{N}_i = \mathbf{N}_{i-1} + \mathbf{I}_i\,\ddot{\theta}_i + \mathbf{l}_i \times \mathbf{F}_{i-1} + \mathbf{r}_i \times \mathbf{m}_i(\mathbf{a}_i + \mathbf{g})$$

where,

m_i: Total mass of link i
I_i: Moment inertia of link i
g: Gravity
F_i: Force excert on link i by link i-1
N_i: Moment excert on link i by link i-1

8.1.3 Joint Power solution (Outer product)

$$\mathbf{P}_i = \mathbf{N}_i \times \omega_i$$

where,

P_i: Power of joint i
ω_i: Joint angle of joint i
$\omega_i = \dot{\theta}_{i-1} - \dot{\theta}_i$

5

INTER- AND INTRA-INDIVIDUAL VARIABILITY OF THE SKI-JUMPER'S TAKE-OFF

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Keywords: biomechanics, kinematic analysis, intra-individual, ski-jumping, take-off, variability.

1 Introduction

Some theoretical and experimental studies, e.g. [1] [4] [7] [8] [9], have considered the take-off as a key phase of the ski-jump. The transition from the in-run to the flight position determines the initial conditions of the flight phase. The dominant role of this important phase has also been confirmed during training. In contrast to the above statements, statistical analyses of the biomechanical take-off data have indicated a relatively low level dependence between the partial information of the take-off and the criterion the length of jump). In many studies, e.g. [1] [2] [3] [8] [9] [13] [17], the correlation coefficients between the biomechanical parameters describing the take-off and the length of jump have occured mainly in the interval r=0.3-0.6, with the percentage of the variability explained by the criterion being relatively low R^2=0.10-0.35.

Multiple regression and correlation analyses have indicated stronger relationships between the parameters and the criterion in cases where some data for the transition phase has been combined with data from the take-off, e.g. [1] [9]. A factor analysis conducted on data from "Innsbruck 95" has determined that only 17% of the variance was explained by the criterion 17]. In addition, only small differences, mostly statistically non-significant, have been found between selected groups of athletes of different performance levels, e.g. [9] [16]. It appears that there are limits to the amount of information which can be determined through the statistical analysis of inter-individual variability.

2 Problem

The validity of biomechanical take-off data is influenced by many different factors. One of them is the number of analyzed athletes and the quality of their performances. Based on our study [12], we have concluded that as the performance quality and the homogeneity of the athletes increases, the correlation dependence between the parameters and the length of jump decreases.

The second possible cause for the low level of validity for the take-off parameters may be related to the basic theory of the take-off. Considerations on the process of optimization during the take-off movements can be found in various papers, e.g. [4] [6] [9] [10]. Based on the multifactor theory of the take-off (published in a previous monograph [11]) the optimization process is defined as a key principle for all defined movement tasks of the take-off (Table 1).

Table 1. Basic tendencies of the take-off factors.

Factor	Characteristics	Tendency
VIGOUR	maximization of the take-off velocity	MAXIMIZATION \
		OPTIMIZATION
AERODYNAMICS	minimization of the air resistance during the take-off	/ MINIMIZATION
ROTATION	achievment of the optimum level of angular momentum in the forward direction	OPTIMIZATION
ACCURACY	all movement actions must be finished at the edge	OPTIMIZATION
ARM ACTIVITY	achievement of the optimal arm movements	OPTIMIZATION

In addition to the principle of OPTIMIZATION there are also other principles which can be defined for the take-off phase [11]:

- The principle of compensation mechanism (multifactor fundamentals of the take-off enable jumpers to achieve a specific performance by performing various combinations of different levels of the related take-off factors).

- The principle of individualization (the take-off is achieved by individual combinations of different levels of the defined take-off factors.

Based on these theoretical considerations, it can be suggested that the realization of the take-off is probably very individual and subjects perform the take-off using different combinations of take-off factors. Consequently, we can formulate a basic question regarding the problem of the take-off. Can the model of the take-off be represented as a general model or an individual model? Based on previous considerations, the following hypothesis can be formulated:

The kinematic patterns of the take-off are individual and the athletes differ in their realizations of the take-off.

3 Methodology

The kinematic analyses of each ski-jumper's take-off has been used in this research. The 2D kinematic data was combined with information from a database system which enabled us to statistically elaborate and compare the data [16]. The kinematic analysis of the take-off provided a set of information describing the position of the ski-jumper's body, the time and distance profile of the take-off, the velocity of the center of gravity in the three directions and the take-off angle. The set of 11 kinematic variables used in our research is described in graphical form in Fig. 1.

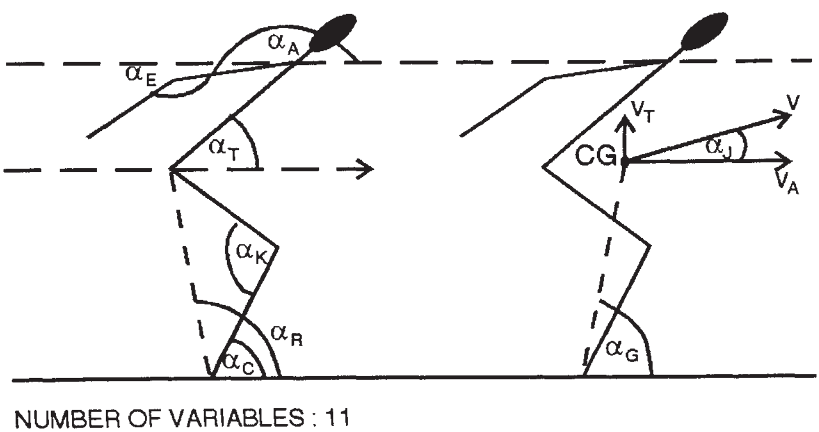

Fig. 1. Kinematic analysis of the take-off. Graphical illustration of evaluated variables.

In addition to these variables, the value "Dist" was computed, based on the procedures described in a previous paper [14], and expresses the distance from the edge in which the take-off is finished. The criterion jump (CLJ) was defined by the length of jump (LJ) and expressed as a percentage of the critical point (K) of a jumping hill (CLJ=100.LJ/K). We have computed the take-off data for the distances -4.0 m, -3.0 m, -2.0 m, -1.0 m, and 0.0 m from the take-off edge by using the procedure "modeling". The statistical analysis was computed using 5 data matrices.

3.1 Subjects

The collection of a large number of take-offs by individuals is very difficult. The minimum requirement for an analysis of intra-individual variability of about 25 samples [5] has not been previously accomplished for studies on ski-jumping. The completion of a set for an individual's data requires the collection of data from different events over a long period of time. Influences on the variability in the data can be attributed to the following factors: the changes in the external conditions during events on different jumping hills and in different weather conditions; different in-run velocities; the evolution of the quality of sports equipment; the evolution of the technique of ski-jumping; and, the evolution in the body dimensions and movement abilities of the young athletes over a long period of observation.

We have chosen only World Cup events on jumping hills with critical points at about K 120m for this study. We have made a selection from our database (presently more than 1200 analyses of different ski-jumping phases are stored in our database) and used the data from the following events during the period 1991–1995: Intersporttournee Innsbruck 1992–1995 (K 110m, four competitions, total number of analyzed take-off phases n= 203); Intersporttournee Bischofshofen 1993 (K 120 m, n=50); World Cup Final Vysoké Tatry 1991 (K 120 m, n=23; World Cup Planica 1993 (K 120 m, n=55). The total number of selected athletes was 18 with the number of analysed take-offs by individuals ranging from 5 to 13 (Mean= 7.6). The athletes were selected from the top half of the Innsbruck event's participants (CLJ varies from 84.15% to 100.68%). As an example, a set of 5 athletes (GOL, HAR, NIS, PAR, SAK) were selected for the comparison intra-individual variability. The number of variables was reduced by a_T (aerodynamics), v_T (vigour), a_G (rotation), a_K and Dist (accuracy).

The study of the relationship between the criterion and the biomechanical variables was made on the basis of the set n=155 pulled from the Innsbruck event analyses (1993, 1994, and 1995), which used the same methodologies, camera placements, and had similar external conditions for each of the competitions.

3.2 Statistics

The following statistical methods from the STATGRAPHICS package were used: Analysis of variance, Multiple range analysis of variance (Tukey, Scheffe), Correlation and Factor analysis.

4 Results

4.1 Inter-individual variability

The basic statistical characteristics of the set INN93–95 (n=155) are very similar to the data INN94 published in the paper [15], but the performance quality and homogeneity of this set was much higher. The values of the correlation coefficients between the kinematic data and the criterion were very low and mainly statistically nonsignificant. A more general perspective of this relationship was derived using factor analyses applied to the 5 correlation matrices (-4.0 m to 0.0 m). Table 2 presents the results of the factor analyses for the take-off phase and 0.0 m.

Table 2. Kinematic analysis of the take-off (0.0 m) Innsbruck, 1993–1995, n=155. Factor analysis—Matrix of rotated factor loadings.

Variable	Factor			Communality
	1	2	3	
CLJ	0.04	**0.26**	**-0.31**	0.17
AV	-0.05	**0.71**	0.08	0.52
α_C	**-0.49**	0.23	**0.80**	0.94
α_K	**-0.87**	0.20	0.11	0.80
α_T	0.04	-0.27	-0.07	0.08
α_A	-0.02	-0.31	-0.12	0.11
α_E	0.02	-0.01	-0.09	0.01
α_R	0.38	0.05	**0.84**	0.85
α_G	0.19	-0.01	**0.92**	0.89
α_J	**0.70**	0.14	0.14	0.53
v	0.11	**0.93**	-0.17	0.91
v_A	-0.01	**0.92**	-0.20	0.88
v_T	**0.70**	0.19	0.12	0.54
Dist	**0.85**	-0.17	-0.14	0.77

Note: Significant loadings are printed in bold-faced type.

The percentage of explained variability of CLJ was very low (before the edge 8% to 10%, on the edge 17%), and relates closely to the findings of our previous study [17]. The relationships between the kinematic variables and the criterion are expressed in a graphical form in Fig. 2.

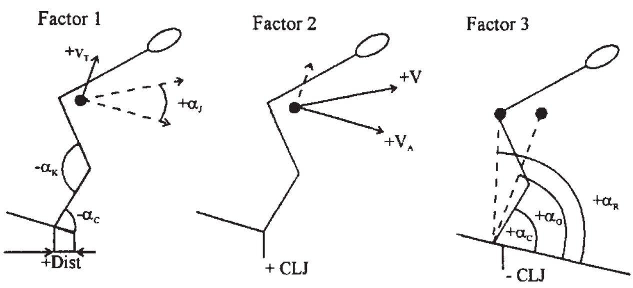

Fig. 2. Kinematic analysis of the take-off (-4.0 m, 0.0 m) Innsbruck, 1993–1995, n=155. Factor analysis—graphical scheme of the significant loadings.

There are significant loadings on the first factor by the variables describing the vertical lift of the body (α_C, α_K), vertical velocity of the take-off (v_T), the angle of the take-off (α_J), and Dist. The sign of the loadings describes the tendency of the relationship between the factor and the variables. The second and third factors are interesting, with a significant (but not high) loading of the criterion. In the second factor, which can be called a factor of velocity (AV, v, v_A), we can see the positive loading of the CLJ. In the third factor, which has significant loadings on parameters describing the forward-backward position of the body, the sign of CLJ is negative. In other words, the result in ski-jumping increases with a more forward position of the body (rotation).

4.2 Intra-individual variability

The study of the intra-individual variability for the kinematic data on take-offs represents many statistical analyses. For this paper we have reduced the amount of analyzed data to five variables (α_K, α_T, α_G, α_T, and Dist) and the criterion, and will use two examples to demonstrate the problem. The analyses of variance have been computed for the five selected take-off phases (-4.0 m to 0.0 m).

The basic statistical characteristics for the analysis of variance for a set of 18 selected athletes is presented in Table 3.

Table 3. Kinematic analysis of the take-off (0.0 m). Analysis of variance and multiple range analysis (Tukey) between individuals, n=18.

Variable	F-ratio	Sig. level	Homogeneous groups	Number of statistically significant differences between individuals	
CLJ	2.573	.002	5	4	
α_K	3.581	.000	3	7	
α_T	16.715	.000	7	50	
α_G	13.477	.000	7	53	$p<0.05$
v_T	2.620	.001	2	4	
Dist	3.745	.000	3	10	

The values of the F-tests are statistically significant ($p<0.001$-0.002) for the criterion and all observed variables. The number of homogeneous groups with similar levels of variability differs for different variables. Five homogeneous groups were separated by the criterion CLJ, but only four statistically significant differences between individuals were confirmed. Similar results were found for the variables α_K and Dist, where the number of homogeneous groups was even smaller, but the number of statistically significant differences between individuals higher (α_K: 7, Dist: 10). A very interesting result was found for the variables α_T and α_G. Seven homogeneous groups of individuals were separated, and about 50 statistically significant differences between individuals were found. Fig. 3 illustrates an example of the comparison of the mean and s.d. for the variable α_T for five selected athletes (position 0.0 m).

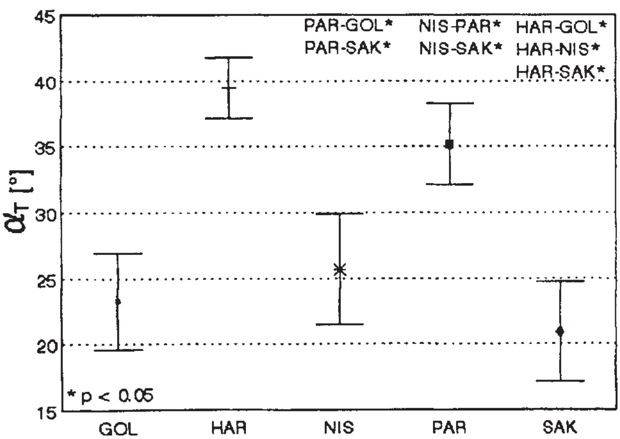

Fig. 3. Comparison of intra-individual variability of measured variable α_T by five athletes, take-off, 0.0 m.

The results of the analysis of variance for the variable α_G were identical. Table 4 shows the statistical characteristics of the analysis of variance for four kinematic variables measured in five take-off positions (-4.0 m to 0.0 m) by five selected athletes.

Table 4. Kinematic analysis of the take-off (-4.0 m to 0.0 m). Analysis of variance for five athletes (GOL, HAR, NIS, PAR, SAK)

Variable	Statistics	Distance to the edge (m)				
		-4.0	-3.0	-2.0	-1.0	0.0
α_K	F-ratio	5.04	3.93	2.21	1.11	1.01
	Sig. level	.00	.01	.08	.38	.41
α_T	F-ratio	18.61	25.18	33.85	42.03	48.37
	Sig. level	25.18	.00	.00	.00	.00
α_G	F-ratio	2.11	2.76	3.41	3.37	1.69
	Sig. level	.10	.04	.02	.02	.17
v_T	F-ratio	.65	.64	1.16	2.18	3.39
	Sig. level	.63	.64	.34	.09	.02

The diagram in Fig. 4 shows an example of the average values of the variable α_G.

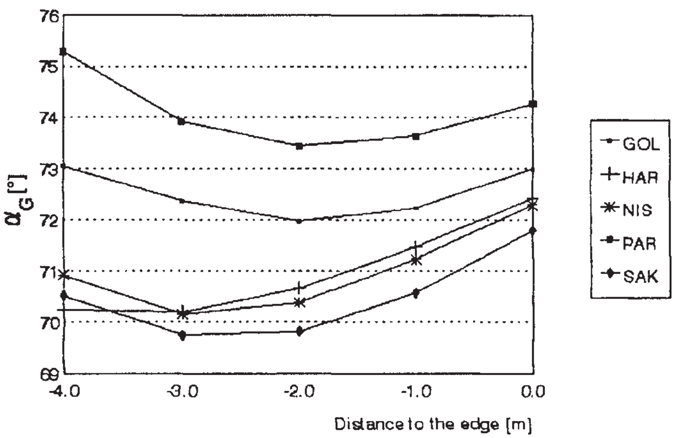

Fig. 4. Graphical illustration of the course of measured variable α_G by five athletes during take-off, -4.0 m to 0.0 m.

Statistically significant differences during the whole take-off were found for the position of the trunk α_T. The angle of knee α_K significantly differs only in the -4.0 m and -3.0 m (F-test significant at), but from the length -2.0m to the edge, the significance of the F-tests decreases. The opposite trend was found for the variable V_T Particularly interesting was the finding that the statistically significant differences for the variable α_G were found only in the positions -3.0 m, -2.0 m, and -1.0 m.

5 Discussion

The results of the factor analysis confirmed previous findings, e.g. [1] [9], that jumpers with high perfomance levels are in a more progressive forward position in the final part of the take-off (0.0 m), and that the velocity of the take-off in the forward direction plays an important role in influencing results. In spite of the fact that the individual correlation coefficients between measured variables and the criterion were very low (only 3 coefficients of correlation were significant,), the factor analysis has provided interesting structures for the relationships between all parameters. The structure of factor loadings (Table 2) has shown the relative independence between three factors. These findings are closely related to our own applications of factor analysis in the previous study [17] and indirectly supports the multifactor theory of the take-off.

Two important factors influenced the weak statistical relationship between the parameters and the criterion. The high performance quality of the set of ski jumpers had lower values for the correlation coefficients than a similar set , but the level of statistical dependence was still significant. The second, but most important factor, is the individualization of the take-off movement solution. A large number of the statistical intra-individual analyses, and some of the examples presented in this paper indicated that the patterns of the take-off are very individual. This is the main reason why the statistical relationships between the biomechanical variables and the criterion based on the linear correlation analysis method are relatively small. When we accept the principles related to the take-off mentioned earlier (optimization, individualization, and compensation mechanism), we may find other statistical approaches to solve these problems. In our previous study [13], multiple nonlinear regression analysis has provided one view. The ideas which have been briefly presented in this paper are the starting points for the next phase in the solution of the individual and general model of the take-off in ski-jumping.

6 Conclusion

- The study of the relationship between 12 take-off kinematic parameters measured at the take-off edge and the criterion has confirmed a very low level of statistical dependence. Only 17% of the variance in the criterion has been explained by the factor analysis.
- The analysis of variance has confirmed the statistically significant differences between individuals during the take-off and the take-off completion.
- Most variations in the take-off have been found in the trunk position (a_T, aerodynamics) and the forward-backward position of the centre of gravity α_G, rotation).
- The results of the study of intra-individual variability have indicated predominant individual variations in the take-off patterns for individuals.

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6

INVERSE DYNAMIC ANALYSIS OF TAKE-OFF IN SKI-JUMPING

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1 Introduction

Functionally the sequence of motions during ski-jumping can be divided into the phases approach, take-off, flight, landing preparation, and landing, all of which have, to a greater or lesser extent, an influence on the length and evaluation of the ski-jump. The take-off is regarded as the most important phase, since it determines the take-off velocity, the take-off angle, the moment of forward rotation of the system 'jumper-skis', and, therefore, the initial conditions for the flight [13]. This is also the reason why an analysis of the take-off motion has been the topic of numerous field investigations using biodynamic methodology. Sobotka/Kastner [10], Sägesser et al. [8], Vaverka [12], and Virmavirta/Komi [13] [14] use force plates built into ski-jumping ramps in order to measure ground-reaction forces during take-off motion. Tveit/Pedersen [11] have developed force recorders, which being mounted in the area of the toes and heels can measure the ground-reaction forces between boot and ski at different points. An extensive investigation of measurements of differentiated ground-reaction forces between the sole of the foot and the boot over the entire course of motion, from approach to landing, has been shown by Schwameder/Müller [9], the examination of ground-reaction forces as a whole, as well as in selected sections, is of special interest in that study.

Another opportunity for determining ground-reaction forces, in addition to the direct dynamic method, is the inverse dynamic method. Here, ground-reaction forces are determined by equations of motion, on the basis of kinematic data, by means of a suitable model. Inverse dynamic methods are reasonably applied where either ground-reaction forces can not be measured directly or precisely enough, or where the determination of joint or structure-internal forces and torques is concerned. Examples from Alpine skiing are found in Nachbauer et al. [7].

In the present investigation, a comparison between the results of a direct and an inverse dynamic determination of ground-reaction forces will be carried out. It will be necessary to show and discuss the resultant differences. In addition, it should be established whether it is basically possible to calculate ‘realistic’ ground-reaction forces with the help of inverse dynamical methods. Because of the complexity of the human body, which demands a high degree of abstraction of the model on which it is here based, this question can not, a priori, be answered. For such a comparison of methods, the selected course of motion may be nearly ideal under the given conditions. Through the small area of motion relative to skis, the relatively slow body motion, which results in acceleration of the entire body without considerable acceleration of partial body masses, and the predetermined path of motion (the in-run) under homogenous conditions (ceramic track), the model can be, on the one hand, simply kept, and, on the other, the result of the direct dynamic measurements will be easily read. Differences in the results are due to neglecting the air forces (especially the lift), the sampling rate of the measurement system and the assumption of a rigid body model.

2 Methods

2.1 Measuring techniques

The measurements for this investigation were carried out in 1992 at the jumping hill (K=105 m) in Stams (Austria). The test person was an Olympic Champion and a member of the Austrian National Team.

2.1.1 Video Analysis

Two synchronized video cameras (50 Hz) were used to film the last part of the in-run and the take-off phase. The jumps were evaluated three-dimensionally using the 3D-Video-Analysis-System of PEAK. Basically, the evaluation using this system is restricted to fixed cameras. In cases of spatial ranges as huge as in this study (15 m), the cameras have to be panned and tilted in order to produce in an acceptable size of the jumper on the film. Drenk [3] developed a method to obtain 3D data of body landmarks using panned and tilted as well as zooming cameras. The object and image coordinates of at least three reference markers are necessary to obtain the pan and tilt angle as well as the change of focus in relation to the calibration frame using an iteration procedure. These informations on the two cameras are needed to calculate the three-dimensional coordinates of the body landmarks of interest. If the filming conditions are strictly adhered to, the algorithms underlying this method guarantee the usual accuracy of fixed cameras in the whole range of filming. Error estimation showed that the mean error for calculating the body landmarks was about ±1 cm for each spatial direction [8].

A known system of reference markers, which is the prerequisite for using the panning-program, was installed on the jumping hill. White and black tennis balls served as reference markers. They were mounted on thin steel wires in a way that the jumper was always surrounded by them in the investigated area. The reference markers and the positions of the cameras were surveyed geodetically.

The last part of the approach and the take-off were analyzed. The body landmarks of interest were digitized and afterwards smoothed by means of a Butterworth filter. The centers of gravity were determined by the segmental mass model of Clauser et al. [2].

2.1.2 Measurement of the ground reaction forces

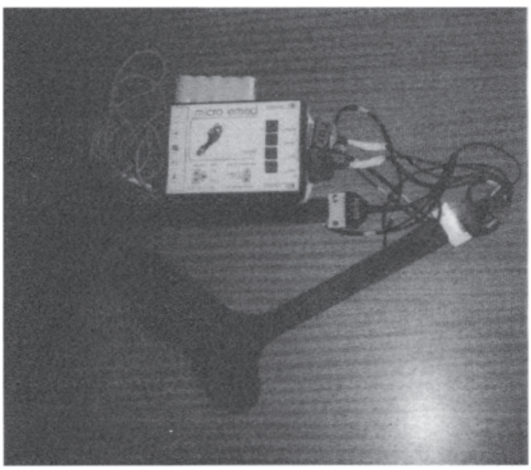

Fig. 1. Mikro-Emed System.

The reaction forces between foot and boot as well as the pressure distribution were determined using the Mikro-Emed-System. This system consists of two Emed-insoles (85 capacitive sensors each, 40 Hz) with a modified and strengthened outer material and a control and storage unit including a battery (Fig. 1). Emed data collection was initiated by remote control and synchronized with the video system. These measurements were used to calculate the overall force and the point of application of force. Since only small forces are transferred to the rim of the boot in the analyzed phases, the point of application of force can be determined quite exactly. Because of the specific measurement technique the Emed-system shows a systematical error of about 5 % below the nominal value [9].

2.2 Inverse dynamic analysis

2.2.1 Model of the ski-jumper.

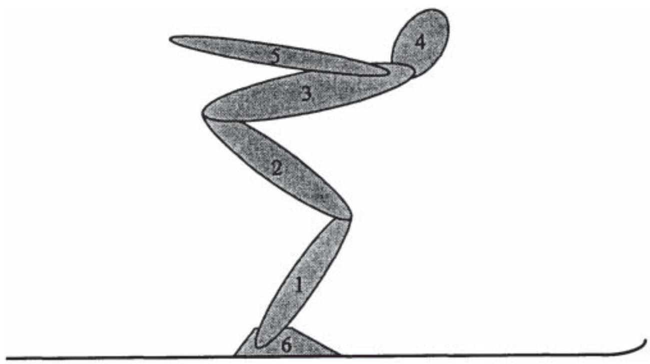

Fig. 2. Model of the ski-jumper.

The ski-jumper is modelled as a planar multibody system consisting of 6 segments (Fig. 2). Segment 1 includes the left and right shank, segment 2 the left and right thigh, segment 3 and 4 represent the trunk and the head. The left and right forearm and upper arm are combined to segment 5 and, finally, segment 6 consists of the left and right ski and ski boot. A global coordinate system is used where x and y denote the horizontal and vertical axis. To define the model completeley, the following data are necessary: mass m_i and polar moment of inertia I_i of the segments as well as their lenght l_i. and the position of the center of gravity s_i (see Fig. 3). Here, we give just the mass m_i of the segments 1 to 5, since the other data are not explicitly needed for the computation of the reaction force in the ankle in equation (13). The data were obtained by the model of Clauser et al. [2]: m_1=8.71, m_2=14.16, m_3=26.26, m_4=4.11, m_5=7.26. Segment 6 is not needed in (13). Thus, we do not give details on it, like on the joint between ski-jumper and ground in section 2.2.4.

2.2.2 Data smoothing

For an inverse dynamic analysis second derivatives of the Cartesian coordinates of the centers of gravity and the orientations of the body segments are needed. We show at an illustrative example that data smoothing is essential. We assume that the x-coordinate of a resting point was determined from three consecutive pairs of video frames. Like in each measurement the results of the video analysis are erroneous, too. We assume that one obtained the result x_1=1 cm, x_2=-1 cm, and x_3=1 and instead of the correct values x_i=0. The acceleration is given by $a=(x_1-2x_2+x_3)/\Delta t^2$ where $1/\Delta t$ denotes the frame rate. Inserting 50 Hz yields $a=(0.01+0.02+0.01)\times 50^2=$ 100 m/s^2. This huge error in the acceleration grows quadratically with the frame rate. Thus, the importance of smoothing is obvious.

The kinematic data were first smoothed by means of a Butterworth filter (3 Hz). Then, the filtered data were additionally approximated by smoothing cubic splines with help of the MATLAB routine csaps. In this routine one has to provide a smoothing parameter $p \in [0,1]$. A choice p=0 corresponds to a least-squares straight line fit through the data, p=1 to interpolation by natural cubic splines. Although approximation by cubic splines is better than a least-squares fit by polynomials of any degree one should mention a large disadvantage of the cubic splines: at the interval ends the second derivatives are zero—and consequently also the accelerations.

As an example we show how the orientation α_2 of the thighs was computed from the filtered kinematic data of the hip and knee joint. The thighs are body segment 2. For simplicity, we omit this index for Cartesian coordinates in this paragraph. Let (x_{hj},y_{hj}) and (x_{kj},y_{kj}) be the position of the hip and knee joint at time $t=t_j$. The indices k, h refer to the hip and knee joint, respectively, and j to the time. We denote the vector between the knee and hip joint by $(X_j,Y_j)=(x_{hj}-x_{kj},\ y_{hj}-y_{kj})$. The angle α_{2j} between the x-axis and the vector (X_j,Y_j) can be computed by the formula α_{2j}=atan2 (Y_j, X_j). The function atan2 denotes the four quadrant inverse tangent. It holds $-\pi<\alpha_{2j} =\pi$. The times when the frames were taken are denoted by t_j. The index j ranges from 1 to 29, the total number of frames. It holds $t_j=(j-1)\ \Delta t-t_0$, where Δt is given by theframe rate and t_0 is chosen such that the ski-jumper reachesthe edge of the jump at t=0. Then, the points (t_j, α_{2j}) were approximated by a smoothing cubic spline with help of the MATLAB routine csaps using the smoothing parameter p=0.9999. The resulting spline function is called α_2 (t). Angular velocity and acceleration are piecewise quadratic or linear functions which were obtained by analytical differentiation of the cubic splinefunction.

2.2.3 Constrained equation of motion

There are many different multibody system formalisms to derive the equations of motion. Classically, the state of a multibody system is described by a minimal set of coordinates *(state space form)*. The equations of motion are a system of ordinary differential equations which can be established e.g. by the Lagrange formalism.

Following Haug [4] the equations of motion can be set up in a much simpler form, when the so-called *descriptor form* is used. Here, the state of a multibody system is defined by a possibly much larger set of dependent coordinates. The coordinates are no longer free to vary arbitrarily, they satisfy constraint equations. In the planar case, the state of a free rigid body can be uniquely described by three variables, the position of a certain point and the orientation of the body.

First, we assume that the body segment i is dissected. To describe its state planar Cartesian generalized $\mathbf{y}_i = (x_i, y_i, \alpha_i)^T$ coordinates are used. Bold letters denote a vector or a matrix and the superscript ^{T} the transpose of a vector or a matrix. Thus, $\mathbf{y}_i$ is a column vector. The components x_i, y_i denote the Cartesian coordinates of the center of gravity and a_i the angle of rotation with respect to the horizontal axis. The equations of motion are given by

$$m_i \ddot{x}_i = f_{xi}, \quad m_i \ddot{y}_i = f_{yi}, \quad I_i \ddot{\alpha}_i = f_{\alpha i} \tag{1}$$

where m_i denotes the mass, I_i the polar moment of inertia with respect to the center of gravity, f_{xi} and f_{yi} the applied forces in x- and y-direction and f_{ai} the applied moment. The vector $\mathbf{f}_i=(f_{xi}, f_{yi}, f_{ai})^T$ is called generalized force.

When the segment i is not free but connected by joints to other segments or to the track of the in-run, additionally constraint or reaction forces occur. For our model of a ski-jumper, the equations of motion are given by

$$m_i \ddot{x}_i = f_{xi} + r_{xi}, \quad m_i \ddot{y}_i = f_{yi} + r_{yi}, \quad I_i \ddot{\alpha}_i = f_{\alpha i} + r_{\alpha i}, \quad i=1, ..., 6 \tag{2}$$

where the vectors $\mathbf{r}_i=(r_{xi}, f_{yi}, r_{ai})^T$ denote the generalized reaction forces. The components r_{ai} represent moments with respect to the centers of gravity (x_i,y_i). To avoid indices, we introduce the vectors

$$\mathbf{y} = (\mathbf{y}_1^T, \ldots, \mathbf{y}_6^T)^T, \ \mathbf{f} = (\mathbf{f}_1^T, \ldots, \mathbf{f}_6^T)^T, \ \mathbf{r} = (\mathbf{r}_1^T, \ldots, \mathbf{r}_6^T)^T$$

and the mass matrix **M**, a diagonal matrix with the entries

$$\mathbf{M} = \operatorname{diag}(m_1, m_1, I_1, \ldots, m_6, m_6, I_6).$$

With this notation, the differential equations (2) can be written in the form

$$\mathbf{M}\ddot{\mathbf{y}} = \mathbf{f} + \mathbf{r} \tag{3}$$

Further, we assume that the constraints can be expressed as a system of algebraic equations

$$\mathbf{g}(\mathbf{y}, \mathbf{t}) = \mathbf{0} \tag{4}$$

between the coordinates **y**. Such constraints are called holonomic. Equations (3) and (4) are called *constrained equations of motion.* Together, both systems of equations are a system of *differential-algebraic equations.* Equation (3) would be a system of ordinary differential equations if the reaction forces r were known functions of the time t, the Cartesian generalized coordinates **y** and the generalized velocities **v**. However, the reaction forces are not known in general. They have to be computed with help of the constraints (4). Using D'Alembert's principle one can show the relation

$$\mathbf{r} = -\mathbf{G}^T\lambda \tag{5}$$

where $\mathbf{G} = \partial \mathbf{g}/\partial \mathbf{y}$ denotes the Jacobian matrix of **g** and λ the vector of Lagrange multipliers. The vectors **g** and λ have the same length. The system of differential-algebraic equations (3) and (4) can be solved as follows: differentiating the constraints (4) twice with respect to time yields the acceleration constraints

$$\mathbf{G}\ddot{\mathbf{y}} = \gamma := -\partial^2 \mathbf{g}/\partial^2 \mathbf{y}(\dot{\mathbf{y}}, \dot{\mathbf{y}}) - 2\partial^2 \mathbf{g}/\partial \mathbf{y}\,\partial \mathbf{t}\,\dot{\mathbf{y}} - \partial^2 \mathbf{g}/\partial^2 \mathbf{t} \tag{6}$$

Note, that γ does not contain second derivatives of **y**. By inserting (5) into (3) and replacing (4) by (6), the differential-algebraic equations (3), (4) can be written as

$$\begin{bmatrix} \mathbf{M} & \mathbf{G}^T \\ \mathbf{G} & \mathbf{0} \end{bmatrix} \begin{pmatrix} \ddot{\mathbf{y}} \\ \lambda \end{pmatrix} = \begin{pmatrix} \mathbf{f} \\ \gamma \end{pmatrix} \tag{7}$$

If the mass matrix **M** is positive definite and if the constraints (4) are independent the linear system (7) has a unique solution for the accelerations and Lagrange multipliers. In the following, the constraints are briefly discussed although they are not needed explicitly.

2.2.4 Kinematic constraints

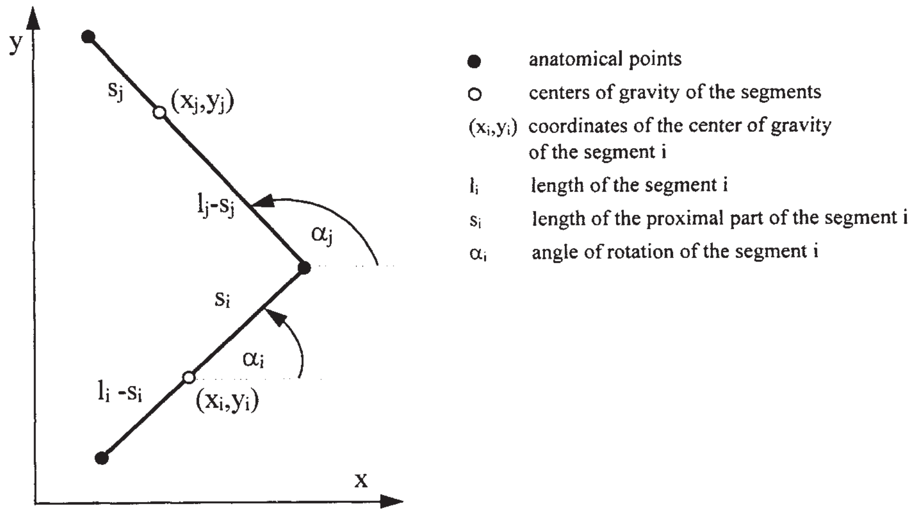

Fig. 3. Model of a revolute joint.

We assume that the body segments are connected by five revolute joints in ankle, knee, hip, shoulder, and neck. If segment i is connected by a revolute joint with segment j, two kinematic constraints hold (see Fig. 3):

$$\begin{aligned} x_i+s_i \cos(\alpha_i) &= x_j - (l_j - s_j)\cos(\alpha_j), \\ y_i+s_i \sin(\alpha_i) &= y_j - (l_j - s_j)\sin(\alpha_j) \end{aligned} \tag{8}$$

Here, l_i denotes the length of segment i (more precisely, the distance between the distal and the proximal joint), s_i the distance of the center of gravity to the proximal joint, and l_i-s_i its distance to the distal joint.

Since there are five revolute joints in our model, we have 10 kinematic constraints of this type. The track of the in-run consists of ceramics. From the construction map the height h of the track is a given function h(x). Thus, an additional kinematic constraint is given by the fact, that the normal distance between a marked point (x_f,y_f) at the ski boot to the track is constant. Finally, the orientation of the skis is tangential to the slope which gives the last kinematic constraint.

$$\tan(\alpha_6) = h'(x) \tag{9}$$

Thus, there are 12 time-independent kinematic constraints.

2.2.5 Muscle forces

Before we continue to define driving constraints, the role of muscle forces should be discussed. Muscle forces create those driving moments in the body joints which are necessary to generate the observed motion (i.e. position and orientation of the segments). Thus, muscle forces could be modelled as rotational actuators which control the relative angles between the body segments. However, we do not know the muscle forces nor the moments that muscles produce. Since we know the time history of the orientation of the segments, we add to the kinematic constraints time-dependent absolute driving constraints of the type (10). Then, the moments produced by the muscles are generalized reaction forces. One can compute from the constraints those moments which actuators in the body joints must produce to generate the observed motion. Since a certain moment might be generated by different muscle activities the muscle forces cannot be uniquely determined from the moments unless a muscle model is defined.

2.2.6 Driving constraints

For an inverse dynamic analysis, the number of independent constraints must be equal to the number of differential equations in (2). We have imposed already 12 kinematic constraints. Thus, one still has to impose 6 driving constraints. For the segments 1 to 5 the orientations α_i are prescribed as functions of the time:

$$\alpha_i = \alpha_i(t), \ i = 1, \dots, 5. \tag{10}$$

The last driving condition is given by prescribing the x-coordinate of a marked point (x_f, y_f) at the ski-boot as a function of time:

$$x_f = x_f(t). \tag{11}$$

The 12 kinematic and the 6 driving constraints form the algebraic constraint equation (5).

2.2.7 Computation of reaction forces

To compute the reaction forces, one could differentiate the algebraic constraints twice and compute the accelerations. However, we compute the accelerations directly by analytical differentiation of the smoothing spline approximations. We insert the accelerations into equation (3). As applied forces we consider only the gravity.

$$\mathbf{f}_i = (0, -m_i g, 0)^T, \; i = 1, \ldots, 6 \tag{12}$$

The reaction forces r are computed from equation (3) by subtracting f. The reaction force acting at the ankle is given by

$$\mathbf{R} = \sum_{i=1}^{5} (r_{xi}, r_{y_i}) \tag{13}$$

Note, that the sum ranges over all segments except segment 6. For a comparison with the measured dynamic data only the component of the reaction force normal to the in-run **R·n** is of interest. Here,. denotes the scalar product and **n** the unit vector normal to the slope and directed upwards. Drag and friction between track and ski act tangentially to the in-run. We do not consider these forces, since we do not know how to distribute them to the segments. Further, these forces do not necessarily act on the centers of gravity of the segments and one has a contribution to the applied moments, too. Applied forces in tangential direction do not contribute to the normal component of the reaction forces. Thus, the normal component does not depend on drag and friction. The lift, however, is in normal direction. It reduces the normal component by its amount, independent on the distribution to the segments. It should not be neglected. According to Baumann [1] its contribution lies between 40 N during the in-run and 80 N during the take-off. Müller [6] performed experiments in a wind tunnel with ski-jumpers in different positions. He confirms the value of 40 N during in-run. During take-off, however, he observed considerably lower values, too. Here, the lift strongly depends on the orientation of the upper body.

3 Results

First, the performance of the investigated jump is described. To this aim we have plotted the jumping platform and stick figures of the ski-jumper in the upper part of Fig. 4. A coordinate system is used where the x-axis is horizontal and the y-axis vertical. The origin is the edge of the jumping platform. On the abscissa the distance to the end of the platform is given. The x-coordinates are positive in direction of the motion, thus the distances have a negative sign as long as the ski-jumper is on the track. The ordinate axis shows the height in meters. To avoid overlapping every second stick figure was plotted. The time difference between two stick figures is 0.04 s. The computed ground reaction force is those component of the reaction force in the ankle (see Eq. 13) which is normal to the track of the in-run. In the lower part of Fig. 4, the computed ground reaction force is plotted in Newtons. The same abscissa was used as in the upper part to be able to compare the results. On the left part of the platform, the in-run is a circular arc with a radius of 97 m. This arc ends at x=-6.48 m, afterwards the in-run is a straight line with an inclination of 11 degrees. The investigated jump is a very good jump of an elite ski-jumper. The body mass of the ski-jumper was 60.5 kg without equipment. The take-off movement of the ski-jumper starts approximately at x=-7 m. The maximum of the ground reaction force is obtained for -4 m. The upper body is rather upright which causes a relatively large air resistance. Nevertheless, the distance of the jump was very long. The arms are directed to the back and upwards, a characteristic feature of the investigated ski-jumper.

The main interest of the paper is a comparison of the computed and measured ground reaction forces. Thus, we have plotted these forces as functions of time in Fig. 5. The time is given in seconds, t=0 corresponds to that time where the ankles of the ski-jumper reach the edge of the platform. The solid line is the computed ground reaction force. The measured values of the ground reaction force are marked by +-signs. These values were approximated by smoothing cubic splines using the MATLAB-routine csaps [5] with a smoothing parameter p=0.99999. The corresponding spline function was plotted as dashed line. Both curves show qualitatively the same shape, the computed forces are up to 10 % higher than the measured ones.

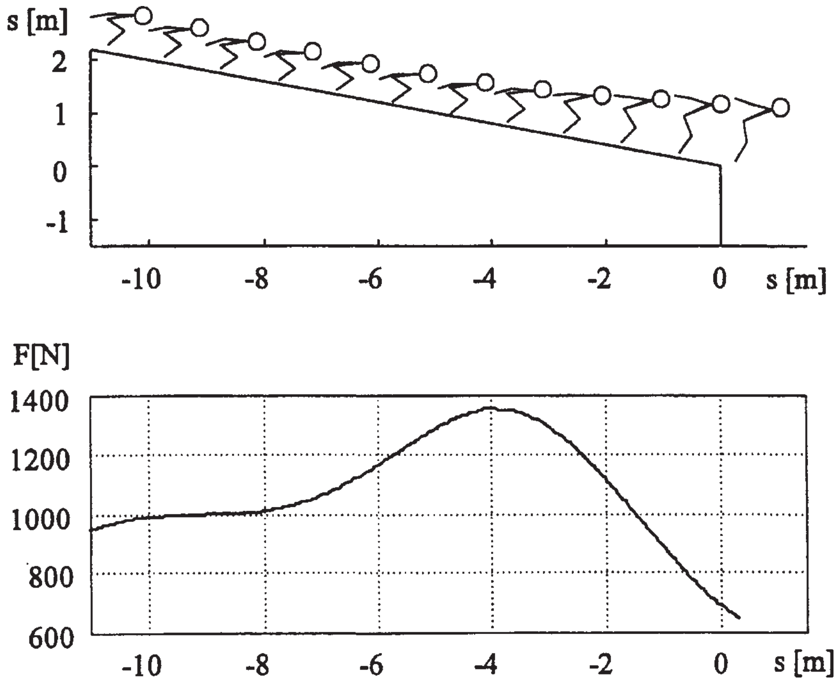

Fig. 4. Stick figure and computed ground reaction force.

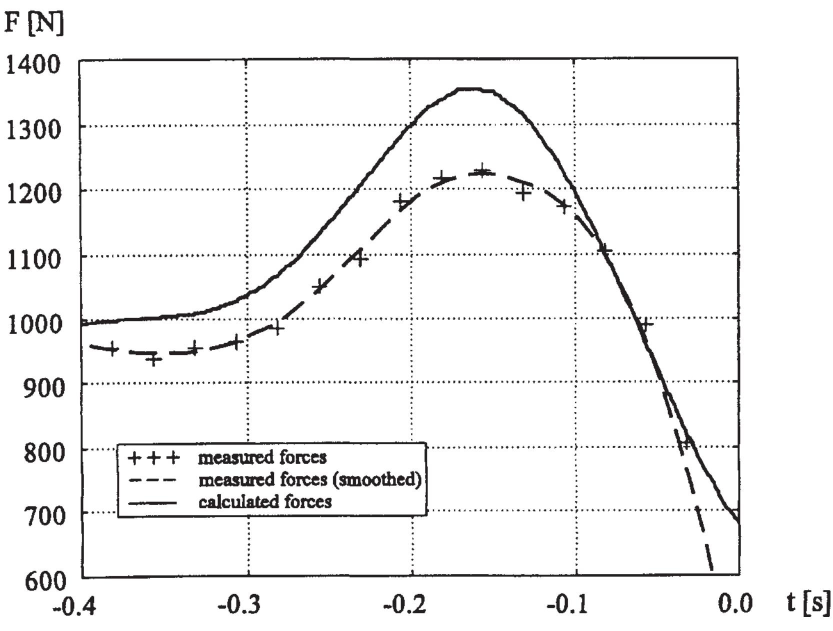

Fig. 5. Computed and measured ground reaction forces.

4 Discussion

Although the measured and computed ground reaction forces (see Fig. 5) correspond surprisingly good one realizes immediately that the largest deviations occur during the take-off movement. Therefore, we first dicuss the accuracy of the ground reaction forces before the take-off movement starts. The computed ground reaction force is approximately 1000 N for x-values between -10 m and -8 m. In this part, the in-run is a circular arc with a radius of 97 m. The ski-jumper keeps his position and can be approximated as a mass point in his centre of gravity. The mass of the ski-jumper is 60.5 kg without equipment. Subtracting the height of his centre of gravity that mass point moves on a circle with a radius r=96.3 m. For a speed v=25.4 m/s the centrifugal force is given by mv^2/r=405 N. Since the inclination of the track is 12–13°, the normal component of the weight is approximately 580 N. Adding both forces one obtains 985 N. This corresponds well with the value of 1000 N computed by inverse dynamics. We cannot present values for the computed ground reaction force for times smaller than t= -0.4 s since the kinematic data have been approximated by smoothing cubic splines. As a consequence the accelerations are zero at the begin of the investigated time interval which corresponds to x=-13.5 m approximately. At t=-0.4 s there is already a small drop caused by this effect. Further, it should be noted that we have neglected the lift, which is 40 N during the in-run according to Baumann [1] and Müller [6]. The lift is directed normal to the motion of the ski-jumper and, consequently, about normal to the track, too. Thus, the lift has to be subtracted from the computed ground reaction force. The region of -10 to -8 m corresponds to times between -0.39 to -0.32 seconds. Here, the measured ground reaction forces are 5 % smaller than the computed forces. This difference could solely be explained by the measuring accuracy of the EMED insoles. Since the sensors of EMED insoles do not indicate pressures below a threshold of 2 N/cm^2 the measured results are systematically too small. The measuring error was determined by laboratory experiments using a Kistler force plate. In our case, the results obtained by EMED insoles can be too small up to approximately 5% of the maximal value of the measured forces. Since the main contribution to the difference between measured and computed ground reaction forces is given by the lift, one could speculate that the measuring errors are noticeably smaller than 5%. There is slight drop in the measured forces for t=-.35 s. The reason is probably just an accidentally low value for the second depicted measured ground reaction force as can be seen from Fig. 5. This low value might be just noise. However, it could be caused by a small unweighting movement of the ski-jumper before the take-off movement or by the fact that the transition of the circular arc to a straight line might not be abrupt which could lead to a smaller curvature near to the transition region.

Next, the take-off movement is investigated. It starts at x=-7 m approximately. The circular arc of the in-run ends at x=-6.48 m. At this position one could expect a sudden decrease of the ground reaction force since the centrifugal force stops abruptly. However, the centrifugal force is compensated by muscle forces. Especially at the begin of the take-off movement the muscle forces will probably grow continuously. Therefore, such a decrease cannot be observed in the computed nor in the measured curves. The ground reaction force reaches its maximal value at x=-4 m. This value corresponds to more than twice the body weight. Regarding the joint angles of the corresponding stick figure in Fig. 4 it is plausible that the muscles generate the maximum moment at this position.

The agreement between measured and computed ground reaction forces is surprisingly good during the take-off movement, too. There are several reasons contributing to the larger differences:

1. In a multibody system the segments are assumed to be rigid. The actual body conditions cause a damping effect. The forces computed by the rigid body assumption are usually higher than the actual forces. These effects are negligible during the in-run when the ski-jumper does not change his position.
2. The lift was neglected. Although the lift during the take-off movement might even be smaller than during the tucked position at the in-run one might expect values up to 80 N for the lift if the position of the upper body is upright (preliminary experiments of Müller [6] in a wind tunnel).
3. As before, experimental measurements with EMED insoles lead to values wich are approximately 5% to low.

5 Conclusions

It is well known that in laboratory experiments the kinematic data obtained by video analysis are sufficiently accurate for inverse dynamics. Our results show that this can also be true in the case of a large field of view like in the present investigation of ski-jumping or in Alpine skiing (see Nachbauer et al. [7]) where the errors in the coordinates are larger by one order of magnitude at least. For a ski-jumper an inverse dynamic analysis was performed during the last part of the in-run and the take-off movement. The ground reaction force was determined and compared with experimental results obtained by EMED insoles. The agreement between both techniques is surprisingly good (see Fig. 5). The difference could be explained by neglecting lift and damping and by a systematical error of EMED insoles. The selected movement was nearly ideal for performing an inverse dynamic analysis. The calibration points could be placed near to the path of the ski-jumper. Hence, it was possible to attain two goals simultaneously, a large image of the ski-jumper and at least three calibration points on each frame. Otherwise, the errors in the kinematic data would be larger. It was demonstrated, that data smoothing is crucial. The film rate of 50 Hertz was sufficently high to resolve the relatively slow motion of the ski-jumper with respect to his center of gravity. One can expect that the results remain valid under more difficult conditions (faster movements, smaller images of the test person,...) if the film rate is sufficiently high.

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7

EFFECTS OF 50 KM RACING ON SKI SKATING KINEMATICS IN THE FALUN WORLD CHAMPIONSHIPS IN 1993

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Keywords: cross-country skiing, ski skating, kinematics, motion analysis.

1 Introduction

Cross-country skiing, and especially its skating techniques, have received some attention in biomechanical research during the past few years. In some studies (1) (2) (3) the effects of race or cycle velocity, the steepness of an uphill, differences between the sexes, between successful and less successful skiers, or the interrelationships between kinematic and temporal parameters of skating have been analyzed. In some studies, e.g. (1) (2) (3), researchers have attempted to analyze kinematic variables during Olympic and World Cup competitions in order to identify the characteristics common to successive competitors. However, as stated by Gregory et al (3) "researchers and coaches have not presented information that identifies kinematic differences between more and less accomplished skiers." This may be because there are a number of parameters, such as equipment (skis, bindings, poles, waxing), tracks, weather conditions, and unknown physiological variables such as fatigue, etc., which are very probably connected with the biomechanics of skiing, but which are difficult to control. As far as the authors are aware, the effects of a long race (fatigue) on skating technique has not been widely reported.

The purpose of the present study was to evaluate the effects of a 50 km race on the skiing kinematics of top level international skiers, by comparing biomechanical parameters determined after 12.4, 29.1 and 45.8 km of skiing. By recording three different times for each skier on the same uphill section, variation due to the track was minimized.

2 Methods

Data collection was performed on February 28, 1993 during the men's 50 km freestyle cross-country competition at the Falun World Championships, where the race consisted of three laps of 16.7 km. At the beginning of the race the air temperature was -1.7°C and snow temperature -3.6°C. The sun was shining. The track was rather hard. The video shooting site was located on the upper quarter of an 800 m long uphill. Split times were determined for each lap and the uphill by the organizers, and gliding times for a 800 m distance were measured by the Finnish service team using photocells (Tr Testi, Finland). The inclination at the video shooting site was 8° and the skiers were using the V1-skating technique. V1 skating involves a double poling thrust (both poles simultaneously) with a skating motion of one ski. When skating on the opposite ski, the arms return forward in preparation for the next double-poling motion, and only the skating leg provides propulsive force. The skier poles on the "strong side", and recovers on the "weak-side". In the middle of a 6 m long videoshooting section of the track, a 4.7 m long and 2.9 m wide area was calibrated using six vertical (2 m) sticks, with a reflecting ball fixed at both ends of each stick. Tachymeter (Nikon DTM-5) measurements and a special computer program were used for calculations of the 3D world co-ordinates of the calibration markers, to a level of accuracy of 5 mm. Two camcorders (25 Hz) were located 25 m in front (in the skiing direction) of the calibrated volume, at 68° to each other on both sides of the track (Fig. 1).

All the skiers were videotaped for the three laps. Of them, Torgny Mogren (TM, Sweden, the winner of the race), Björn Dählie (BD, Norway, 3rd), Johann Muhlegg (JM, Germany, 6th), Maurilio de Zolt (MZ, Italy, 12th) and Jukka Hartonen (JH, Finland, 14th) were selected for further motion analysis that was performed using an Ariel Performance Analysis System (version 6.91). Muhlegg was analyzed only for the first and second lap, because during the third lap he was partly hidden by an other skier at the filming site. One cycle was digitized (25 Hz), starting four frames before the strong-side pole plant, and ending four frames after the following strong-side pole plant. A 20-point model, including the poles, was selected for the motion analysis. The direct Linear Transformation and cubic spline smoothing (0.7) algorithms were applied to the data of the two digitized views. Temporal, displacement, velocity and movement direction variables were calculated for different phases of a cycle. Figures 2 and 3 show, as examples, how vertical displacement and velocity vector angle for the body's center of mass (CM) were determined.

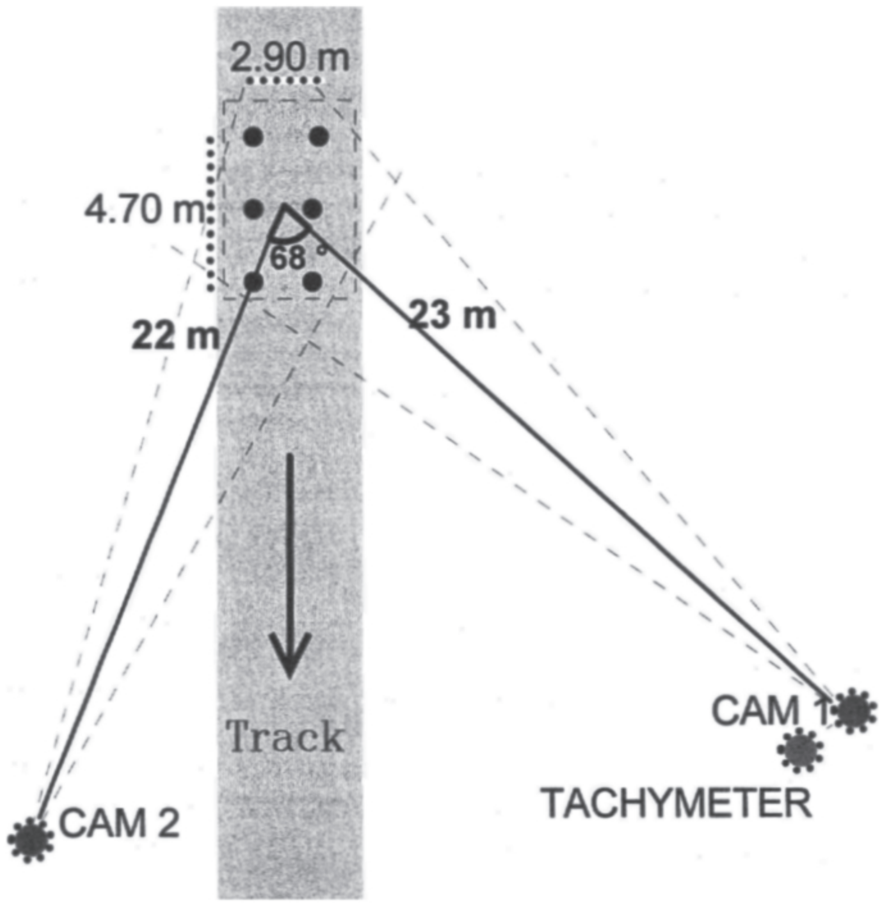

Fig. 1. The filming site (the black dots describe the locations of the calibration sticks), the two cameras (Cam 1 and Cam 2), and the tachymeter. The arrow describes the skiing direction and the gray area the track.

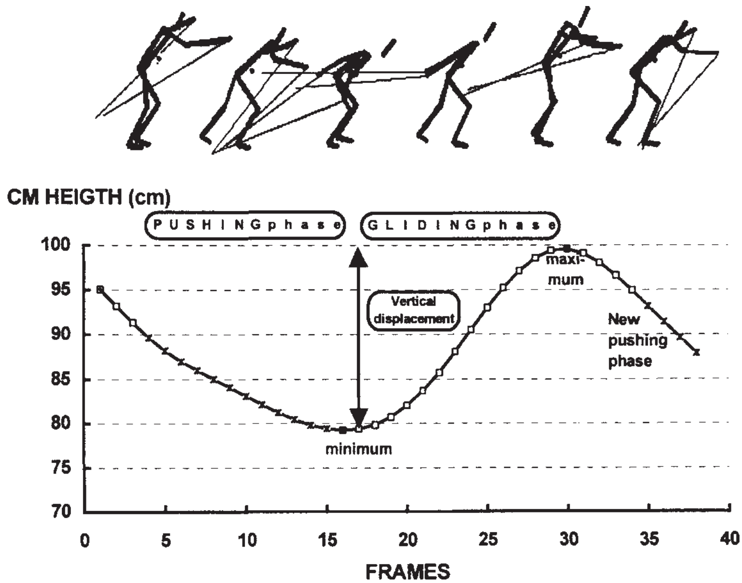

Fig. 2. Height of the body's CM at different phases of a cycle.

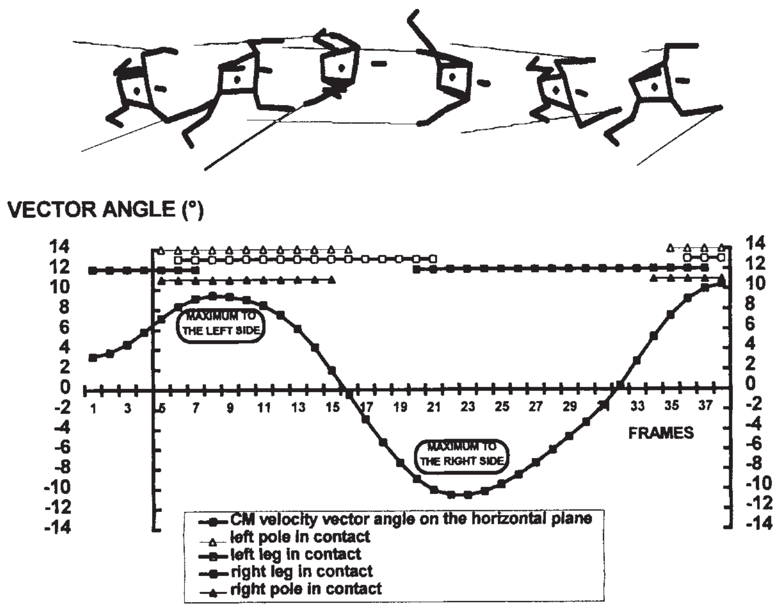

Fig. 3. Velocity vector angle to the skiing direction on the horizontal plane during a cycle. Ski and pole contacts are shown on the top of the graph and respective stick figures above the graph.

3 Results

The mean lap times of the skiers increased from the first to the second (t= 6.98, p<.01), and from the second to the third (t=4.22, p<.01) lap, by 4.1% and 4.4%, respectively (Fig. 4). The increases were smaller for the winner (2.0 % and 1.6 %, respectively) than for the other skiers. In the uphill, on which the videorecording took place, the mean split time (Fig. 5) increased from the first to the third lap by 7.2% for the winner, and 10.9–18.4% for the other skiers (t=6.89, p<.01). The respective changes in the mean cycle velocity of the body's CM (Fig. 6) for the analyzed cycle were 11.9% and 14.2–18.0% (t=15.4, p<.001). Figure 7 summarizes the changes in the downhill gliding times measured for the two first laps. On average, the gliding times increased by 3.2% (t=5.10, p<.01).

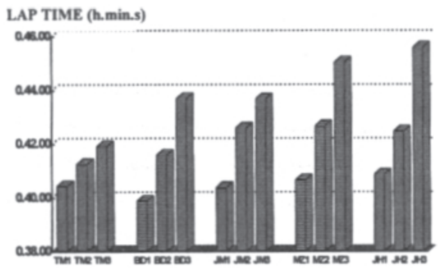

Fig. 4. Lap times for the five skiers and three laps.

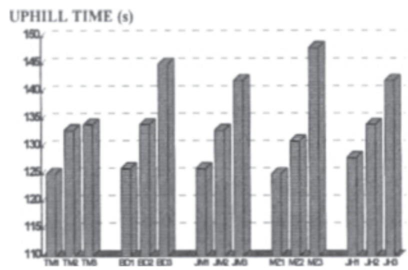

Fig. 5. Uphill split times for the five skiers and three laps.

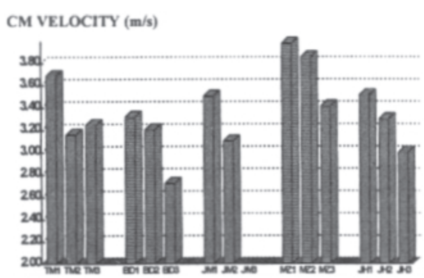

Fig. 6. The mean cycle velocity of the body's CM for the three laps.

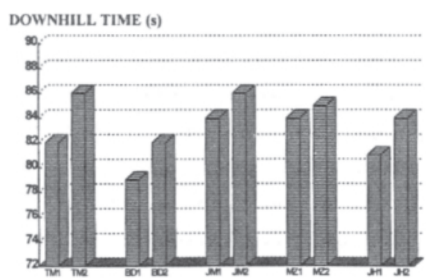

Fig. 7. Downhill gliding times for the two first laps.

The relationship between lap times and split times in the analyzed uphill is shown in Fig. 8, and between the uphill times and mean cycle velocities of the body's CM during the analyzed cycles in Fig. 9. Figure 10 depicts relative changes of the velocity of the body's CM during the analyzed cycle for the three laps. No systematic changes as a function of laps were found.

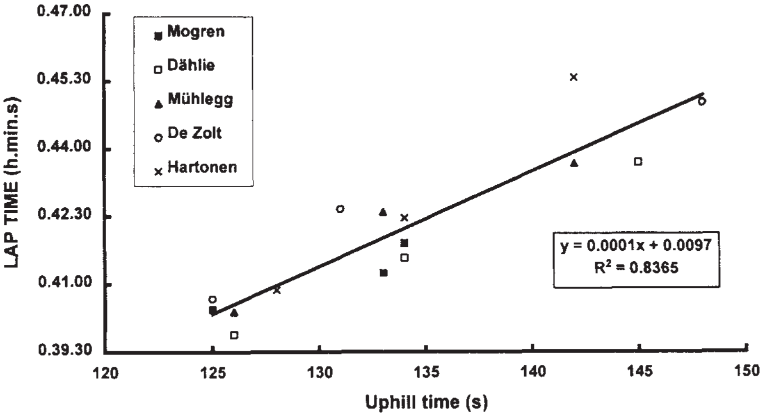

Fig. 8. Relationships between the uphill lap time and uphill split time.

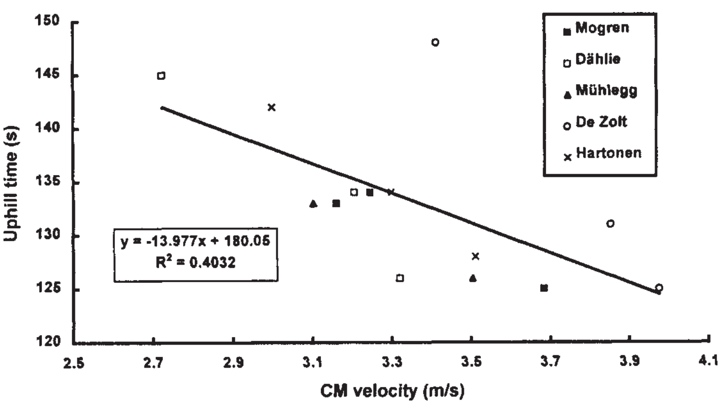

Fig. 9. Relationship between the uphill split time and mean cycle velocity of the body's CM.

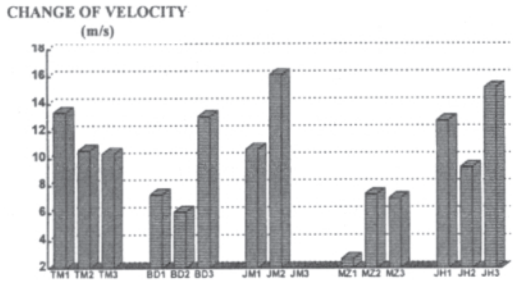

Fig. 10. Change (max—min) of the velocity of the body's CM during a cycle for the five skiers and three laps.

On average, cycle duration showed an increasing trend (t=2.00, p<0.1) of 5.8% (Fig. 11), and cycle length decreased (t=4.05, p<.05) by 9.2 % (Fig. 12) from the first to the third lap. The respective changes for the winner were 3.3% and 9.8%.

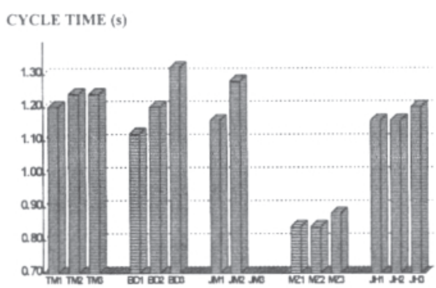

Fig. 11. Cycle times for the three laps.

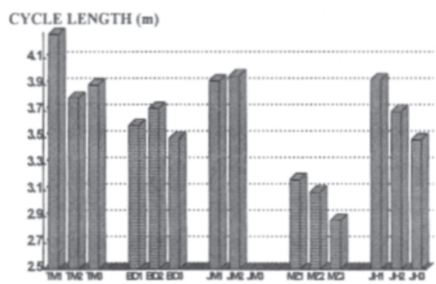

Fig. 12. Cycle length for the three laps.

Up and down movement of the body was described as vertical displacement of the height of the body's CM during a cycle (Fig. 13). There was no systematic change during the race. The angle of the CM velocity vector on the horizontal plane was selected to describe the side movement of a skier during a cycle. As shown in Fig. 14, the CM moved sideward at a greater range of angles (to the left+to the right, t=7.83, p<.01) during the third lap than it did during the first lap.

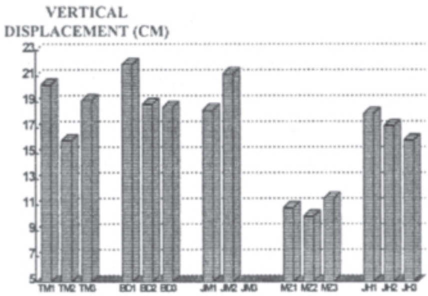

Fig. 13. CM vertical displacement during one cycle.

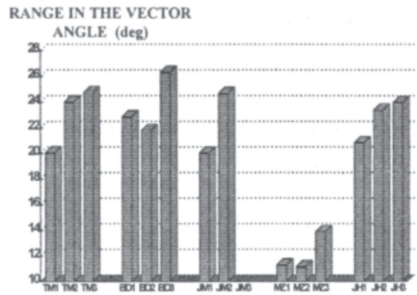

Fig.14. Range in the CM velocity vector angle on the horizontal plane.

4 Discussion

The high correlation coefficient between the lap time and uphill split time suggested that skiing time on an uphill predicted the lap time among top level skiers at the Falun World Championships rather well. On the other hand, the relationship found between the uphill split time and mean cycle velocity of the body's CM suggests that one cycle can be considered as a rough estimate of what is happening during uphill skating in general. The dependency between the uphill split time and CM velocity was rather high at individual skier level as well, as can be seen in Fig. 9.

Downhill gliding times increased from the first to the second lap, suggesting changes in the weather, in skies/waxing, and/or in the speeds of the skiers in the beginning of the downhill, prior to the measurement site of the track. Björn Dählie had the shortest gliding times during both laps while the gliding time of the winner, Mogren, for the second lap was the longest among the studied skiers. The similar trend between lap times and uphill times, but not between lap times and gliding times, suggests the importance of uphill skating for the final time and placing in the 50 km race at the Falun World Championships.

The effect of the 50 km skating was seen as an increase in the lap time, decrease in the mean cycle velocity of the CM, increase in cycle time and decrease in cycle length in uphill V1-skating. Contrary to expectations, vertical movements of the CM did not systematically increase during the skiing but sideward movements were performed at greater angles at the end of the race. This may indicate, that due to the length of the race and decrease in the skiing velocity, energy at the end of the competition tended to be wasted more in sideward movements than at the beginning of it.

The great inter-individual variations in the biomechanical parameters of ski skating as compared with the rather small, and in some cases, non-systematic changes during the competition, suggest that in further analysis and further studies more attention should be paid to explanation models based on individual, rather than group level data.

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8

MANAGEMENT OF THE SPORT TRAINING PROCESS WITH CROSS-COUNTRY SKI RUNNERS THROUGH MODERN APPARATUS METHODS AND MEANS

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Keywords: cross-country skiing, training device, tests.

The contemporary training process of highly qualified competitors is based on objective methods of prognosis of efficiency, and on quantitative determination of the training load, corresponding to the physical condition of the competitor at the moment, and towards the aim of the conditioning. The search for new and effective ways of increasing the functional possibilities of the competitor's organism during a minimal time span, i.e. for optimizing the training process, has led to programming the volume and intensity of the load in accordance with the reactions of the organism. Our team, which includes competitors, coaches and research workers, has also worked towards solving the problems mentioned above. Our work is the basis for the following presentation of some of the results we have obtained.

1 Introduction

The aim of our research was the development of a theoretically based and functioning system for an objective quantity management of the training process in cross-country ski runners. In that respect we created sound and functional specialized technical facilities for monitoring and quantitatively evaluating the training load used *in a complex training system device for cross-country ski running on an artificial track.*

On the basis of many experiments and serious research connected to the implementation of various methods and facilities, the following methods were developed: methods for evaluating and monitoring the physical loading in laboratory and natural conditions; methods for the laboratory determination of the effective zone at work for endurance; methods for hypoxical simulation of the training session of the cross-country ski runner, etc.

The different stages of our research work included 116 men and 54 women, all highly qualified cross-country ski competitors and biathlonists. The mathematically processed data was much larger than the data concerning the participants in the experiment.

2 Development of a complex training system

Our results were dependent on the facilities and methods we used, therefore, they must be briefly described. The complex training system combines optimal conditions for dynamic loading of the artificial tracks, and the potential to measure work done with ergometric devices. It is better than ‘well-known’ training systems because it allows the cross-country skier to ski with poles throughout the year. This develops the possibility for the adequate modelling of the ergometric loading, along the structure and locomotion of cross-country running in natural conditions.

In order to make our point, we would like to recall the selectivity (established by Zaziorski 1960) of the transition of training results. This is a relevant point for seasonal sports (like skiing), which incorporate a large scale of facilities in the training process. It is a well known fact that the more one masters a sport, the less one is able to transfer the results of the training process from one training device to another. In other words, the selectivity increases because of specific adaptation changes happening in the organism of the competitor.

We would also like to mention that recently, more and more authors (I. Holmer, P.O.Astrand, V.Borilkevitch, etc.) think that research into physical efficiency, including the biological parameters involved, has to be made under ergonomic loading, which is close to the physical exercise the coompetitor specializes in (the natural structure of the movements). Only then can these parameters most precisely reflect his/her true possibilities.

The training system for cross-country skiing on an artificial track consists of a transporter, with a potential to monitor velocity up to 8 m per second, and a changing slope, up to 20 degrees uphill and 10 degrees downhill. It consists of three segmented tracks. The main (middle) one, where the skiing takes place, is a profile plastic track. The two peripheral rubber- surfaced tracks enable the competitor to work with poles.

The mechanism of the device has tristor monitoring and enables a smooth change of velocity over a wide range. The hydraulic system helps angle the training device. A computer monitor supervises the program for the training, or for the functional tests, related to the velocity and the steepness of the slope, as well as the biological and the technical parameters. The device has facilities for recording and processing information on heart activity, a system for gas analysis, possibilities for biochemical research (e.g. the determining of the concentration of milk acid-lactate in the blood), hypoxical stimulation, tensometry, and a videosystem with a synchronized electronic measurement of the time on a video monitor.

With our device, the power of the work done is measured quickly and conveniently through direct measurement of the distance passed (S), and the slope of the track (a), and the possibility to measure the coefficient of friction (K_d) of the permanent quality parameters of the material, of which the artificial track and the surface of the skis are made (including the specific oil used for influencing the friction).

The close relationship between cross-country skiing along an artificial track and on snow was confirmed by the high correlation between the ergonometric results, from cross-country skiing on the specialized training system and results from competitions. For the different groups and teams, the coefficients of the range correlation move from 0.54 to 0.94, and in certain cases they even reach 1.0. The big differences between them are due mainly to the influence of the choice and oiling of skis upon cross-country skiing performance. The highest coefficients are measured in competitions and control trials with the same oiling of the skis.

In support of this we are going to use the results of research on ‘the transfer of the training results’, using training facilities with definite similarity, for instance, cross-country skiing on an artificial track and on roller-skates. After a two-week training camp on snow (Dagstain), the changes in achievements on an artificial track are positive, and on average rise 2.5% above the results of control testing just before the camp. At the same time, the influence of snow preparation on test roller-skates is negative. The registered achievements average 4.2% lower than those before the camp on snow. It’s obvious that here ‘transfer of the training results’ is inverted. This reveals the degree of similarity for the benefit of cross-country skiing on artificial track, but at the same time strongly proves its selectivity, even in conditions which are extremely close to the technique and the functional influence of the training facilities.

We would like to state that the ‘training device for cross-country skiing on an artificial track’, which happens to be the only one appropriate for work during the whole year, can be used not only as a specific training facility when there is no snow available, but also as a main device for acquiring integral evaluation, diagnostics, and objective control during the year-long or more preparation of the cross-country skier.

3 Determing of the specific efficiency

The overall physical efficiency is usually seen as the quantity of the mechanical work done (Karpman V.L.—1968). That's why the work to the limit in most cases is the measure for the level of efficiency (Hadjiev, N., Donchev, D., 1983).

In our case, the runner who uses the device along the above-mentioned standard methods (test 1, 2 etc.) does specific work with skis and poles, having engaged his/her whole muscular apparatus. That is why the volume of that work to the limit determines his/her *'specific efficiency'* as well. The possibility of working with quantitative parameters for the overall continuity of loading (t), achieved distance (S), work (A), and work per kilogram of body weight (A/kg), etc., presupposes as precise comparison, and an analytical evaluation of the degree of readiness, with a high correlation of results in cross-country skiing.

In order to stress the importance of this, we would like to emphasize that in skiing, the sports performance, which is an 'optimal integral criteria for sports efficiency' can be used only in a definite and very short period of time.

According to us, there is still a possibility for a compromise. This is the purpose of specific efficiency through the training device for cross-country skiing on an artificial track. An advantage is the close similarity of cross-country skiing on an artificial track to the structure of the main movement activities in cross-country skiing, its suitability throughout the whole year, and last, but not least, the possibility for quantitative evaluation, i.e. for registering a definite sports result in permanent, measurable, qualitative parameters.

Through various research and experiments, we determined a model for specific loading, applicable for a vast area of research on cross-country ski runners. The continual approbation, checking different sources, and research of foreign experience enabled us to focus our attention on 'ladder-like loading to the limit' with a track slope of 3 degrees. The step continued for three minutes with an initial velocity for women of 7 km/h, and for men of 8 km/h, increasing the velocity at each step by 1 km/h.

The testing supposes mainly two variants: Test 1, with a pause of 30 sec for biochemical probes, and Test 2, with no pause. The model gives linearity (Wkg=0,4168 V km/h) and a gradual increasing of the load (20–40 W in accordance to the weight), until the maximal specific efficiency for a relatively stable condition of the physiological functions for the different steps is reached.

Our initial orientation towards the standard methods of an artificial track presupposed the use of ladder-like loading up to the limit, with a pause of 30 s for Test 1, only in cases in which a blood test was needed. For determining the specific efficiency, we planned Test 2, or loading according to the same method, but without a pause. But the mathematical processing of the factual material, the differences in endurance and the inadequate reaction of the different competitors to both methods assured us of the necessity of using Test 1, because of its wider possibilities and higher informativeness. Contrary to all expectations, the integral criteria for both tests, the time (t) for reaching the limit, turned out to be of a higher correlation to Test 1 for prognosis of the result in cross-country skiing (=0.9115 for men and 0.9748 for women; and 0.8386 for men and 0.8896 for women for Test 2).

This is probably because the pause for blood testing changes the character of the loading. The pause itself enables recovery and the effect of this is comparable to the changes in a short downhill during cross-country skiing. Because of this, Test 1 is nearer to conditions typical for cross-country skiing.

In general, the average parameters for ergometric loading with Test 1 are higher than those with Test 2, with about 12% for men and 9% for women. But there are cases, mainly with competitors with lower results in cross-country skiing (about 20% of the whole number of competitors), in which the pause in loading with Test 1 lessens their adaptation possibilities. With them the difference in their performance between Test 1 and Test 2 is negligible. The obvious conclusion is that the precise determining of the specific efficiency requires a precise modeling of the movements not only according to their form, but also according the physiological essence of the specific loading.

The application of the facilities we used, which enable the monitoring of essential biological parameters, showed us additional possibilities for contemporary monitoring of the training process. One of them is the *laboratory assessment of the effective zone of efficiency and endurance for cross-country skiers.*

Many scholars (Hirsch 1977) define endurance as the optimal zone of intensity for the development of aerobic productive training load, in which the concentration of the lactate in the blood is about the limit of the anaerobic exchange (4 mmol/l).

Through the implementation of the described methods for specific ergometric loading of the training system (which allows adequate modelling close to cross-country skiing's natural environment), we followed changes in pulse rate and concentration of lactate in the blood at each step. The reactions of the heart-vessel system at different levels of the metabolical processes were made into graphics, from which, through extrapolation, we determined the individual critical pulse rate of each competitor while working for endurance, i.e. the pulse rate in the zone of aerobic-anaerobic transition ‘pano’ close to the anaerobic limit (lactate 4 mmol/l). The research was carried out four times, with 20 high quality cross-country skiers over a one-year time span.

On the basis of this pulse rate established in natural environmental conditions (cross-country skiing, roller cross), we adjusted the intensiveness of the training load for each competitor by means of incessant monitoring of the rate of heart contractions (telemetry or pulse tester). Blood probes for the concentration of the lactate created additional possibilities and conditions for corrections in the training process.

The research showed that when the training condition was good and there were no hampering factors (illness, acclimatization changes, etc.), the pulse with lactate 4 mmol/l is individual, and comparatively regular for each competitor, with average change of ± 5 beats per minute.

With these objective methods for quantitative evaluation of the specific ergometric efficiency, and for determining the work for endurance, we also made an experiment for economy in the training process through *hypoxical stimulation*. The limitations in time, and the danger of declining health of the competitor stimulated us to search for new methods for improving elite sports performance.

High-altitude training sessions, or training in decreased partial oxygen pressure is not a novelty. The effects have been proved and the positive results have been researched for more than thirty years. Nevertheless, there still are unused and undiscovered possibilities for increasing the efficiency of the training process.

In cross-country skiing, unlike many other sports, high-altitude training is not a question of individual choice, or the point of view of a coach or competitor. It is a compulsory condition, because most of the competitions and training sessions are held at comparatively high altitudes. Moreover, the wide use in contemporary training sessions of glaciers, when there is no snow available at 3000–3500 m above sea level, creates the problem of training a cross-country skier in hypoxical conditions. This type of training has not only an essential sports-pedagogical effect, but also an important economic relevance. We would like to note that in many cases, expensive summer snow training on glaciers does not live up to our expectations, because of the neglect or the non-existence of necessary preliminary training.

Lack of knowledge about the specific impact, laws, demands, and variability of the hypoxical training is one of the reasons for the limited development of new aspects in its use as a reserve for improving sport results.

If high-altitude training is comparatively well researched, the positive effect of combining -altitude training with training in normal conditions is less well known (Dellinger, 1981). One of our aims was to conduct experiments and research and disclose some of the applications of such a combined training. Our interest in this field involved different mechanisms for the generation of oxygen deficiency in normal conditions, when the human organism is physically loaded: increased consumption, difficulty in oxygen transportation with hypoxy of the media, and limited supply of oxygen from outside.

It was necessary to solve the problems of hypoxical stimulation in training conditions. The well known methods, which involve barocamera or gas mixtures with decreased content of oxygen, turned out to be unacceptable, so we turned towards the method of Melvin Henkin and Jordan Laby, based on the principle of using reduced air. The apparatus was constructed by 'Inspir Air Corporation', California.

Technical Description

It has the appearance of a small, convenient backpack weighing 1800 g. Its basic elements are:

1. Facial mask with calibrated opening
2. Tanks
3. Containers for the absorbator
4. Respiration tubes
5. Filter
6. Cooling mechanism
7. Absorbator—containing violet ethyl indicator; its color turns from white to violet when used up. While inhaling, because of the gas exchange in the lungs, part of the oxygen (approximately 21%) is taken away.

The exhaled air has already less oxygen in it (about 16%), but the carbon dioxide floats towards the tanks, and before reaching them passes through the containers of the special absorbator for the isolation (purification) of the carbon dioxide. With successive inhaling and exhaling, a combination of air from the natural environment and recycled air from the tank is made. The mixture simulates the conditions of a certain altitude, depending on the size of the opening in the facial mask. The important point is that this gas mixture adds the necessary altitude, i.e. if you are standing 600 m above sea level (which is the altitude of Sofia), and are using a 2300 m gauge, the simulated altitude is 2900 m.

If necessary, the combined effect in training can be achieved by taking off the mask, which will automatically normalize the conditions. This is a change, which cannot be achieved under natural conditions through any kind of facilities.

The research was carried out during the first basic mesocycle of the preconditioning period of the year. It lasted four weeks and covered all training facilities included in that period:

1. Running—all varieties
2. Roller-skates—both free and classical
3. Cross-country skiing on an artificial track
4. Cycling
5. Exercises with apparatus
6. Physical labour in the open air.

The hypoxical stimulation was carried out in 19 of 28 training days (68%) at average altitude 2740 m above sea level.

In order to follow the development of the effect of hypoxical stimulation we took four blood probes in the biochemistry lab. The probes showed the quantity of erethrocites and the percentage of hemoglobine at the beginning of the experiment, and at the end of the second, third and fourth weeks. In order to determine the dynamics of the specific ergometric efficiency, we carried out the accepted standard probes for cross-country skiing on artificial track, with readings of gas exchange and rate of heart contractions at the beginning and at the end of the experiment. During the experiment we used neither biological stimulators, nor any means for restoration.

We were mostly interested in the parameters which informed us about the extent of the physiological changes, resulting from the combined impact of simulated altitude training and the training under normal conditions.

The blood probes at the beginning and at the end of the experiment show a percentage growth in the contents of hemoglobine, i.e. of the oxygen capacity of the blood from 87 to 104%, accompanied by a strong quantitative increase of the erethrocytes which determine the breathing surface of the blood, from 4 440 000 to 4 500 000. Tangible changes, however, can be seen during the third week, when the hemoglobine reaches 100 % and the number of the erethrocytes reaches above 5 110 000. That is why we can determine the necessary time for positive changes in the blood and for the adaptational physiological processes.

The positive effect of the high altitude simulation led to a considerable bettering of the specific ergometric efficiency, which grew from 16 1/2 min at the beginning to 19 min at the end of the period.

The only parameter hampering the interpretation of the results is the irrelevant growth of the maximal oxygen consumption from 73,36 ml/min/ kg to 74,66 ml/min/kg.

The careful analysis of the movement of the blood tests along the ladder of the incessant ergometric loading to the limit shows the economy in the energy needed, which explains the reason for the increased efficiency at a nearly equal level of maximal oxygen consumption. Nevertheless, it is self-evident that additional research on the adaptation mechanisms in high altitude simulation, connected to the methods for its application, the degree of loading, the working altitudes used, their variation, etc. is necessary. The results achieved:

The possibility of simulating all altitudes, the combination of high-altitude training and training under normal conditions, the limited risk of injuries because of stress to the heart system, the shorter period of time and the decreased load on the muscles and bones of the human, all show the importance of the application of high-altitude simulation. Moreover, with rehabilitation, injuries and recovering procedures, its use in labs along with different training devices becomes a necessity.

4 Conclusions

The results of the research work led us to the following conclusions:

1. The system for managing the training process for cross-country skiers is highly effective, and when applied, leads to its improvement.
2. The objective basis for the use of the system comes form the functional, highly specialized apparatus facilities, through which highly informative methods for controlling the conditions and the quantity regulations of the impact of training upon the cross-country skiers are carried out.
3. As a principle, this methodological approach can successfully find application in the training process of competitors in all sports disciplines.

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9

A MATHEMATICAL METHOD FOR THE ANALYSIS OF TRAJECTORIES IN GIANT SLALOM

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1 Introduction

Several factors affect performance in alpine skiing. While the skier's anthropometry and physiology (heart dimensions, aerobic and anaerobic power, lower-limb power, body composition [1–2]), the biomechanic and kinematic factors (speed, friction, acceleration [3–4]), and the technicalenvironmental factors (wax, temperature, snow characteristics) have already been investigated, the skier's trajectories during an actual run have never been analyzed by quantitative testing. Analyses are most often performed in laboratory setting, where the testing conditions cannot perfectly reproduce the real conditions.

In giant slalom, the skier has to ski in a wavy course, with maxima and minima at each gate. The analysis of these trajectories cannot be performed with the conventional metric approach (linear distances, angles between each gate) because this approach does not allow to quantify the shape component of the trajectory. Indeed, each slalom run is characterized by a peculiar trajectory with a particular form that should be analyzed in its entirety. Form can be viewed as a combination of size and shape. Shape refers to the outline independent of its orientation, relation to reference planes, and dimension (or size) [5]. The conventional metric measurements usually elude the quantitative definition of shapes and of shape modifications [5–6]. Conversely, more sophisticated mathematical methods allow a quantitative analysis of shape and of its changes.

A wavy trajectory such as a giant-slalom run could be analyzed by a periodical function like the Fourier series. The Fourier series are a curve-fitting procedure used to compute a mathematical function which describes the outline, and which can be used to compare different outlines. Complex forms are thus decomposed into a series of cosine and sine functions of increasing frequency [7]. This method analyzes the global shape characteristics of a profile, and control for size differences, differing spatial orientations, and the dependency on reference planes. Size and shape components of each profile can thus be analyzed separately. Moreover, it is possible to measure the distance skied for each slalom run.

In this report, we have reconstructed the giant-slalom runs using Fourier analysis in order to compare the trajectories between skiers of different levels while skiing the same ski run under standardized conditions.

2 Materials and Methods

2.1 Sample and data collection

Data collection was performed on the ski runs of Aprica (SO, Italy) in mid-January 1995. A 5-gate giant-slalom ski run was prepared on a slope of 134.4 m in length and with a drop of 92 m in altitude (from 1373 m above to 1181m above sea level). Distance between the start and the first gate was about 23 m, and between each gate was about 25 m in length, and 4 m in width (Fig. 1). Three male skiers aged 30 years (one high-level amateur G.M., two semiprofessionals

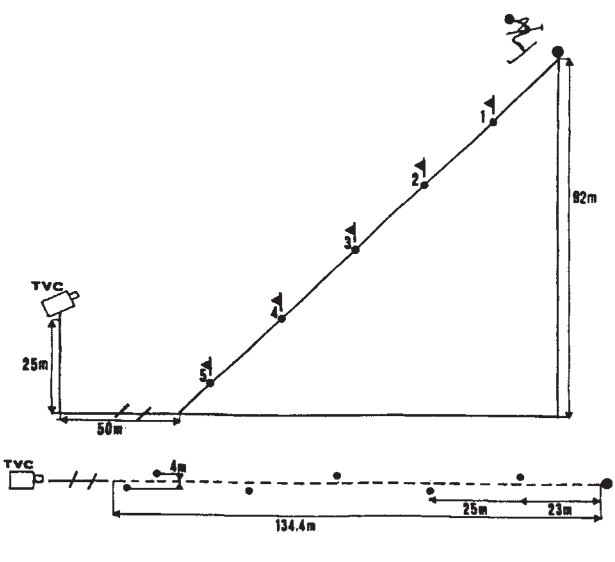

Fig. 1. Experimental setting, aerial and lateral views. Slalom run, start, gates, and position of the TV camera.

Table 1. Anthropometric characteristics, speed, distance skied (absolute value and percentage relative to the ski run) of the three skiers

Skier	Height (cm)	Weight (kg)	Speed (km/h)	Distance skied Absolute (m)	Percent (%)
G.M.	160	73	37.402	108.05	2.90
B.B.	175	70	42.348	107.28	2.17
C.V.	180	76	43.859	107.21	2.11

B.B., C.V.) participated in the experiment (Table 1). Each of them repeated the same giant slalom run three times; time for each run was measured using photocells, and the skier's speed calculated. The experimental protocol was previously illustrated to the skiers, and informed consent obtained from all of them. To avoid circadian modifications of performance [8–9], all runs were performed in the early afternoon on a cloudless day. The three skiers began the runs randomly.

A Sony CCD 800E TV camera operating at 25 Hz (25 frames per second) was positioned about 25 m above the ski run, at a distance of about 50 m from the end of the ski run, and each skier was filmed during the run. The successive positions of the skier during each run were digitized using a semi-automated instrument (LAFAL Videoanalyzer, CUBE srl, Milano, Italy) interfaced with a PC (IBM PS/VP 6382 466 DX 2/S, IBM, Portsmouth, UK), which allowed the selection of single frames and their notation for further analysis and control. The system has an electronic zoom that allows fine definition of all details.

Before the slalom runs, a calibration procedure was performed: the distances between the gates were accurately measured, and a first film briefly photographed their positions (calibration frames). Before all subsequent calculations, the calibration frames were analyzed. The gates' positions on the ski run were digitized, and an algorithm, developed for this purpose, used those positions together with their real (metric) distance for the correction of parallax and measurement calibration.

Every third frame was analyzed, and the skier position was calculated from the image of the feet: both left and right feet were digitized, and mean coordinates computed. This position should correspond to an approximate "centre of gravity" of the skier projected on the snow [10]. Digitization was performed by teams of two operators each. Each landmark was located by one operator and its position controlled by the second one.

For each skier and each run, the relevant data points (x, y coordinates) were obtained.

2.2 Fourier analysis

The coordinates of each skier were analyzed by Fourier analysis [6, 11], separately for each run. Analysis was restricted to the run between the five gates, for a total run of 105 m, corresponding to about 100 data points. The trajectory was flipped at 180° about the perpendicular to the mid-trajectory (midline between inter-gate width) to create a "mirror" image [6]. This imposed symmetry simplified the calculation of the Fourier equation (the sine component vanishes, and the equation contains the cosine component only). Data points were thus doubled. All the subsequent calculations were performed by a computer (Z-Station 466 Xn, Zenith Data System Co., St. Joseph, MI) programmed by one of the authors (V.F.F.).

Using the least square method, a Fourier analysis of the skier's trajectory was performed (1), with period τ=360=2.n original data points [11]. Series were truncated at the 15^{th} harmonic, because the higher degree coefficients were negligible.

$$y = \frac{a_0}{2} + \sum_{m=1}^{15} [a_m \cdot \cos \cdot (\theta \cdot m \cdot x)]$$

where m=harmonic (from 0 to 15)

a_m=cosine coefficient of m harmonic

$\theta=2\pi/\tau$ with τ=normalized outline length=2.n original data points.

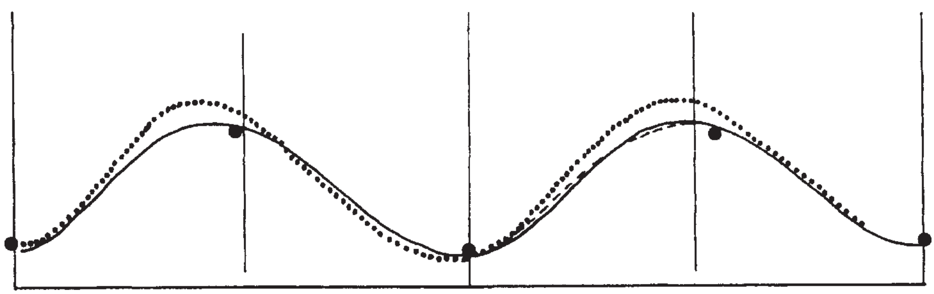

Fig. 2. Mean trajectories reconstructed by Fourier analysis. Y axis is magnified five times. G.M. (point line); B.B. (broken line); C.V. (continuous line).

2.3 Error of method

The experimental (environmental and skier-specific) conditions were carefully standardized and controlled, and no significant modifications undertaken during the experiment. Another source of error was recognized in the identification of the skier's foot during the digitization process, both within and between different operators.

To quantify this source of error, one of the nine runs was randomly selected, and it was independently digitized ten times each by two different groups of operators. Fourier reconstruction was performed, and the relevant coefficients and trajectories analyzed. In no case was a significant error added to the measurements.

3 Results

All the runs were mathematically reconstructed by Fourier analysis, without significant discrepancies between the original and reconstructed plots. The three runs by the two best skiers (B.B. and C.V.) were well reproducible, without significant shape, size (Fourier analysis), or speed differences (photocells). Conversely, skier G.M. showed some between-repetition variability.

Mean values were computed for each skier, and further compared (Table 2): the mean trajectories of B.B. and C.V. were practically superimposed, while the mean trajectory of G.M. was significantly different from the other two (Fig. 2). Most of the difference depended on the different approaches to the gates: skier G.M. began the bend when he was further from the gate than the other two skiers. In the figure, the Y axis was magnified five times to better show the different trajectories next to the gate. Indeed, the total distance skied by G.M. was larger than the distance skied by B.B. and C.V. (Table 1). In addition, this skier had also a different technical level, with a significantly lower speed.

Table 2. Fourier coefficients (cosine component) of the slalom runs. Mean and standard deviation of three runs for each skier. The series were truncated at the 15th harmonic.

H	G.M. a	SD	B.B. a	SD	C.V. a	SD
0	3.13074	0.046721	2.77995	0.073323	2.77738	0.118006
1	0.06548	0.116308	0.08065	0.032096	0.07631	0.042857
2	0.36464	0.041979	0.29956	0.056099	0.35901	0.038892
3	0.72370	0.131064	0.35460	0.076657	0.44180	0.165027
4	-2.65803	0.042622	-2.39136	0.104814	-2.31380	0.050654
5	-0.56034	0.122447	-0.30596	0.086197	-0.35060	0.092636
6	-0.19563	0.053595	-0.12765	0.073748	-0.19675	0.009701
7	-0.18501	0.046577	-0.15109	0.015656	-0.08955	0.028010
8	-0.17308	0.079195	-0.13612	0.015265	-0.18791	0.009097
9	0.04919	0.041147	0.00815	0.004673	0.01253	0.065040
10	-0.05710	0.051358	-0.03313	0.035196	-0.02849	0.046735
11	0.03446	0.061584	-0.04488	0.039614	-0.02837	0.037986
12	-0.01019	0.041960	-0.00963	0.039201	-0.04303	0.024302
13	0.03755	0.078734	0.00614	0.033220	0.02380	0.058033
14	0.00456	0.032295	0.00329	0.034020	0.01841	0.043912
15	-0.05582	0.020644	-0.01677	0.031779	-0.03089	0.030845

4 Discussion

A high anaerobic power and a large fat-free mass have been found to predict alpine-skiing ability [2]. Indeed, these physiological and anthropometric characteristics are common to other anaerobic sports, and they are not specific to skiing [2, 12]. In elite skiers, more specific tests should be developed to better quantify the performance, and to devise more advantageous strategies for training [12]. Moreover, no single physiological or biomechanical variable has shown to be the distinctive characteristic of a ski champion, but usually, superior performance is the result of several well-performed factors [3]. Therefore, the quantification of actual performance during a competition or a training session could offer a more comprehensive tool to analyze ski performance in different situations. Namely, the analysis of the trajectory skied could offer such global evaluation. The analysis of running time and speed cannot quantify giant-slalom performance because of the different ski tracks, and of the disparate environmental conditions.

Among the elements affecting the performance in giant slalom, the actual distance skied, the speed at each gate, and the friction on the snow seem to be particularly influential on the skier's trajectory. The method developed in this report allowed a quantitative analysis of the trajectory (size and shape characteristics), and could give some insight into the effect of some of these factors.

The actual distance skied by each skier is usually longer than the run. This difference depends on technical factors (how the skier bends on the gate), on the skier's gliding, on errors, on changes of direction imposed by holes or ice. For example, two equal trajectories (both size and shape) can be skied in different times if two skiers have different gliding. The two best skiers (B.B., C.V.) had similar trajectories, but different speeds: they had different gliding, due to anthropometric and gliding differences.

Fourier analysis allows the evaluation of the shape characteristics of a profile alone. This is particular useful in skiing: the skier choses the trajectory to reduce the loss in speed at the gate, and the shape difference between two trajectories quantifies the effect of the different ski techniques.

The method could be used to verify the training and technical progress of a skier, but it could also be used to analyze the trajectories during competitions. It is a first step toward the quantitative evaluation of the technical characteristics of each skier. Moreover, the variability of each skier in travelling the same track in standardized conditions could be a measure of neuromuscular coordination.

In this regard, we have already developed quantitative methods to analyze the individual and team coordination in sport performance outside the laboratory [10, 13–15], finding that, in standardized conditions, well-coordinated individuals (or teams) repeat the same movement (or play scheme) with the same morphological characteristics. In the analysis of ski jumpers, Pedotti and Rodano found that athletes the same level show similar vectograms for the execution of the movement [4]. Correspondingly, well-coordinated skiers, in standardized environmental conditions, will probably ski the same trajectory on the same skirun. Fourier analysis of their characteristics could supply a quantitative evaluation of the skier's neuromuscular coordination. In the present investigation, the amateur skier G.M. had a lower repeatability of his trajectories than the two semiprofessional skiers. A similar result was recently found by

Sanders and Owens: their investigation on the golf swing demonstrated that the patterns of movement were consistent and well-reproducible in the elite players, but not in the novice players [16].

5 Acknowledgements

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10
SIMULATION TECHNIQUES APPLIED TO SKIING MECHANICS

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1 Introduction

Skiing, cross-country or downhill, is a delightful activity; nevertheless, good performance requires high co-ordination, good physical conditions and a correct match of skier characteristics to equipment. All these factors are also very relevant to safety.

Due to the complexity of the problems involved, skier and equipment are generally studied separately, both experimentally and theoretically.

Regarding downhill skiing and jumping, some papers deal with kinematic analysis of movement, or with aerodynamics, others analyse mechanical characteristics of skis (stiffness, natural frequencies, vibration damping, etc.), generally in a well defined environment; some others concern measurements of action exchanged between ski and skier for safety aims. On the other hand, however, only a few papers deal with comprehensive models of the athlete with the equipment (e.g., [1]). Analogously, for cross-country skiing, several studies deal with kinematic analysis of movement, but little is reported on the mechanical modelling of the interaction skier-ski-snow.

Ski simulation may have several profitable applications: for example, in free-style jumps, it allows testing of a new exercise before its execution and to find the best conditions (velocity and momentum, as well as limb movement) required for reaching a good landing posture. It is also possible to predict the effects on skier performances of changes in mechanical and geometrical characteristics in skiing as well as in skier movements. Computer simulation allows analysis of the effect of the variation of one single parameter at a time. This is rather impossible for experimental tests on snow, because the latter are affected by many environmental factors. Nevertheless, field experiments are absolutely necessary, are essential for testing and optimising mathematical models.

At present, the simulation of an entire race is not feasible, because it requires the input of a huge amount of data, such as data concerning the description of the race course; the simulation of a single phase is, on the contrary, affordable and profitable.

2 Methods

Our system is made of two sub-models: some interconnected chains of rigid bodies modelling the skier are linked to flexible elements modelling ski and snow. The characteristics of the link between the two sub-models is related to the kind of binding connecting the skier and the equipment.

2.1 Human Model

The human body model consists of 3-D chains of rigid bodies.

In our approach, the number of bodies and the degree of freedom of this model can be freely chosen according to the complexity of the simulation or analysis intended. The upper part of the body can be replaced, for instance, only by a single rigid body when simple ski phases (such as traverse skiing) are studied or made of several bodies in order to simulate complex jumps. The correct degree of freedom is also related to the aim of the analysis (e.g. orthopaedic evaluation or entire body motion), and to the amount of data available. As an example, the knee joint can be schematised by a revolute pair, as well as by a six dof joint.

For skiing simulation we generally use a 16-segment model with 39 internal dof (full human model), or a two-leg model with a HAT (Head, Trunk and Arms) segment with 6 internal dof.

In order to evaluate, the geometrical and inertial parameters for each subject required by the dynamic equations, a program [2], based on regression equations built on statistical bases, has been developed. The minimum input required for computing all subjective parameters (160 for a full model) are height and weight, nevertheless the input of other geometrical parameters (e.g. trunk height, chest circumference, thigh length, etc.) allows the model a better description of the analysed subject.

In order to formulate human-body dynamics we use a method based on homogeneous matrices ([3], Appendix A): both the absolute and the relative position, velocity and acceleration are described by 4×4 matrices, as well as inertial properties, external loads and momentum. This approach allows embedding both the linear and the angular terms in the same formula.

To derive the equation of motion, a Lagrangian approach has been adopted, leading to a system of equations, which, in matrix form, can be written as follows:

$$\mathbf{M}\ddot{q} + \mathbf{C}(\dot{q},q) = \mathbf{F}_1(q,\dot{q},t) + \mathbf{F}_2(q) \qquad (1)$$

where **M** is the mass matrix, **C** a vector holding the weight, the centrifugal and Coriolis action (**M** is an nxn matrix, n is the number of dof. q, and **C** is a vector of n rows). $\mathbf{F}_1$ and $\mathbf{F}_2$ contain the component on the joint co-ordinates of the forces and torques applied to the skier by the actuators (muscles) or transmitted by the equipment (external actions can be easily included).

2.2 Generation of skier's movements

During performance, the skier moves each body segment relative to the others in order to acquire balance, execute an action (such as a turn or traverse), or to cause a propellent action. Therefore, it is important for the "human model" to allow a simple input procedure for these movements or actions.

Our model accepts two main kinds of input: joint torques and (or) displacements, and external actions. If joint torques are assigned as a function of time and of limb position, they form the $\mathbf{F}_1$ vector and the resulting joint and body accelerations can be calculated.

The major shortcoming of this approach, if one chooses to generate joint torques from scratch, is the difficulty to reproduce desired movements, since joint movements are coupled in a complex (non-linear) way, and they also are related to the skier configuration. The effect of the interaction of the skier with the snow is another factor that deters movement predictability in this approach.

A second possibility, best suited when kinematics data on joint-related movements for similar exercises are available, is to input the acceleration of the moving joints. This method can also be profitably adopted to observe the entire body motion resulting from synthesised relative movements of the body segments.

If the acceleration $\bar{\ddot{q}}_i$ of the i^{th} dof. is known, then the i^{th} equation of the system (1) can be replaced by:

$$\ddot{q}_i = \bar{\ddot{q}}_i(t)$$

Once the joint accelerations are computed, the torques required for the movement are obtained by substituting the acceleration values in the discarded equations:

$$\mathbf{F}_1 = \mathbf{M}_i\ddot{q} + \mathbf{C}_i(q,\dot{q}) - \mathbf{F}_2$$

For this kind of input we developed a "Law of Motion pre-processor" that allows extraction of the required data (displacement, velocity and acceleration) with knowledge of, for example, the displacement values in a few intermediate time instants only.

This approach is generally adopted for the inverse dynamic analysis of actions whose kinematic data have been collected, for instance, by means of opto-electronic systems or by electro-goniometers. This procedure, which is well tested in other sports characterised by an aerial phase (e.g. diving, high jump, etc.), can result in incorrectly high calculations of joint-torques during the contact phase when small errors in body position are present.

To prevent this, we implemented a "mixed" approach: we model the muscles around a joint as a torque generator with a first order linear feedback, to which is added a threshold for the maximum value of the resulting torque

$$\begin{cases} F_{1i} = -G_i(q_i - \bar{q}_i(t)) - D_i(\dot{q}_i - \bar{\dot{q}}_i(t)) \\ F_{1i\,\min} < F_{1i} < F_{1i\,\max} \end{cases}$$

where $\bar{q}_i$, $\bar{\dot{q}}_i$ are the control functions (desired joint angle and velocity), q_i, ‘ are the actual joint values and G_i and D_i the feedback parameters (G=proportional, D=Derivative).

These procedures can obviously be combined: therefore, some joints can be displacement driven, others torque driven, and yet others can have a linear feedback.

2.3 Action exchanged between skier and equipment

The action exchanged between equipment and skier depends on the relative motion allowed by the bindings.

The constraints, simulated by stiff springs, exert actions preventing the relative motion between a body segment and the connected equipment: for example, downhill bindings and ski boots, in a simplified model, prevent both relative displacements and rotations between leg and ski (or, in more detail, between the leg and a node of the ski model, as shown below). Therefore 6 springs—3 linear and 3 torsional—are introduced in order to constrain all the 6 related dof.

Cross-country bindings leave one related dof. between foot tip and ski, thus only 5 constraints are added.

If $\mathbf{M}_{ski}$ is the position matrix of the connecting node on the ski, and $\mathbf{M}_{seg}$ is the position matrix of the body-segment frame (whose origin is located on the connection), their relative position $\mathbf{M}_{rel}$ and velocity $\mathbf{W}_{rel}$ are given by:

$$\mathbf{M}_{rel(ski)} = \mathbf{M}^{-1}{}_{ski}\mathbf{M}_{seg}$$
$$\mathbf{W}_{rel(ski)} = \mathbf{W}_{seg(ski)} - \mathbf{W}_{ski(ski)}$$

From the relative position and velocity matrices, the vectors of the relative displacements *D*rel and velocities *V*rel can be extracted. Thus, the components of the action exchanged—in a frame fixed with the ski—are:

$$Act_i = k_i D_{rel,i} + c_i V_{rel,i}$$

where k_i and c_i are the stiffness and damping coefficient associated with the i^{th} constrained dof.

The components of these actions on joint loads can then be computed (see appendix A).

2.4 Ski Model

The internal structure of a ski is quite complex: different materials with specific mechanical characteristics and with a complex assemblage are used in order to obtain the appropriate behaviour for each race.

Ski properties, stiffness, damping, and mass can be determined both by means of complex FEM analysis which take into account the internal structure of the ski, by means of experimental measurements or by a combination of the two approaches.

These properties can be quite accurately reproduced by means of simplified F.E. models consisting of an appropriate number of 3-D beam elements (6 dof. per node).

Input data for this model, other than node position, depending on ski axis, and element connectivity, are: average material properties (Young and tangential modulus), density, sections properties (in correspondence to the nodes), i.e. section moments of inertia (J_{1x}, J_{1y}, J_{1z}, J_{2x}, J_{2y}, J_{2z}) area, width and height (w_1, h_1, w_2, h_2).

Such a model neglects, for example, the local bending of a section, but allows a sufficiently detailed description of the ski, avoiding the need for solving an extremely difficult computational problem.

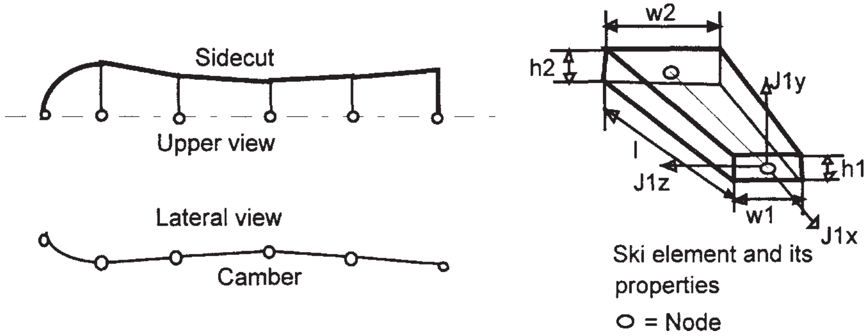

Fig. 1. An example of ski model with beam element properties.

Element load vector (due to weight) and stiffness, mass and damping (Raleigh damping) matrices are determined and assembled in a local (to the ski) reference frame. We suppose that the ski is connected to a body segment only in correspondence to a node, whose orientation $\mathbf{R}_{\text{ski}}$ is taken as representative of the orientation of the whole ski.

Since ski deformations are assumed to be small, the global mass, stiffness and damping matrices can be obtained as follows:

$$\mathbf{M} = \mathbf{R}^T{}_{ski}\mathbf{M}_{ski}\mathbf{R}_{ski}$$
$$\mathbf{K} = \mathbf{R}^T{}_{ski}\mathbf{K}_{ski}\mathbf{R}^T{}_{ski}$$
$$\mathbf{C} = \mathbf{R}^T{}_{ski}\mathbf{C}_{ski}\mathbf{R}^T{}_{ski}$$

The equation of motion for a ski is:

$$\mathbf{M}\ddot{q} + \mathbf{C}\dot{q}_{rel} + \mathbf{K}q_{def} = F_{ext} + F_{ski-snow} + F_{ski-man}$$

where the matrices are “6n×6n” and vectors are “6n” with n number of nodes. The term F_{ext} contain the weight and other eventual loads, $F_{\text{ski-snow}}$ the action exchanged between ski and snow and $F_{\text{ski-man}}$ the action exchanged between skier and ski.

The equations of motion, both for ski and for skier, are integrated with an implicit (Newmark) method.

2.5 **Contact model**

Modelling the contact between ski and snow is not an easy task: snow is a very complex material and its properties are related to many factors such as the pressure exerted and the temperature. Moreover, the behaviour of the ski on a particular kind of snow depends on other factors, among which, for instance, the ski-sole treatment and the edge sharpening are quite important.

Despite its simplicity, the ski model adopted for this work seem to be adequate to describe the generalities of the phenomenon studied even if some details are neglected.

For evaluating the contact forces, we sampled the ski surface with a net of points lying on the lower ski surface: during time integration of the motion equations, the position of each of these points is computed and, therefore, the presence of contact between ski and snow can be detected. More into detail, each element has an mxn (m along length and n along the width) net of control points whose position can be computed from node displacement and control-point location (P_{iiLoc}) ($1 \le i \le m$, $1 \le j \le n$) in the undeformed configuration.

The displacement P_{ai} of a point on the element axis, in correspondence to the i^{th} row of points, and, therefore, the pose of the i^{th} element section, with respect to the reference element, can be computed by using the element shape function.

$$P_{ai}(x) = \mathbf{Disp}(x) Drel$$

where **Disp**(x) is a 6×12 matrix containing the element shape function evaluated in correspondence to the i^{th} row (at distance x from the element origin) and *Drel* are the node displacements relative to their undeformed, displaced position.

With P_{ai} and the undeformed section position $\mathbf{M}_{Sec}$ it is possible to build the pose (position and orientation) $\mathbf{M}_{SecDef}$ of the deformed section with respect to the element, and then to compute the absolute coordinates of point P_{ij} ($\mathbf{M}_{ElemSki}$ is the element position matrix with respect to the ski reference $\mathbf{M}_{ski}$):

$$P_{ij} = \mathbf{M}_{Ski} \mathbf{M}_{Elem-Ski} \mathbf{M}_{SecDef} P_{ijLoc}$$

The velocity of the section to which point P_{ij} belongs, and consequently the velocity of point P_{ij} itself (VP_{ij}), is obtained from node velocity through the shape functions **Disp**(x).

Points P_{ij} and P_{i+1j}, whose positions can be obtained in the same way as for P_{ij}, define an axis directed along the edge of the deformed ski.

We use a reference frame with origin in P_{ij}, with an axis perpendicular to the snow surface; a second, perpendicular to the edge and lying on the surface; and a third, parallel to the surface and directed along the intersection edge-snow.

The components of VP_{ij} in the edge reference define the velocity of deepening $VP_{ij\text{-deep}}$ (component along the surface normal), of sliding $VP_{ij\text{-slid}}$ (along the edge), and of skidding $VP_{ij\text{-skid}}$ (perpendicular to the edge).

Snow reacts, in different ways, both to ski deepening and to ski sliding and skidding. The action exchanged between ski and surface, preventing deepening, is directed upward (the surface can sustain only a compression load) and can be expressed as:

$$F_{deep} = -k_{deep} D_{ij} - c_{deep} V_{ij-deep}$$

The point penetration D_{ij} is computed as the distance between P_{ij} and the surface.

We suppose that the other two action components, parallel to the surface, could be created by friction between ski and snow. We neglect the dependence of the coefficient of friction on velocity and pressure, but we consider it as a function of the local ski edging, i.e. the angle between the local norms to the snow surface and to the lower ski surface. The edging can vary along the ski due to ski deformation.

The friction force is then given by:

$$F_{fric-slid} = -\mu_{slid} F_{Deep} \text{atan}(k_1 VP_{ij-slid})$$
$$F_{fric-skid} = -\mu_{skid}(\vartheta_{edge}) F_{Deep} \text{atan}(k_2 VP_{ij-skid})$$

These forces are then referred to the element axis and their contribution tothe nodal load is computed:

$$F_{ski-snow,Pij} = F_{ax}(F_{Deep}, F_{Fric-Skid}, F_{Fric-Slide})\mathbf{Disp}(x)$$

where $Fax(F_{Deep}, F_{Fric-Skid}, F_{Fric-Slide})$ is a 6×1 vector that includes action from deepening, sliding and skidding.

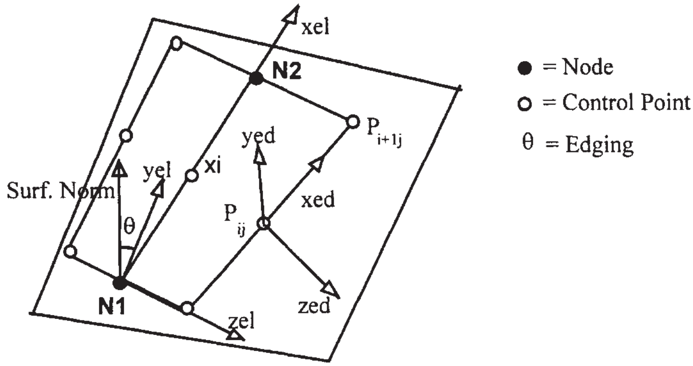

Fig. 2. A sketch of an undeformed ski element, with element frame (xel, yel, zel) and edge frame (xed, yed, zed).

This procedure is repeated for each control point and for each element. When all elements have been examined the total nodal contact load is computed.

3 Preliminary results

To test the feasibility of the model for skiing simulation we performed some simple preliminary tests.

3.1 Free-style jump

We simulated the aerial phase of a free-style jump: appropriate initial condition on body position and velocity were given, together with the relative movements between body segments. Fig. 3 show the output of this simulation.

With this kind of simulation, the athlete, or the coach, can plan the exercise and then observe the resulting body motion, as well as check the landing position.

Modifications to the exercises can be executed to improve the "score" of the jump and/or to reach a better (safe) landing posture.

We observed also the landing phase: in Fig. 4 are also reported the different phases of a landing. It is possible to note the ski deformation (and vibration).

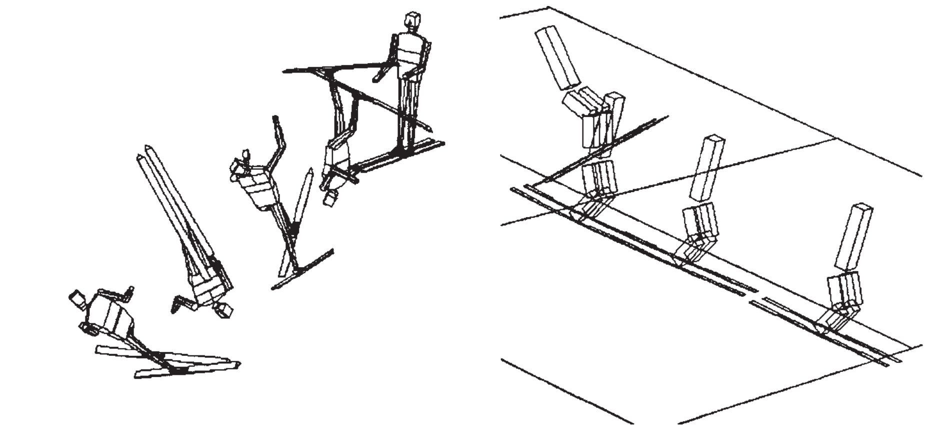

Fig. 3. Free-style jump (left). Landing phase (right).

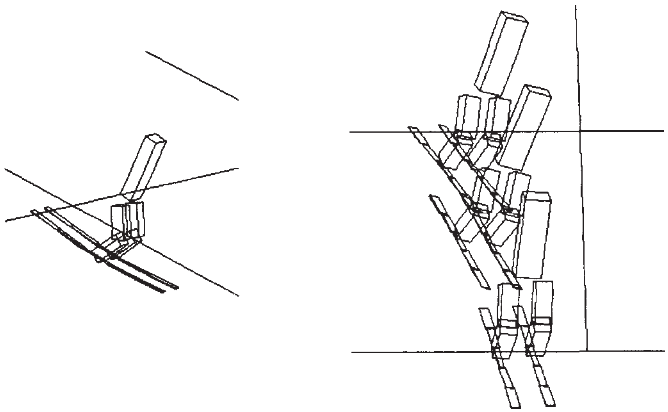

Fig. 4. Landing phase (left) and turn (right).

3.2 Traverse phase

The initial conditions of velocity parallel to the slope were given and the skis of the two tests have different torsional stiffness. The results show that softer skis produce a more pronounced lowering of the skier (Fig. 5).

3.3 Turn

We simulate the beginning of a carved turn, starting at the fall-line with three different kinds of skis: stiff and soft ski with straight edges and soft with a side cut. We assumed that the skier had loaded the external ski in correspondence to the internal edge.

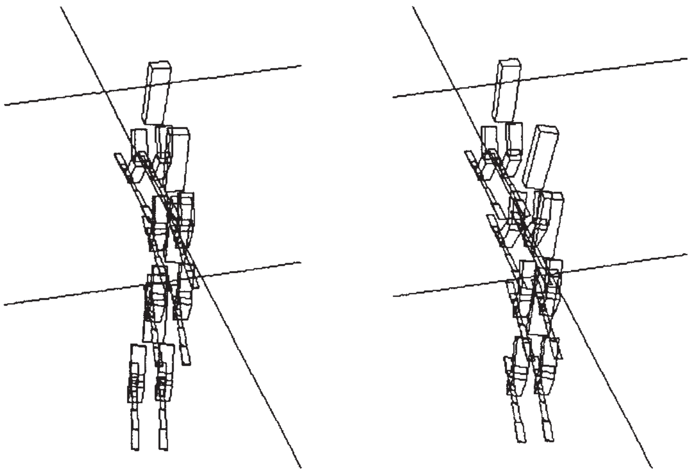

Fig. 5. Traverse with lower (left) and higher torsional stiffness ski (right).

The stiff ski, at the end of the simulation time (3 sec.), just begins to turn, while the softer ones have steered through a greater angle. The soft kinds of skis, leaning on the snow along their edges, bend more than the stiff ones and therefore they turn easily (their “natural” radius of turn shorten). This is shown in Fig. 6 where, for the same initial condition and without any movements of the skier, the straight ski takes longer before turning.

We also observed that, zeroing the load during the turn, the skis tend to lie flat on the surface, starting a more pronounced skidding.

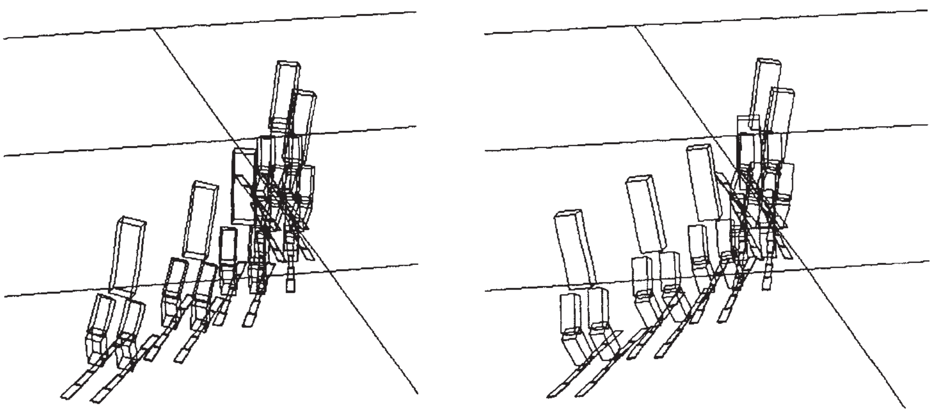

Fig. 6. Turn with a stiff non-chattering ski (left). Turn with a soft chattering ski (right).

4 Conclusion

The preliminary tests of the system of programs based on the new model capable of simulating the aerial phase, the impact phase and the most important phase of skiing in which skis are on the snow, are very encouraging.

Movements of free-style skiing, cross-country skiing and downhill skiing can be simulated, taking into account, for instance, ski vibration, ski sinking into the snow, and ski chattering.

The model has been successfully validated for the aerial phase by means of experimental data currently available for some sports [4]. Tests on the snow are under development in order to optimise and validate the model in other skiing phases.

For the preliminary tests, average constant parameters have been used for the mechanical proprieties of the snow, such as stiffness, damping or friction with the ski sole [5]. This can lead to some errors, because they can vary along the slope and they also depend on time. Future versions of the programs will allow inputting different values of these parameters along the course and to define them as a function of time—during a race, for instance, ski temperature changes substantially.

Notwithstanding the previous statement, the actual version of the system of programs is very profitable especially when the aim of the tests is to analyse the effects of few parameters while keeping all the other internal or external conditions constant.

Another part of the system that we are now improving is the interface with the user in order to simplify the procedure required to build the desired movement. The objective of this effort is to allow the direct use of the system by ski trainers and coaches.

Even though the system is quite flexible and includes a finite element procedure, the program can run on standard personal computers.

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Appendix A.

In this appendix we give some details on the homogeneous matrix approach to multibody system dynamics.

The pose (orientation and position) of a rigid body (1) and, therefore, of a frame rigidly connected with the body, with respect to a frame (0), can be given by a 4×4 matrix $\mathbf{M}_{0,1}$

$$\mathbf{M}_{0,1} = \left|\begin{array}{ccc:c} & \boldsymbol{R}_{0,1} & & \mathbf{t}_{0,1} \\ \hdashline 0 & 0 & 0 & 1 \end{array}\right| = \left|\begin{array}{ccc:c} x_x & y_x & z_x & t_x \\ x_y & y_y & z_y & t_y \\ x_z & y_z & z_z & t_z \\ \hdashline 0 & 0 & 0 & 1 \end{array}\right|$$

where $\mathbf{R}_{0,1}$ is the relation of body (1) with respect to (0), and $\mathbf{t}_{0,1}$ the origin of frame (1). If the homogeneous coordinates of a point P1 belonging to the body, are known with respect to the body frame, its coordinates P_0 with respect to the base frame are:

$$P_0 = \mathbf{M}_{0,1} P_1$$

If $\mathbf{M}_{ij}$ is the position of body j with respect to i, and $\mathbf{M}_{j,k}$ represent the pose of body k with respect to j, then the pose of k with respect to i ($\mathbf{M}_{i,k}$) is given by the product:

$$\mathbf{M}_{i,k} = \mathbf{M}_{i,j} \mathbf{M}_{j,k}$$

The angular and linear velocity of a body, in a given frame, can be represented by the velocity matrix

$$\mathbf{W} = \left|\begin{array}{ccc:c} 0 & -\omega_z & \omega_y & v_x \\ \omega_z & 0 & -\omega_x & v_y \\ -\omega_y & \omega_x & 0 & v_z \\ \hdashline 0 & 0 & 0 & 0 \end{array}\right| = \left|\begin{array}{ccc:c} & \underline{\omega} & & \mathbf{v}_o \\ \hdashline 0 & 0 & 0 & 0 \end{array}\right|$$

where $\mathbf{v}_0$ is the velocity of a body point passing through the frame origin and is body angular velocity.

The velocity of a point P, belonging to this body, can be obtained as:

$$\dot{P} = \mathbf{W}\,P = \begin{vmatrix} \dot{x}_P \\ \dot{y}_P \\ \dot{z}_P \\ 0 \end{vmatrix} = \begin{vmatrix} & \underline{\omega} & & \mathbf{v}_o \\ 0 & 0 & 0 & 0 \end{vmatrix} \begin{vmatrix} x_P \\ y_P \\ z_P \\ 1 \end{vmatrix}$$

Similarly, the relative acceleration of a body with respect to a reference frame may be expressed by the acceleration matrix **H** as:

$$\mathbf{H} = \dot{\mathbf{W}} + \mathbf{W}^2 = \begin{vmatrix} & \mathbf{G} & & \mathbf{a}_0 \\ 0 & 0 & 0 & 0 \end{vmatrix}$$

and the acceleration of a point P can be obtained as:

$$\ddot{P} = \mathbf{H}\,P = \begin{vmatrix} \ddot{x}_P \\ \ddot{y}_P \\ \ddot{z}_P \\ 0 \end{vmatrix} = \begin{vmatrix} & \mathrm{G} & & a_o \\ 0 & 0 & 0 & 0 \end{vmatrix} \begin{vmatrix} x_P \\ y_P \\ z_P \\ 1 \end{vmatrix}$$

Gravity can be expressed also as a 4×4 matrix **Hg**.

The relationships needed to express these matrices, known in a frame s, in another reference frame r, whose position with respect to frame s is given by $\mathbf{M}_{sr}=\mathbf{M}^{-1}_{rs}$ are:

$$\mathbf{W}_{(r)} = \mathbf{M}_{r,s}\,\mathbf{W}_{(s)}\,\mathbf{M}^{-1}_{r,s} \quad \text{and} \quad \mathbf{H}_{(r)} = \mathbf{M}_{r,s}\,\mathbf{H}_{(s)}\,\mathbf{M}^{-1}_{r,s}$$

Having expressed all the matrices in a same reference, the relative motion between different bodies (i j k) can be expressed as:

$$\mathbf{W}_{i,k(r)} = \mathbf{W}_{i,j(r)} + \mathbf{W}_{j,k(r)} \quad \text{and} \quad \mathbf{H}_{i,k(r)} = \mathbf{H}_{i,j(r)} + \mathbf{H}_{j,k(r)} + 2\mathbf{W}_{i,j(r)}\,\mathbf{W}_{j,k(r)}$$

(These matrix expressions are formally equal to Coriolis' Theorem).

Analogously the action exerted on a body, the inertia and momentum can be represented, respectively, by the 4×4 matrices, $\mathbf{\Phi}$, $\mathbf{J}$, $\mathbf{\Gamma}$.

To express these matrices in a frame r, if they are known in a frame s, these relationships must be used:

$$\mathbf{J}_{k(r)} = \mathbf{M}_{r,s}\mathbf{J}_{k(s)}\mathbf{M}^{t}_{r,s} \qquad \Gamma_{k(r)} = \mathbf{M}_{r,s}\Gamma_{k(s)}\mathbf{M}^{t}_{r,s} \qquad \Phi_{k(r)} = \mathbf{M}_{r,s}\Phi_{k(s)}\mathbf{M}^{t}_{r,s}$$

Acceleration inertia and action matrices (for a body) are related by this relationship (Newton's law):

$$\Gamma_{k(r)} = \mathbf{M}_{r,s}\Gamma_{k(s)}\mathbf{M}^{t}_{r,s}$$

The instantaneous Screw Axis of a body can be obtained from its velocity matrix **W**, dividing it by the module of the angular velocity (if 0) (or by $\mathbf{v}_0$ if=0), and another 4×4 matrix is obtained: **L** matrix. Matrix **L** transforms as **W** and **H**.

$$\mathbf{L} = \frac{\mathbf{W}}{|\overset{r}{\omega}|} = \left|\begin{array}{ccc|c} 0 & -u_z & u_y & b_x \\ u_z & 0 & -u_x & b_y \\ -u_y & u_x & 0 & b_z \\ \hline 0 & 0 & 0 & 0 \end{array}\right| = \left|\begin{array}{ccc|c} & \underline{\mathbf{u}} & & \mathbf{b} \\ \hline 0 & 0 & 0 & 0 \end{array}\right| \qquad |\overset{r}{\omega}| = \sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2}$$

One-dof joints have a very simple **L** matrix, and n-dof joints can be represented as a chain of n joints with one dof.

The dynamic equations, for a chain of N rigid bodies (some of them can be fictitious to represent multiple dof joints), with N dof q, using a Lagrangian approach, are:

$$\mathbf{M}\ddot{q} + \mathbf{C}(\dot{q}, q) = \mathbf{F}_1(q, \dot{q}, t) + \mathbf{F}_2(q)$$

where:

$$\mathbf{M}[i,m] = Trace[\sum_{h=m}^{N} \mathbf{L}_{i(0)} \mathbf{J}_{h(0)} \mathbf{L}'_{m(0)}]$$

$$\mathbf{C}[m] = Trace\left[\sum_{h=m}^{N} (\tilde{\mathbf{H}}_{0,h} - \mathbf{H}_{g(0)}) \mathbf{J}_{h(0)} \mathbf{L}'_{m(0)}\right]$$

where $\tilde{\mathbf{H}}_{0,h}$ is the acceleration of body h when all are zero. (The *trace* of a square matrix is the sum of its diagonal elements.)

$\mathbf{F}_1[m]$ is the action (force or torque) on i^{th} dof and

$$\mathbf{F}_2[m] = (\sum_{i=1}^{N} \Phi_{i(0)}) \otimes \mathbf{L}_{m(0)} .$$

is the component of external action on the i^{th} dof load ($\otimes$ defines a pseudoscalar product for these 4×4 matrices).

All matrices involved must be expressed in the same reference (0). This is possible because, during the integration process, the position (q values) and velocities $(\dot{q})$ are known and therefore, for each segment, matrices **L**, **W**, **J**, **Φ**, and $\tilde{\mathbf{H}}$(acceleration of a segment when all $\ddot{q}$ are zero) can be computed using the relative kinematics and the transformation relationships.

11
TURNING THE SKIS WITHOUT 'MECHANISMS OF TURNING'

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Keywords: parallel turns, ski technique, turn of the skis, mechanisms of turning, biomechanics, alpine skiing.

1 Introduction

As the techniques of skiing are in principle 'invisible' [1] the only possibility is to deduce them logically. Even biomechanical research is not able to recognize techniques immediately. It is a basic feature of scientific research to logically analyze the problem at hand before beginning empirical research and to discuss logically the empirical results. Therefore, based on a new concept of 'structure of motion' [2], a logical procedure will be presented allowing a systematical inference of turn technique. Following this procedure, fundamental biomechanical and other already existing knowledge has to be considered [2], [3].

2 A logical way to see through 'invisible techniques'

Question: How do parallel turns basically work?

- As we are first to recognize the essentials of technique, we have to reduce the question to a situation which is easy to survey.
- Therefore, we discuss single turns from one traverse to the other on a plane slope, excluding jumping from one edge to the other.

Statement: The skier performs certain activities, by means of which he causes the skis to move over the snow in an appropriate way.

- As a common point of departure we assume that the skier influences the motion of the skis.
- Of course the skier must keep balance as a secondary condition.

Question: By means of which activities in the very complex motor behaviour do we essentially influence the motion of the skis?

- This is the crucial question, because the answer will determine adequate teaching techniques.
- The controversy over this question has continued through several decades.
- This question has not yet been thoroughly answered.

Statement: One can only clarify the essential activities, if one knows how the skis actually move, are able to move, or should move on the slope.

- So far researchers have been looking (in vain) at the skier for adequate activities. Now there is a change in perspective.
- Because of complex motor behaviour, we have to (re)infer the essential activities from the intended motions of the skis [2].

Question: How do the skis actually move on the snow?

- This is the key to understanding, because through clarification of this question we can deduce decisive knowledge about techniques and for practical applications.
- This question has been neglected for a long time, so there was room for many opinions about those movement techniques which, in part, changed very quickly.

Statement: First the skis drift inward over the outside edges (faster at the tips) and then they drift outward over the inside edges (faster at the tails): 'inward-drifting' and 'outward-drifting', respectively (see Fig. 1).

- It is logical that the skis move in the way illustrated in Fig. 1:

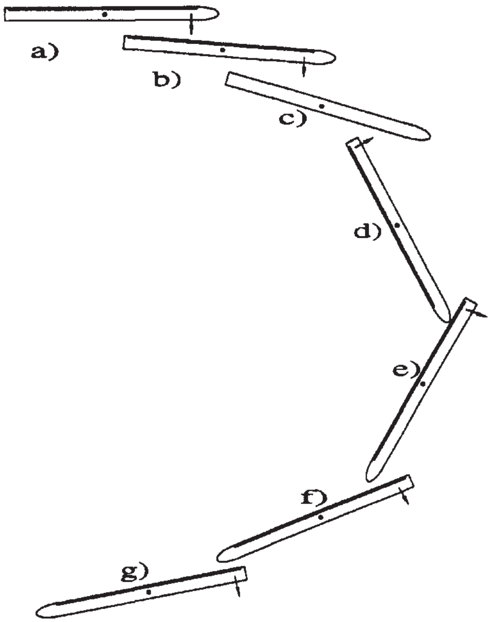

Fig. 1. The motion of the skis. (The gripping edge is highlighted and translation is reduced.)

In every turn there is a change from the outside to the inside edges of the skis. At the onset of edge release, the skis are able to slip inward (see Fig. 1, a-c); to perform the intended, turn it is useful that the tips slip faster.

After change of edge the skis are able to slip outward (see Fig. 1, c-g), then the tails suitably slip faster. Increase of the edge angle stops the drifting motion.

- We found this particular motion of the skis by biomechanical analysis in every turn that was performed [4].
- In appropriate situations one can see this motion of the skis with the naked eye.
- Taking into account the condition of edge angle on the slope, it is impossible to assume a different motion of the skis. (Of course it is possible to jump from edge to edge.)
- Note that the motions of ‘inward-drifting’ and ‘outward-drifting’ already include the turning of the skis.
- Turning with bottom of the skis flat on the snow does not exist.

Question: How must the skis be influenced in order to move as was described?

- It would be premature to ask how the skier must act. We cannot know this by the described motion of the skis.
- First we have to clarify the requirements for the particular motion of the skis from a mechanical point of view.

Statement: The drifting of the skis inward and outward can be induced by the weight and lateral support of the body alone.

- Fig. 2 clearly illustrates how lateral forces inward (a) and outward (b) are induced by the force of support F_{St}.
- As an important precondition, the skis must be able to slip inward and outward by appropriate edging.
- If the body is appropriately inclined, specific activities of the body are not required.
- Especially unweighting of the skis by up-and-down movements of the body is not required and does not make any sense, because the lateral motion of the skis is achieved just by supporting the weight.

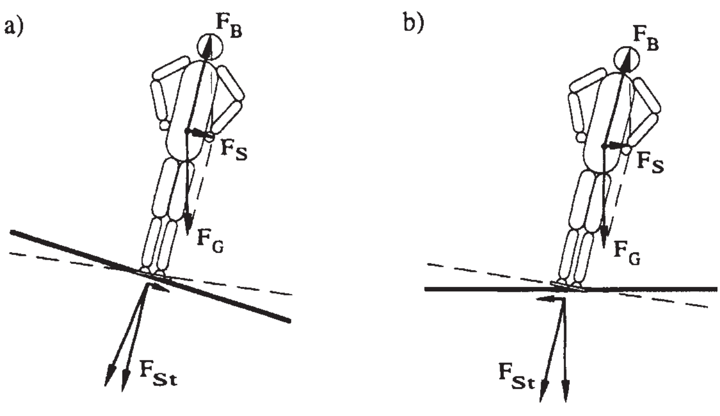

Fig. 2. The causes of drifting inward (a) and drifting outward (b).

Question: Why do the tips slip faster when ‘drifting inward’ and the tails when ‘drifting outward’?

- Now the problem is reduced considerably.
- We have only to clarify a little change in the slipping of the skis.

Statement: When 'drifting inward', lateral forces enhance slipping of the tips or brake slipping of the tails. When 'drifting outward' the opposite applies.

- It is not possible to assume an active turning of the skis, because the edges are set when 'drifting inward and outward' (see Fig. 1). The edges change instantaneously (see Fig. 1, c).
- We have to assume that lateral forces, by influencing the skis at the tips or at the tails, change slipping of the tips and the tails, respectively.
- These alternatives are the logical continuation of the idea that lateral forces at the tips of the skis could enhance drifting of the tips.

Question: Which alternatives do actually occur?

- Now we ask for the possibilities of the skier to produce such forces.
- Because of the aforementioned alternatives, search for adequate activities of the body is much easier.

Statement: Only a 'falling inward' is needed in order to achieve the required lateral forces. Note that the binding is located behind the middle of the ski.

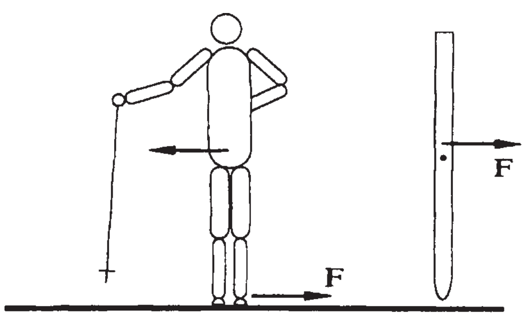

Fig. 3. The relation between 'falling inward' and lateral forces.

- Fig. 3 illustrates how 'falling inward' produces lateral forces on the skis by action and reaction because the binding is located behind the middle of the skis. Thus slipping of the tails is braked when 'drifting inward'.
- When 'drifting outward' (after change of edge), the inclination produces lateral forces which enhance slipping of the tails (see Fig. 2, b).
- Biomechanical analysis confirms that 'falling inward' induces 'drifting inward' [4]. We could not verify the idea to exert pressure on the tips in order to enhance 'drifting inward'.

- Thus we revealed incredibly simple movement techniques: 'Falling inward' alone fulfills the essential conditions for performing turns—i.e., change of edge, ability to slip, inclination, and lateral forces.
- The reader may try out for him- or herself that turns are possible in this way.
- 'Mechanisms of turning' of any kind whatsoever are not of relevance.
- That 'stepping' is not required we may conclude from the fact that an inclination ('falling inward') of the skier is required. A 'rotary push off from the inside ski to the outside ski would be an outward displacement of the body. On the contrary, a different activity is required which looks very similar: lifting the inside ski alone can initiate or enhance 'falling inward'. So the body is not displaced outward, but the activity implies a 'non-stepping'. (We change only the ski: 'change of ski').

Question: Do there exist further activities which can effect these lateral forces?

- The question is posed, because we usually do not perform turns by 'falling inward' alone.
- We can clearly notice a change from one angulation to the other especially when performing shortswings.

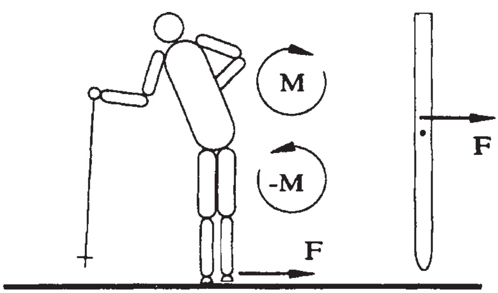

Fig. 4. The production of lateral forces on the skis by 'lateral reaction of moments'.

Statement: By moving from one angulation to the next ('lateral reaction of momenta'), lateral forces can also be exerted on the ski.

- 'Reaction of momenta' as an analogue to action and reaction means the coexistance of two momenta in relation to the same axis of rotation. The counterrotation of the two parts of the body happens at the same time. All joint activity is basically a 'reaction of momenta' (for details cf. [3]).

- 'Lateral reaction of momenta' means the simultaneous counterrotation of legs and upper body in relation to the sagittal axis (see Fig. 4). This activity clearly produces lateral forces against the skis which exert the same effects as 'falling inward'.
- We found this lateral activity of the body in every turn by a bio-mechanical analysis [4].
- Note that we have to distinguish the aforementioned momenta from the 'mechanisms of turning' which have until now been claimed, e.g. leg-rotation, anticipation, or counterrotation. Again such rotatory effects are not of relevance (for the edging see Fig. 1).

Question: How does leaning forward or backward influence the motion of the skis?

- This is an old question in the discussion of skiing techiques.
- As we cannot detect further lateral activities, we can procede with this question.

Statement: Leaning forward or backward influences the intensity of drifting of the tails when 'drifting outward' (change of direction).

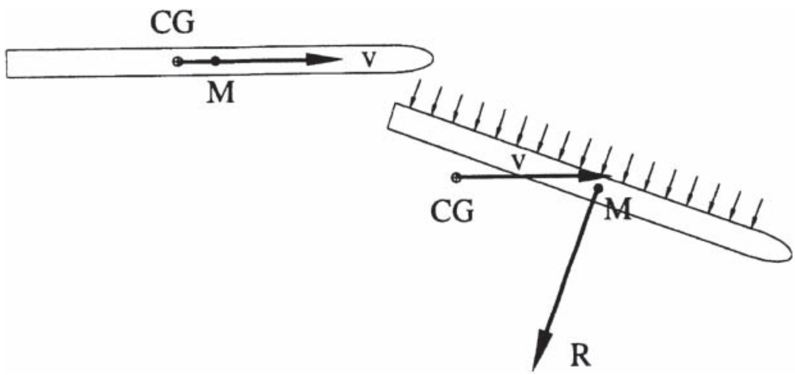

Fig. 5. How drifting of the tails of the skis is influenced.

- In Fig. 5 we can see that, due to inertia after onset of rotation, the Center of Gravity (CG) of the skis and the skier tends to maintain the direction of motion (v) and to turn the system. The more CG is displaced backward, the stronger the effect.

- In the exact terms of physics, the sum of friction forces at the edge (R) acts approximately on the middle of the skis (M). Depending on the distance of the friction force from the CG of the system, the skis obtain a particular momentum. Through this momentum, we can control change of direction.
- By taking into account this effect, it becomes clear that turning of the skis is usually no problem, if a certain change of direction has already been accomplished.
- If we lean backward very far and enhance edging, the skis are carving at the tails. Thus we are usually able to finish turning. (Note that the functions of the edges vary from enhancing to braking sideslipping.)
- When ‘drifting inward’, an enhanced backward displacement of CG is apparently not useful, because the onset of ‘drifting outward’ may be impeded.

Question: How does the skier control balance?

- As the basic causes of the motion of the skis are clear, we can deal with the problem of balance.
- Because we have already clarified leaning backward and forward, we shall only deal with balance in the frontal plane.

Statement: By ‘falling inward’ the skier adopts an unbalanced position only for a short moment in order to gain dynamic balance when turning.

- The force F_S illustrated in Fig. 2 is exactly the lateral force (centripetal force) the skier requires for changing direction of motion and performing a turn. If the skis also change direction and perform a turn, the skier is in a dynamic balance, i.e. despite inclination and lateral force F_S the skier does not fall.
- The required centripetal force F_S, depending on the radius of the turn and the speed, is continuously changing; therefore the skier has to control this force in an appropriate way. He can do this (apparently without conscious awareness) by changing magnitude and direction of ground reaction force F_B (see Fig. 2) by means of varying vertical posture, weight distribution on inside and outside ski and angle of edging. Furthermore, the skier can control inclination by planting the pole.

3 Summary

We have sketched a logical procedure allowing the inference of complex motor behaviour or 'invisible techniques' step by step. Although limited space does not allow an extensive analysis of the subject, we can deduce the following results:

- When performing a turn from one traverse to the other on a plane slope, the skis move on the snow in a characteristic way: 'inward-drifting' and 'outward-drifting' (see Fig. 1).
- Because this particular motion of the skis requires specific effects and the skier has only a limited number of possibilities to suitably influence the skis, we can infer a simple movement technique: turns are clearly accomplished by a combination of 'falling inward' and 'lateral reaction of momenta'.
- Attempts to clarify techniques of skiing that have been proposed so far (leg turning with the skis flat and unweighted on the snow, stepping with rotary push off, rotations) are not compatible with the specific motion of the skis and are not founded on reasons or empirical evidence.
- Note that turns are not produced by turning the skis (pivoting) but by lateral support F_B of the skier; this support results in the required centripetal force F_s (see Fig. 2).

4 Conclusion

The following statements are of crucial significance for a full understanding of skiing techniques:

- So far explanations of movement techniques have been limited to a simple situation. It is not possible, however, to give reasons for an optimal or standard performance in order to get from one traverse to the other [2]; on the contrary, a great variability of performance does exist for this situation. 'Falling inward', 'lateral reaction of momenta', forward and backward displacement of the body and edging can be performed in many different ways and this may produce very different 'inward-drifting' and 'outward-drifting'.
- On the basis of this variability in the activities of the skier, we can also understand and explain parallel skiing under different conditions of terrain [4]. Apparently there does exist only one technique or structure of parallel skiing [2], which is a simple and variable concept.

- After all, ‘turning the skis without mechanisms of turning’ is no surprise if we take into consideration a different perspective: the system ‘skis/ skier’ is turned by momenta of the slope (see Fig. 5); the skier has only to accomplish the appropriate contact between skis and slope.
- A new concept of skiing techniques requires new teaching methods (Snow-plow turn and stemming are not compatible with the described techniques). In the meantime we have developed, tested but not yet published new methods of teaching parallel skiing which are based on the new knowledge.

However that may be, note that we ourselves do not turn the skis—rather, the skis turn us.

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12
MUSCLE ACTIVITY OF THE INSIDE AND OUTSIDE LEG IN SLALOM AND GIANT-SLALOM SKIING

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Keywords: electromyography, ski technique, slalom skiing, giant-salom, alpine skiing, biomechanics.

1 Introduction

Alpine-skiing technique requires varying amounts of bilateral support from the legs. In racing and in recreational skiing, controversy exists regarding how much the outside leg is used compared to the inside leg [8]. Although highly dependent upon snow conditions and terrain, information of this nature has implications for conditioning skiers and teaching ski technique.

Although a direct comparison between inside and outside leg function is not apparent in the skiing literature, some insight may be gained from previous studies. Nachbauer and Rauch [7] noted that forces on the outside ski were 1.5 to 6 times greater than on the inside ski during slalom (SL) and giant-slalom (GS) skiing, which supports the belief that the outside leg is dominant in the turn. Other investigators [1–6] have studied the electromyographic (EMG) activity of several leg muscles during skiing. One common observation regarding the inside leg was the high activity level of the rectus femoris, which was attributed to its' function as a hip flexor. Berg et al. [1] reported no differences in rectus femoris activity, but found that the overall EMG activity of the vastii was significantly greater for the outside leg in GS skiing. Beyond these observations, little has been reported regarding bilateral muscle activity during skiing. Therefore, the purpose of this study was to compare the muscular activity patterns of the inside versus the outside leg and trunk in competitive racers during slalom (SL) and giant-slalom (GS) skiing using quantitative parameters of EMG.

2 Methods

2.1 Data Collection

2.1.1 Subjects

Seven competitive ski racers (4 males and 3 females) gave their written, informed consent to participate in this study. All skiers were members of their national teams. The testing took place in November at Beaver Creek, Colorado, as the skiers were in final preparation for their competitive season.

2.1.2 EMG

Skin preparation for surface electrodes consisted of shaving hair where necessary and cleansing the skin with alcohol. Bipolar (~3 cm separation) surface electrodes (Ag-Ag/Cl) were placed over the following 12 muscle groups on the right side of the body—lower leg: anterior tibialis (AT), medial gastrocnemius (MG); thigh: vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), medial hamstrings (MH; semimembranosus and semitendinosus), biceps femoris (BF), adductors (AD), gluteus maximus (GM); and trunk: rectus abdominis (RA), external obliques (EO), erector spinae (ES). An additional electrode that acted as a ground was placed over the bony projection of the anterior superior iliac crest. Proper electrode placement was confirmed by specific manual muscle testing.

Isometric maximum voluntary contractions (MVC's) were collected pre-and post-testing, and provided a relative reference for the EMG amplitude during skiing. The positions for eliciting MVC have been reported previously [2].

During skiing, EMG was monitored via telemetry with a four-channel transmitter (Noraxon, Inc., Scottsdale, AZ) that was positioned on the subject's lower back with a belt. The EMG signals (bandwidth 10–770 Hz) were sampled at 1000 Hz and recorded onto magnetic disk.

2.1.3 Video

Qualitative video recordings of the skiers were taken at 30 Hz with a Panasonic 5100 video camera (Panasonic, Secaucus, NJ). The camera and EMG video recordings were synchronized using a manually triggered pulse based on the leading edge of the video frame.

2.1.4 Skiing Protocol

Representative sections of SL and GS courses were set by the Head Coach of the U.S. Ski Team according to F.I.S. standards. The courses were placed parallel to one another on the same slope to insure a similar contour. The GS course consisted of seven turns and the SL course had eleven turns. The snow at each gate was marked with dye to insure exact placement of the turns from day to day. This was necessary because the slope was groomed daily to maintain consistent snow conditions.

Since the capacity of the EMG telemetry unit was four channels, the muscles were partitioned into three sets. Set 1 included the VL, VM, BF, and MH. Set 2 consisted of the AT, MG, RF, and AD. Set 3 was made up of the RA, ES, EO, and GM.

Data collection was conducted over five days with a maximum of two subjects tested per day. The testing protocol for each session consisted of several warm-up runs and then each subject skied three runs of GS and three runs of SL for each muscle set; a total of 18 runs. Testing of muscle sets was balanced across subjects to prevent any bias due to order. Each run lasted eight to twelve seconds, with three to six minutes between each start.

2.2 Data Analysis

Information from turn three, a right turn where the right leg was inside, and turn four, a left turn where the right leg was outside, were analyzed and reported here. These particular turns were chosen because they were in the middle of the course where the subjects were up to speed, in the rhythm of the course, and were constrained by a preceding and subsequent turn. EMG and time parameters were averaged across trials.

2.2.1 Video

Qualitative video analysis matched phases of the ski turn with the EMG and related that information to particular movement patterns. Fundamentally, skiing consists of a series of turns with a transition between each. Three experienced observers independently partitioned the turns into phases using time code. Three phases; initiation (IP), turning (TP), and completion (CP), were distinguished for GS, while only two phases, IP and TP, could be distinguished for the shorter SL turns. Descriptions of the phases have been reported previously [2].

2.2.2 EMG

The raw EMG signals were processed using a root mean square (RMS) algorithm with a 15 ms time window. EMG parameters were analyzed with software that incorporated the phase boundaries identified from the video analysis. Dependent variables were the peak (PA) and average (AA) amplitudes, and duration of each phase. Peak and average EMG were expressed as a percentage of MVC. There were several instances of missing EMG data due to dropout of the telemetry signal.

2.3 Statistics

Descriptive statistics were calculated for the dependent EMG variables of absolute PA (mV) and AA ($mV\cdot s^{-1}$), and duration (ms) in SL and GS for all twelve muscles. Repeated measures analysis of variance (ANOVA) was used to compare the dependent EMG parameters from the outside versus the inside leg and trunk muscles in SL and in GS. Paired t-tests were used to check for differences in pre- and post-test MVC's. The level of statistical significance was set at $P<0.05$.

3 Results

Descriptive characteristics of the seven skiers were (mean±SD): age of 20.1±1.7 y, height of 1.70±0.1 m, and mass of 68.4±14.0 kg. The snow was predominantly artificial and conditions were very consistent from day to day. Temperatures ranged from approximately -7 to 5°C with predominantly sunny weather, and several instances of snow flurries.

The phase and overall turn durations for SL and GS are given in Table 1. For GS the duration of the right turn (1478 ms) was significantly longer than the left turn (1358 ms) due to a significantly longer turning phase (16.5%). In SL, the turning phase was also significantly longer for the right turn (7.1%), but the overall turn duration was similar.

Graphs of RMS EMG for SL and GS, averaged across subjects and trials, and normalized overtime, are displayed in Figure 1. In general, EMG activity from muscles positioned towards the inside or outside of the turn displayed similar patterns for all but two muscles in one phase of SL. For GS, there were differences in at least one phase for all but four muscles. Average amplitude over the whole turn was greater than 50% MVC for nine out of twelve muscles in both SL and GS. There was substantial interindividual variation in muscle activity with coefficients of variation ranging generally from 20% to 45%. However, reliability for average amplitude was good, as indicated by intraclass correlation coefficients that ranged from R=0.76 to 0.98.

Table 1. Mean and SD for phase and total durations (ms) for turns where the instrumented right side was inside (In) and outside (Out) in slalom and giant slalom.
p<0.05 for SL (*) and GS (†).

	Slalom				Giant Slalom			
	In		Out		In		Out	
Muscle	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Initiation	125	33	125	24	169	35	160	36
Turning*†	735	85	676	64	915	101	786	80
Completion					394	93	413	93
Total†	861	83	801	64	1478	75	1358	116

3.1 Slalom

In SL, muscle activity typically increased from initiation and peaked in the mid-turning phase. Exceptions to this pattern were the ES and the outside GM, which peaked before midway in the turning phase. The only differences between average or between peak EMG amplitudes measured from the inside and outside of the turn were for the MG and VL, which were greater for the outside leg in the initiation phase of the turn (Fig. 1A).

3.2 Giant Slalom

For GS, muscle activity typically increased from initiation into the turning phase and peaked late in the turning phase or early in the completion phase before decreasing. There were eight muscles that had significantly greater average EMG amplitude on the outside compared to the inside of the turn during at least one phase, and only one muscle that was greater on the inside (Fig. 1B). During the initiation phase, the VM had greater activity when it was on the outside of the turn. During the initiation and turning phases, the VL, BF, and GM displayed greater muscle activity when on the outside of the turn. Average amplitude of the MH was also greater on the outside during the turning phase. In the completion phase, the RF, AD, and RA all had significantly greater activity when on the outside compared to the inside. The only muscle that had greater activity when measured from the inside leg was the VM during the completion phase.

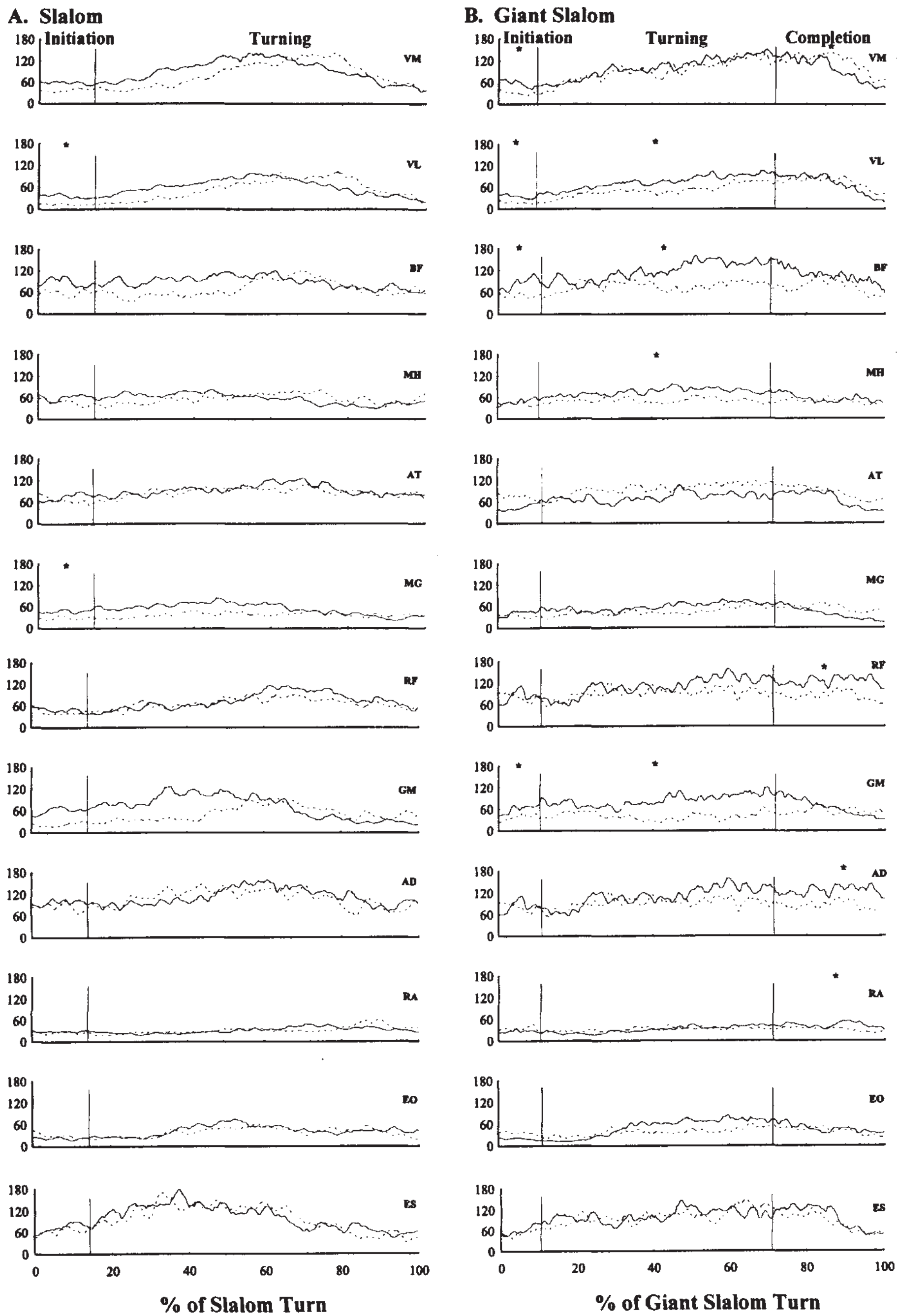

Fig 1. Mean and SD for phase and total durations (ms) for turns where the instrumented right side was inside (In) and outside (Out) in slalom and giant slalom.

4 Discussion

By instrumenting only one side of the body and measuring EMG activity over two sequential turns, the assumption implicit to this study was that the turns were similar. Although the turns were set identically in terms of shape and terrain, there were still significant differences in the duration of the turning phases. However, these differences were not relevant because the primary dependent variable, average EMG amplitude, is independent of phase duration.

Perhaps the most surprising results from this study are the similar and relatively high levels of EMG activity observed bilaterally for many muscles. In SL, average amplitude was similar within all inside/outside muscle pairs except the MG and VL during the short initiation phase. In GS, the same pattern held for eight of twelve muscles during the long turning phase. Although EMG activity is not directly representative of muscle force, we expected it would more closely reflect the pattern of greater reaction forces (1.5 to 6 times) measured from the outside ski by Nachbauer and Rauch [7].

One plausible explanation for similarities in muscle activity is the different body positions typical in SL and GS skiing. In SL, the racer can ski a straighter line through gates that hinge at the base. Since the SL racer does not turn as completely at each gate, he main tains a fairly upright posture that is more similar bilaterally than in GS. The SL turn is also shorter, leaving less time for independent leg action. In contrast, the GS turn is longer and normally forms a more complete arc. The skier's angulated body position in the turn is typically accomplished by keeping the inside leg flexed and the outside leg more extended, as indicated by the knee-angle data of several authors [1, 7]. Therefore, the extended out side leg may benefit from more skeletal support, while the flexed inside leg may require more muscular support. The muscle activity required to stabilize the flexed leg may approach that of the extended leg, even if the extended leg is supporting more of the skier's mass.

Significantly greater activity from the MG and VL of the outside leg during the initiation phase of SL may be indicative of the increased forward and medial pressure that is typical of a SL turn. Such pressure could be created through plantar flexion of the ankle and extension of the knee.

In GS, the VL, BF, and GM showed the most unilateral dominance, being significantly more active on the outside leg during both the initiation and turning phases. These muscles are prime movers and stabilizers of the knee and hip, and increased muscle activity on the outside leg confirms their dominant unilateral function in GS skiing. The VM, however, was more active on the outside only during the initiation phase, similar to its pattern in SL. The dominance of the vastii on the outside leg agree with the results of Berg et al. [1]. The MH were more active on the outside only during the turning phase, suggesting a rotary function in steering the ski as well as stabilizing the knee.

During the completion phase of GS, there were significant differences in average amplitude for the AD, RF, RA and VM. The adductors were active at high levels throughout the turn, suggesting their involvement in stabilizing the hip and knee, and in bringing the center of mass back over the skis in the completion phase. Greater muscle activity for the RA on the outside was only apparent during the latter half of the completion phase and may indicate deceleration of the trunk under eccentric conditions. Extension of the trunk relative to the thigh at this point in the turn is supported by the hip-angle data of Berg et al. [1].

In contrast to statements on dominant RF activity from the inside leg by several authors [3, 4], our data (Fig. 1B) agree with Berg et al. [1], and indicate similar EMG activity of the RF during the initiation and turning phases, which corresponds to their "eccentric" phase. However, the fact that the inside RF is just as active as the outside, certainly provides additional support for its role as a hip flexor in GS skiing. The significantly greater average amplitude of the RF on the outside during the last part of the completion phase may be, as with the RA, related to decelerating trunk/hip extension.

The greater activity of the VM on the inside leg during the completion phase of GS may be associated with the initial transfer of weight to the new outside ski just before unweighting of the skier occurs.

In summary, despite evidence that greater forces are supported by the outside leg in skiing, SL was characterized by similar bilateral muscle activity. Differences in body position that relate to skeletal and muscular support may explain these bilateral similarities. In GS, although many muscles positioned on the inside and outside of the turn had average am plitudes of greater than 50% MVC, the VM, VL, MH, BF, and GM on the outside leg had significantly greater activity during the initiation and turning phases, as did the RF, AD, and RA during the completion phase.

The authors gratefully acknowledge the assistance of Cindy Suplizio, Steve Swanson, Mike McGarry, Jeanne Schultheis, and Tricia Murray in data collection and analysis.

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13
THE EFFECT OF DIFFERENT USES OF THE UPPER LIMB ON BODY COORDINATION DURING RHYTHMIC PARALLEL TURNING

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Keywords: parallel christie, motor-learning process, electromyography, alpine skiing.

1 Introduction

Regardless of the motor-learning process and the respective progressions used in the different ski schools that lead to the parallel Christie, the pedagogical patterns are dominated—in a combined order—by the extension-flexion mechanism, by the trunk torsion, and by the pressure cross-over between the dale- and uphill leg [1] [2] [3] [4] [5] [6] [7] [8] [9]. Using the poles for support and for initiating the extension in order to overcome up to 1000 N [10], but also for the body equilibrium and/or to launch the turn, is not always evident nor clear.

With regard to sport-specific EMG, the literature reveals that a number of Olympic-sport disciplines have received a lot of attention (e.g. swimming, cycling, running and skiing), while other sports have received but little attention, and many sports none at all. Clarys and Cabri [11] reviewed the use of EMG in the study of sports movements, among which 17 alpine-ski studies were identified. Their review of EMG research in downhill skiing dealt with the special slalom, giant slalom, super-giant slalom and downhill racing, including ergonomic and pedagogical aspects. It was acknowledged that measuring muscle activity in alpine-ski movements in field conditions is among the most difficult kinesiological investigations because there are so many uncontrollable variables [12] [13] [14]. Even if some of these variables can be calculated, they remain approximations [15] [16].

Most of the "EMG and Alpine skiing" studies deal with competitive approaches and it has been clearly stated that there is a distinct neuromuscular motor control difference between the competitive and recreational skier [3] [4] [17] [18] [19]. Consequently, the basic parallel Christie is therefore different from the competition parallel turn. The only common denominators are (1) the emphasis on eccentric muscle activity as the skier opposes the downward pull of gravity, which may be a somewhat slower (and lower) eccentric action of longer duration during each basic parallel Christie, and (2) the omnipresent rhythmic element with a continuous repetition of crouch phase, turn-initiation, turn-execution and exit-phase sequences, with, of course, tighter turns with greater torsion forces during alpine racing or intense recreational skiing [9] [20].

Previously, in studying three basic turns, the authors compared the muscular patterns of the Stem Christie, the Stem Turn and the Parallel Christie in order of increasing difficulty of execution. The Stem Christie and Parallel Christie showed higher levels of rhythmic movement (92 and 84%, respectively), while second initiation movement of the Stem Turn produced 74% repetitive rhythmic patterns only. In addition, its agonist-antagonist co-ordination pattern was more complex and did not correspond with the classic findings for the flexion-extension mechanism.

The relation between the activities of the agonist-antagonist airs (two flexors vs. two extensors) were clearly different at the level of co-contraction in the Stem Turn when compared with the first initiation movement (Stem Christie) and the third initiation movement (Parallel Christie).

The rhythmicity of the parallel Christie induces the effective use of the poles and this explains in part the choice of this particular movement for the study of the influence of different arm strategies on the overall neuromuscular control for the benefit of motor learning.

The purpose of this study was to measure the muscular activity with kinesiological EMG during different parallel turns (on location) and to verify the influence on the neuromuscular co-ordination of agonists and antagonists of the legs, arms and trunk of (1) planting the pole; (2) just holding and pretending to plant the pole; and (3) skiing without poles, with the arms on the back.

2 Procedures

Twelve male ski instructors with French ski-school certificates participated in the study and were, prior to the experiments, informed of the nature of the testing procedures and the importance of correct movement execution.

The analog raw EMG was recorded on location with a portable seven channel FM recorder (TEAC HR30 E) and with pre-amplified bipolar surface electrodes supplied with a precision instrumentation amplifier (AD 524, Analog Devices Norwood, USA). These electrodes were fixed on the midpoint of six muscles located as agonist—antagonist muscle pairs in the arms (M. biceps & triceps brachii), the legs (M. rectus and biceps femoris) and the trunk (M. obliquus abd. ext. & M. erector spinae) respectively. The hardware for the EMG data acquisition was designed for multi-disciplinary purposes. The skier was not to be disturbed during the movement. The system has a freedom of action (continuous measurement over several minutes). Several muscles as well as audio-resistance phenomena were eliminated by means of high input impedance amplifiers [21]. The raw EMG was full-wave rectified and enveloped using a moving average principle and normalized to the highest-peak-amplitude procedure per subject and integrated [22] [23]. Further analysis procedures were carried out with the Electromyographic Signal Processing and Analysis System—E.S.P.A.S. Statistical analysis was performed on the IEMG values using a paired student-t test. Qualitative pattern specificity characteristics were analysed with the IDANCO-EMG pattern evaluation system [9].

The field measurements took place in Tignes (France) on a slope with constant inclination. In an earlier study [9] it was shown that the IEMG—as a reference for muscular intensity—decreased and increased depending the slope angle (Fig. 1). In order to avoid this influence we have chosen the upper part of the previously used slope (11°–169 m and 14 turns).

3 Results and discussion

3.1. Specificity

The full-wave rectified, averaged, and as linear envelopes, normalized EMG was first subjected to a qualitative control. The six different muscles of each subject for each parallel Christie trial with the different arm strategies was analysed for specificity with the IDANCO System [24].

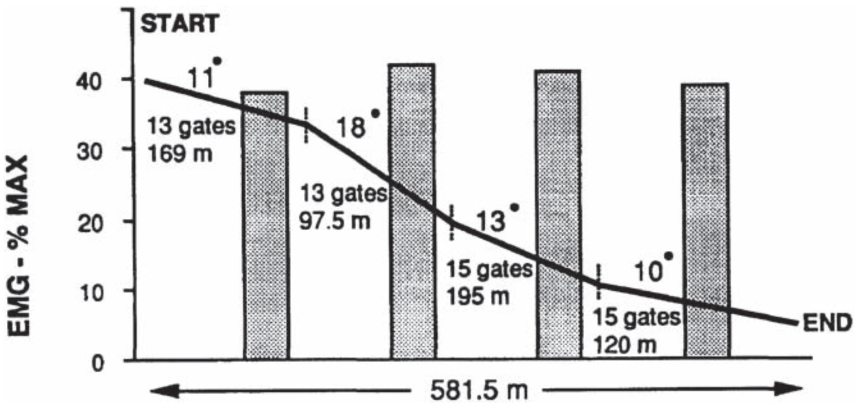

Fig. 1. Muscular intensity is influenced by the slope inclination regardless of the distance of the descent [9].

This EMG pattern-quality and similarity-comparison system is based on the principle of form similitude of curves. Despite the repetitive nature of the movement sequences studied, no identical patterns were found at all. Skiing with the arms on the back was different from the parallel Christie while planting the pole in 67% of the cases and was different from the parallel turn with just holding the pole 85% of the patterns.

The comparison of turning while planting with turning while pretending (or just holding) the pole indicated 31% ANalogue (good similarity) and 65% COnform (poor similarity) patterns.

Table 1. Average intensity (% IEMG) per muscle, for all subjects (n=12) using 3 different arm strategies

Muscle	Plant pole	Hold pole	Arms on back
M. biceps brachii	35.0 (12.2)	36.4 (7.6)	46.0 (10.9)
M. triceps brachii	26.0 (6.9)	34.1 (12.0)	35.6 (9.9)
M. obliquus ext. abd.	32.1 (16.0)	35.6 (10.7)	39.0 (15.8)
M. erector spinae	44.7 (6.3)	54.8 (9.0)	49.0 (13.5)
M. biceps femoris	38.0 (12.0)	42.6 (10.0)	44.2 (8.8)
M. rectus femoris	36.3 (12.7)	37.8 (7.7)	38.5 (5.6)

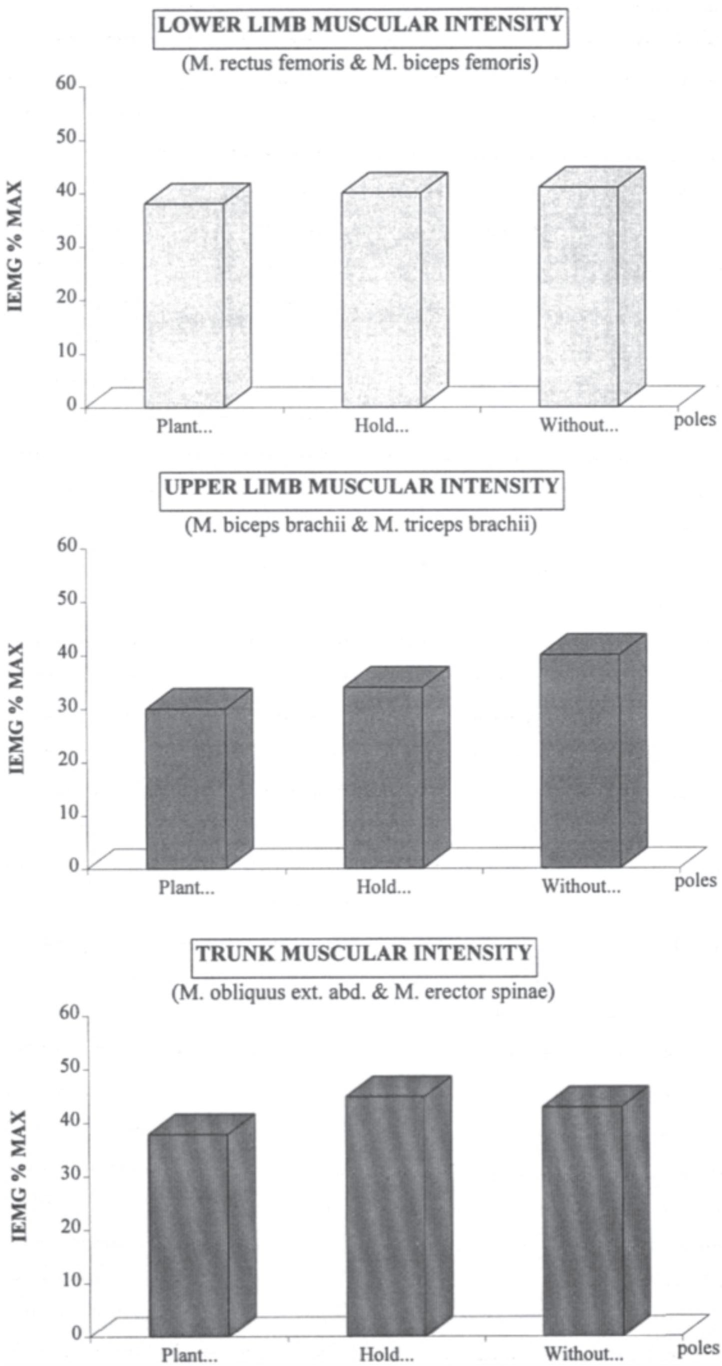

Fig. 2. Muscle participation per body segment (IEMG % Max=Highest peak/subject averaged)

The muscular similarity was expected to be higher than the results found. The parallel Christie without poles and with the arms on the back seems to be a different movement.
However the EMG while planting the ski pole showed a highly cyclic pattern but with less muscular co-activation and less eccentric work than one usually finds in more competitive skiing.

3.2. Intensity

The mean IEMG of the six investigated muscles for all subjects are listed separately for the three arm strategies in Table 1.

The average of the IEMG of both the agonist and antagonist gave an indication of the muscular intensity per segment shown in Fig. 2 and all the mean EMG data of all muscles over a left and a right turn for all subjects is presented in Fig. 3.

For the respective muscles and body segments, we notice an increase of activity from turning with planting the pole (lowest) to skiing without poles (highest). Between the parallel turn with just holding the poles and without poles, we found no differences.

However, “without poles” versus “planting poles” ($p<0.01$) and “just holding poles” versus “planting poles” ($p<0.05$) were clearly different (Fig. 3).

Obviously the parallel Christie with the effective planting of the pole for support and initiating the turn is the most economic variation and thus best for the beginning stages of the learning process.

In addition, just holding and/or pretending to plant the ski pole creates extra loading on the back (M. erector spinae—Fig. 2)

4 Conclusion

These data suggest that planting the poles during the parallel Christie may benefit the apprentice skier in the beginning of the learning process, due to the muscular economy associated with it.

Both the pattern similarity and muscle intensity comparisons indicated that the basic parallel Christie is influenced by the different arm strategies.

These data suggest also, that skiing with poles without effectively usingthem, is the first progression towards more competitive parallel turning, but it creates additional loading of the back.

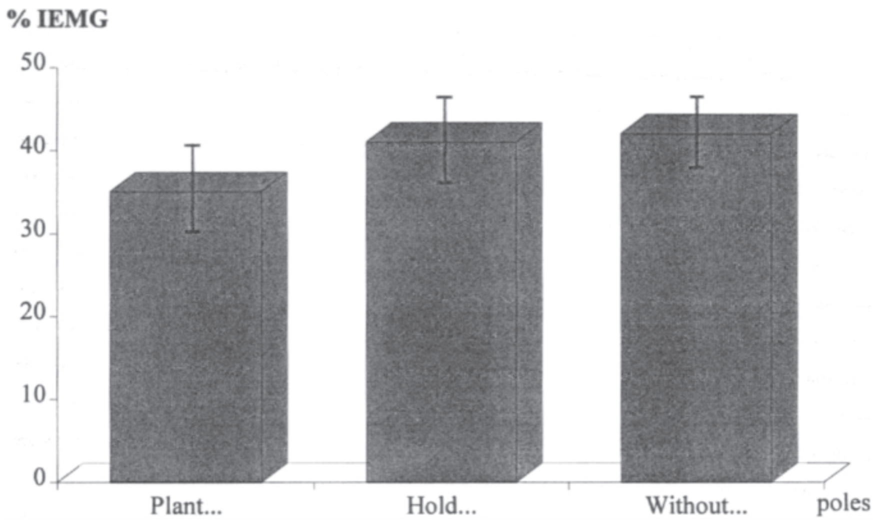

Fig. 3 Average muscle intensity (of a left and right turn) for all subjects and all muscles for the three different arm strategies of the parallel Christie.

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14
PRESSURE DISTRIBUTION MEASUREMENTS FOR THE ALPINE SKIER—FROM THE BIOMECHANICAL HIGH TECH MEASUREMENT TO ITS APPLICATION AS SWINGBEEP-FEEDBACK SYSTEM

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Keywords: biomechanics, pressure distribution, feedback, alpine skiing.

1 Introduction

Knowledge about pressure distribution inside the ski boot can be used for optimizing material aspects and the individual fitting of the ski boot, and also for the assessment and improvement of skiing performance itself. Fifteen years ago, measurements of that kind were not feasible because of the lack of appropriate sensor technology. Since then systems have been developed which allow for the collection of pressure information underneath the footsole and also along the tibia without affecting the skier.

For the dynamic measurement of pressure distribution inside the ski boot, basically the same methods as in regular sport shoe research [1, 4] are suitable; an overview of the pressure measurement systems, used in biomechanics, is given by Schaff [8].

In skiing, only two measuring principles have been able to meet the special requirements—adequate humidity and temperature resistance—inside the ski boot. First, there is the capacitive method with measuring insoles and tibia mats (MICRO EMED), and second, there is the piezoresistive principle with hydrocells as pressure transmitters (PAROTEC).

The following will present and discuss different principles of pressure measurements from the past to the present, focusing on the special situation inside the ski boot. The practicability of these methods and their biomechanical/measuring-technical aspects in the application for scientific studies will be emphasized.

2 History of pressure measurements in ski boots

In 1983, pressure measurements in the laboratory with ski boots were first performed by Hauser [2] and Sehattner [13], who were using a capacitive measuring mat attached to the skin of the subject. This method, which finally led to the novel-system® (EMED), was perfected, thus providing continually better quality of the laboratory measurements of the pressure underneath the foot. In this period, the first field measurements were also taken, using "portable" data storage units or heavy telemetric devices. In 1982 the amplifier storage unit had a weight of 8 kg, the data-loggers of today are small and weight only about 500 g (Fig. 1).

Fig. 1. Parotec® Datalogger with exchangeable memory card.

In basic research, most experimental results have been achieved with the capacitive insoles, which are characterized by relatively high resolution and low thickness of the sole. The EMED tibia mat system helped to reveal major differences between rear-entry boots and conventional ones as regards the resulting tibia pressure. Skiing with the first rear entry boots, for instance, with their characteristically high pressure at the upper end of the boot, turned out to be more difficult than when using conventional boots with widely homogeneous pressure distribution. Modifications to the rear entry boot, based on measurements with the capacitive system, established comparable characteristics regarding this criterion, thus indicating the importance of such measurements for assessing the effects of design changes. From this time, measurement-supported ski boot development, using the results from either laboratory or field testing, directly applied to the human being, has been established.

Since alpine skiing and especially ski-racing are extremely dynamical sports, the limits of the capacitive system for higher-frequent analysis have been reached. Its boundary frequency of 100 Hz restricts its use for vibration and damping measurements. As there were no other commercial products available, our own developments had to be carried out. Since 1990, therefore, we have been working—in cooperation with industry—on a new, high-frequent measuring device for alpine skiing. The demands of the new system, resulting from our experiences with capacitive method, can be summarized as follows: possible sampling frequencies over 500 Hz and high robustness of the transducers and cable connections.

Measurements with elite skiers

Since the elite ski race ought to be one major field of application, great importance was placed on it. For the past three years, the hydrocell method has been used routinely and meets the demands in ski-race investigations.

Together with a synchronized video-analysis, which allows for the display of pressure and video information simultaneously, quick and reliable data can be collected with appropriate sampling frequency up to 1000 Hz, normally 200–250 Hz. For obvious reasons we may not publish detailed information on the pressure distribution found with elite ski racers of national teams, but the reports [9, 16] confirm the importance of the pressure development underneath the heel during the turn.

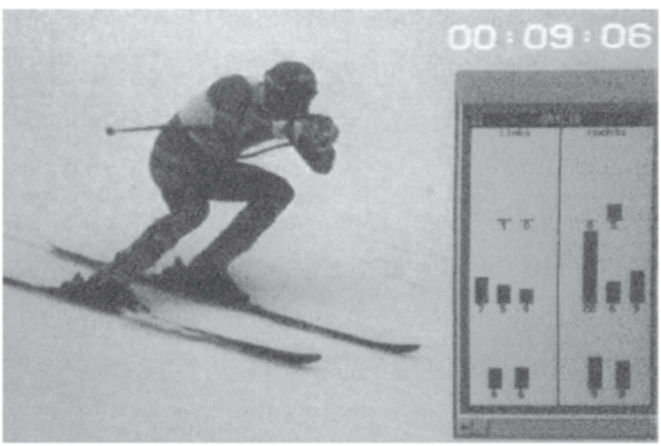

Fig. 2. Pressure distribution taken from Patrick Ortlieb during a downhill at Kandahar, Garmisch.

For example, Fig. 2 shows Patrick Ortlieb, the 1996 world champion for downhill skiing, during a run at the Kandahar in Garmisch. The bars overlaid on the video represent the actual pressure at the anatomic landmarks that can be seen in Fig. 3. The pressure distribution seen in Fig. 2 indicates a well centralized position and steering forces on both edges causing high pressure values at metatarsal I of his right leg, but also significant values at metatarsal IV/V of his left leg. The moderate heel pressure also points out that the skier has an optimal gliding position. Such a position can be found from various athletes, although individual variations occur.

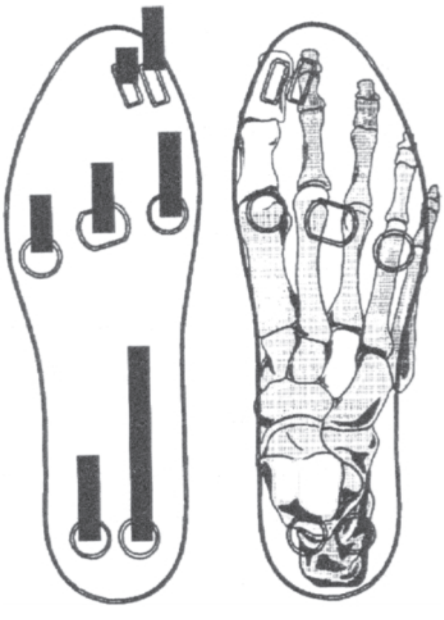

Fig. 3. Location of the pressure transducers used with elite skiers.

Not only in downhill skiing, but also in super-G and giant slalom, a properly equalized pressure distribution during gliding periods and an increasing heel pressure, just at the right moment during steering, seems to be the key to good performance. Even high performance athletes like Anita Wachter (Fig. 4) can work on their position by analyzing their pressure distribution during the run. Such an analysis, its interpretation and derived conclusions have to be done individually and in close co-operation with the coaches. The results of this process might help the athlete to perform better, but are not the topic of this paper. However, having experience of over 50 measuring days with elite skiers, we can conclude that the hydrocell technology has proven to be a reliable, reproducible tool in assessing pressure distribution in the ski boot under rough conditions. Although the system in use allows measurements with two soles, each carrying 16 measuring points, the reduction to 7 points on each side offers sufficient information and was more acceptable to both the athlete and the coach.

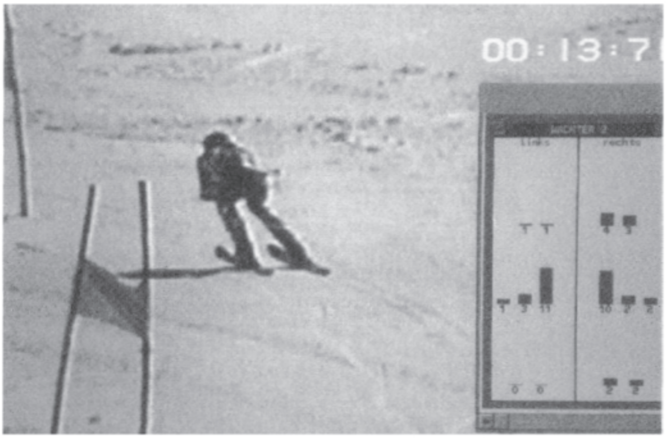

Fig. 4. Performance optimization of Anita Wachter using video overlay technique with pressure distribution measurements.

However, the desire to perform measurements collecting data from all around the foot during skiing still remained. In particular, the heel pressure and its relation to the pressure distribution in the boot was of interest.

3 In search of the optimal measurement tool

In 1995, we conducted the first measurements with a new system, developed for performance- and boot-design studies. The so-called ‘measuring sock’ allows an “all-around” determination of the pressure inside the boot at altogether 64 of the most interesting contact points between foot and boot. Fig. 5 shows the device mounted on the foot and Fig. 6 displays an overview of the different pressure transducers. This high-tech mat, which was primarily designed for basic research, allowed, for the first time, a real inside look at the boot in action. Commonly, we synchronize these sock measurements to a video recording of the runs, which gives us the opportunity to later overlay the colour-coded pressure information to the video picture. The special software needed for this purpose also allows interpolation of the pressure data before visualizing it. This form of displaying the collected data has proven to be very helpful for the interpretation of pressure distribution.

Fig. 5. The “measuring sock” mounted on the foot.

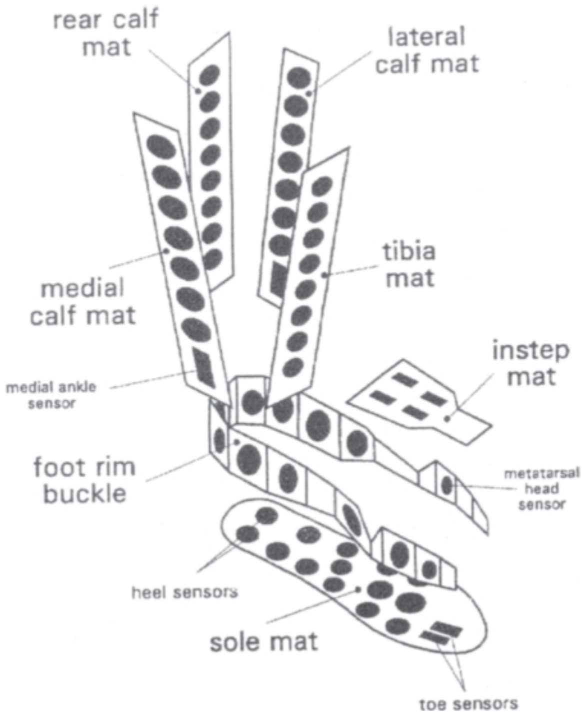

Fig. 6. The different parts of the “measuring sock” with location of the 64 transducers.

Figures 7a, b, c show three phases of a hopped short turn overlaid by the interpolated pressure distribution of the left leg. In Fig. 7a the skier is still air borne and pressure is just transmitted at the in-step mat as a reaction to the explosive up unweighting. Some pressure can also be seen in the area of the medial ankle. Fig. 7b shows a moment at the beginning of the steering phase when the skier is in a well centralized position, increasingly flexing the joints, especially the ankle joint. Therefore, high pressure values appear, here at the lower part, of the tibia mat, but there is also significant pressure at the heel and the medial fore foot. At the end of steering, shortly before the next release, the skier shifts his weight backwards and also increases edging, which can be seen by remarkable pressure along the medial foot rim and highest values at the heel (Fig. 7c).

Fig. 7. Pressure distribution around the foot at different phases of a hopped turn.

Looking at pressure data displayed in this form helps to explain at least some of the questions concerning the interaction between foot and boot during the turn. Fig. 8 gives an example for such an interaction, showing the principle characteristics of the pressure values at the medial toe and those at the foot's in-step, collected during a right-left combination with parallel turns.

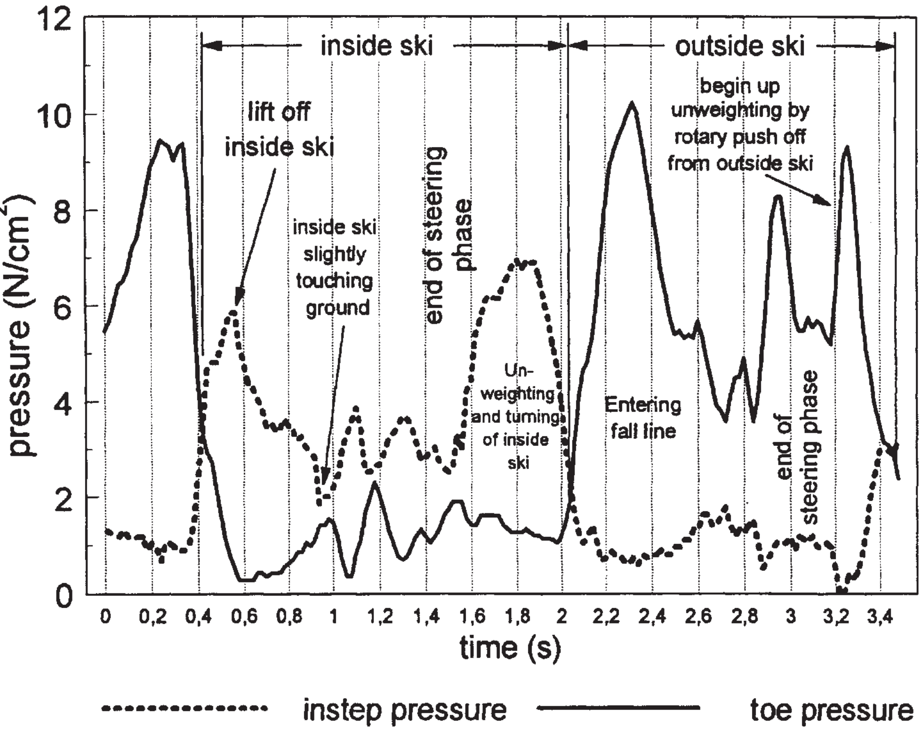

Fig. 8. Time history of the pressure values at the medial toe and the instep during a combination of parallel turns.

Besides performance aspects, former studies from Schaff [12] and measurements like those described, revealed the importance of the ski boot's design, concerning the resulting pressure distribution during the different phases of the swing. These effects have been the subject of a design study, which compared four ski boots of different manufacturers under similar conditions. The results showed interesting differences between the boots tested and could be used as basic criterion for their classification. Fig. 9 compares the resulting pressure maxima at the tibia during a set of short step turns (*"Umsteigekurzschwünge"*). Although there is still no final consent as to how the "ideal" pressure distribution along the tibia should look, some criteria at least seem to be obvious and must be accomplished. Concerning maximum pressure, the absolute values should not go far beyond 25 N/cm²—pain threshold for men lies at about 30 N/cm² [5, 6]—and should not be applied constantly. Values too low along the tibia, however, may also have negative effects, as the pressure feedback might suffer from the fact that the threshold of the tactile elements is not adequately exceeded. This phenomena could be seen with the former Nordica Polaris®, an exceptionally high boot with extremely low pressure values along the tibia, which for this reason did not establish itself on the market. Concerning these criteria, the boots in Fig. 9 can satisfy all the needs, but they differ concerning the location and the gradient of the pressure distribution. Boot A, for example, shows relatively smooth changes with a local maximum in the lower third, whereas Boot B has a pressure concentration at the lower end and a distinct decline toward the top. Two local pressure spots can be seen from Boot C, and Boot D seems to have an area in the middle, where hardly any pressure is transmitted.

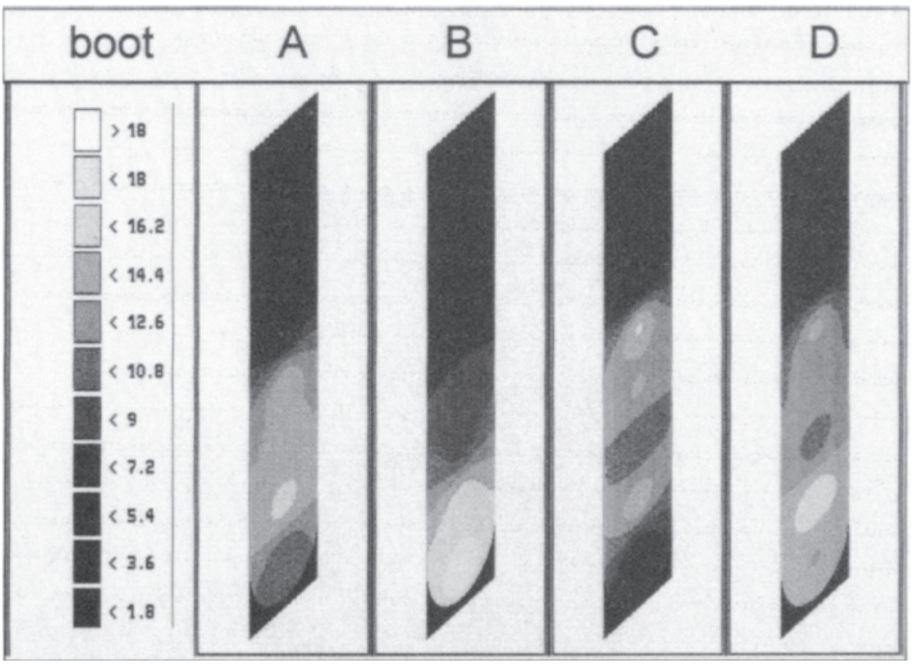

Fig. 9. Interpolated pressure maxima along the tibia from four different ski boots.

When interpreting measurements like these, not only the actual movement (from the video-overlay) but also the skier's impressions and feelings have to be taken into account. Howeve, r if this is done correctly, this technology is a valuable tool for the optimization process in ski boot design.

4 A practical application of heel pressure measurements

From the highly sophisticated scientific method, which culminates in the above mentioned measuring sock, a system has been derived, which represents just the basic element of all pressure-distribution devices, a single measuring-cell. Its signal is used for the feedback of pressure information to the skier, making the system applicable for learning, education and training purposes. This biofeedback system (SWINGBEEP®), which has been realized in co-operation with the University Sport Institute of Vienna, transmits an acoustic signal to the skier and an optical to the instructor or coach, as soon as the heel pressure exceeds an adjustable threshold. The components of the system (a main unit with volume and sensitivity adjustment, the pressure transducers, the ear phone and the two optional lamps) can be seen in Fig. 10. The idea behind the system is to provide a simple method for accelerating and optimizing the learning process, not only in alpine skiing, but also in other disciplines (e.g. classical cross-country skiing, skating, snowboarding, etc.).

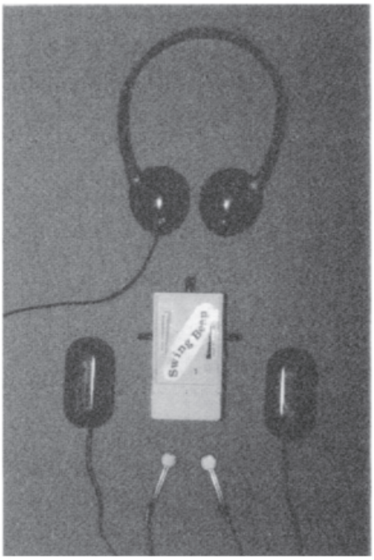

Fig. 10. Components of the SWINGBEEP®-System for the education of ski instructors.

Its application in alpine skiing is based on the fact that the timing of the heel pressure (Fig. 11 a,b,c) is an important criterion for performance and can be changed more easily, having the accustic (and objective) feedback signal as additional learning information. As the principle characterstics of the heel pressure are basically visible in all skiing techniques from plow to parallel turn, the system has a variety of applications.

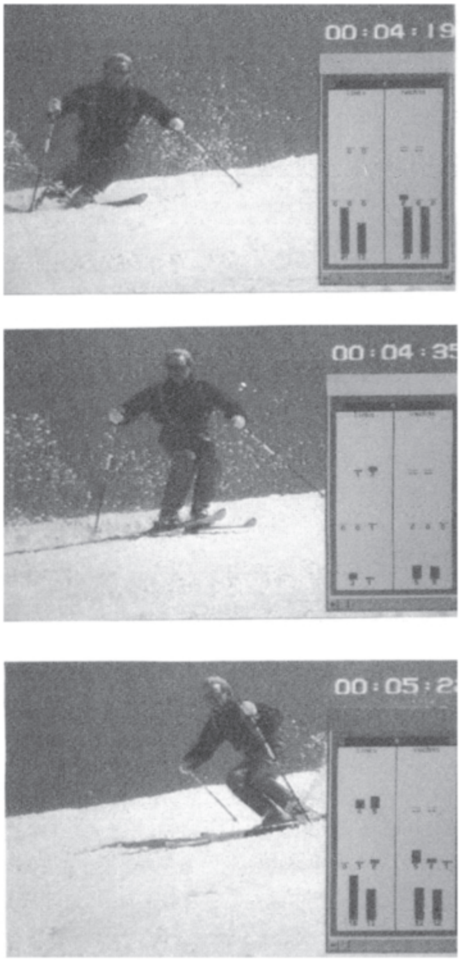

Fig. 11. Characteristic timing of the heel pressure during parallel short turns.

A video demonstration can best show its usage, the pressure information will be made visible for the observer through the help of high performance LEDs fixed at the boot (Fig. 12). The different turns have been demonstrated at the Interski Congress in Japan, and are summarized in video compilation that is available by the authors.

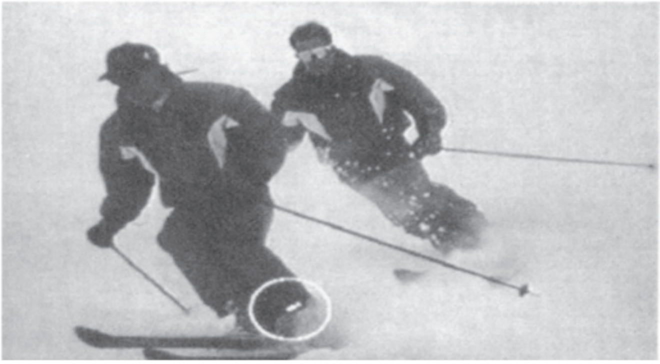

Fig. 12. Application of the SWINGBEEP®-System for the education of ski instructors.

The feedback system has been tested by over 100 skiing instructors and skiers over a period of two years. It is currently used for a prospective multicenter study to prove its relevance with respect to an enhanced learning curve.

5 Discussion and future aspects

Fifteen years of experience and constant modification with pressure measurements in skiing served as a basis to achieve a real-time feedback solution for the skier.

The content of this paper is intended to give an overview and an inside look at different aspects of pressure measurements while skiing. It may serve as a methodical reference but does not supply statistical data and studies. We would kindly like to refer to the cited literature.

The advantage of pressure distribution measurements inside the ski boot, for product development, technique analysis or for the support of motor learning, is that it can be applied with any normal ski boot. The skier does not have to use a special measuring binding or a special ski boot, but can ski with familiar equipment.

Therefore, pressure-distribution measurements will influence the approach to alpine skiing more and more. The measuring sock and the SWINGBEEP-System represent two actual examples of this tendency.

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15

SKIING TECHNIQUE IN SWING TURNS: DISTRIBUTION OF STRESS ON THE HIP-JOINT ARTICULAR SURFACE

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Keywords: alpine skiing, hip-joint pressure, dysplasia, biomechanics.

1 Introduction

Distribution of stress on the hip-joint articular surface is related to the incidence of hip arthrosis [1]. The incidence of hip arthrosis among people with high exposure to sports is significantly higher compared to those with low exposure [2] [3] [4]. Any degree of acetabular dysplasia in sportsmen additionally increases the probability of premature development of hip arthrosis.

During skiing changes in the position of the upper body occur. They are associated with varying degrees of pelvic tilting, which influence the resultant hip-joint force and the hip-joint contact stress distribution, [5] [6].

The aim of this study was to determine how acetabular dysplasia and pelvic tilt affect the distribution of stress on the hip-joint articular surface after shifting of the upper part of the body towards the weight-bearing leg in slow skiing.

2 Methods

A three-dimensional model of the hip-joint articular surface is used in order to calculate distribution of stress on the hip-joint articular surface after shifting the upper part of the body towards the supporting limb. As the model is presented in detail elsewhere [7], only a brief review of the model is given here. In this model, the femoral head is represented by a sphere, while the acetabulum is represented by a fraction of a spherical shell [7]. The radius of the hip-joint articular surface sphere (r) is taken as the mean of the radii of the femoral head sphere and the acetabular shell. It was proposed [8] that stress at a particular point in the hip-joint articular surface (p) is approximately proportional to the cosine of the angle between this point and the pole of the stress distribution (γ): $p=p_0 \cos\gamma$, where p_0 is the value of p at the pole where stress is maximal. The stress integrated over the entire weight-bearing area yields the resulatant hip-joint force:

$$\int p\, dA = \mathbf{R}\,. \tag{1}$$

The weight-bearing area of the articular surface is taken as a portion of spherical surface bounded by the lateral and medial intersecting planes inclined for angle ϑ_{CE} (centre-edge angle of Wiberg) and ϑ_M, respectively with respect to the sagittal plane of the body [7]. The medial angle ϑ_M, is determined at the point where the cosine function of the stress distribution (cosg) reaches the value 0. If the pole of stress distribution lies within the weight-bearing area, the maximal value of the stress on this area p_{max} is identical to p_0. The pole may however lie outside the weight-bearing area. In this case p_{max} is attained somewhere at the lateral intersecting line [7].

The resultant hip-joint force **R** for various body positions is calculated separately by using a static three-dimensional model of the adult hip in the one-legged stance [9, 10, 11]. For calculating **R,** different positions of the body in the one-legged stance are simulated by different values of the lever arm **a** of the force ($\mathbf{W_B}$-$\mathbf{W_L}$), where $\mathbf{W_B}$ is the weight of the body and $\mathbf{W_L}$ the weight of the leg.

In the reference body position in the one-legged stance during skiing (Fig. 1A), the magnitude of the lever arm **a,** which lies in the frontal plane of the body, is calculated according to the approximative expression of [12]:

$$a_n = \frac{W_B \cdot C - W_L \cdot b}{W_B - W_L}\,, \tag{2}$$

where c is the lever arm of the ground reaction force application point radius vector, and b is the lever arm of the force $\mathbf{W_L}$. When determining the magnitude of $\mathbf{W_L}$, the approximative relation of [13] is used: W_L=0.16. W_B. The values of b and c as functions of half the distance between the centers of the two femoral heads D can be estimated according to McLeish and Charnley (1969): b=0.48. D, C=1.01. D. In the inclined body position in the one-legged stance, where the center of body mass is displaced towards the supporting leg (Fig. 1B), the lever arm of the force (WB-WL) is reduced ($a \leq a_n$).

In the reference body position in the one-legged stance (Fig. aA), the inclination of the pelvis towards the horizontal plane (described by the angle φ) is approximately zero. In the inclined body position in the one-legged stance (Fig. 1B), where the trunk is inclined towards the supporting limb, the pelvis is inclined relative to the horizontal plane. The inclination of the pelvis towards the horizontal plane (φ) is related to the degree of inclination of the trunk relative to the sagittal plane of the body. On the other hand, the inclination of the trunk relative to the sagittal plane is related to the lever arm of the force $(\mathbf{W_B}$-$\mathbf{W_L})$, i.e. the lever arm **a** (Fig. 1). Therefore the inclination φ depends on the lever arm **a**. Thanks to its simplicity the following approcimative relation is used in this work.

$$\varphi = \varphi_0 (1 - a/a_n) \ , \qquad (3)$$

where φ_0 is the value of φ at a=0.

If the angle φ is increased, the lateral coverage of the femoral head, i.e. the angle ϑ_{CE} is increased as well:

$$\vartheta_{CE} = \vartheta_{CE,0} + \varphi \quad , \qquad (4)$$

where $\vartheta_{CE,0}$ is the value of ϑ_{CE} in the reference body position (Fig. 2A) where $\varphi = 0$

3 Results

In the inclined body position of the one-legged stance, where the center of body mass is displaced towards the supporting leg (Fig. 1B), the magnitude of the lever arm **a** is reduced relative to its normal value a_n (Fig. 1A). Consequently, the magnitude of **R** and the corresponding contact stress in the hip-joint articular surface are reduced, as shown in Figs. 2 and 3. The decrease of the stress after the shift of the upper part of the body towards the supporting leg depends on $\vartheta_{CE,0}$ and φ_0, where $\vartheta_{CE,0}$ is the value of the centre-edge angle of Wiberg $\vartheta_{CE,0}$ at $a=a_n$, while φ is the value of φ for a=0.

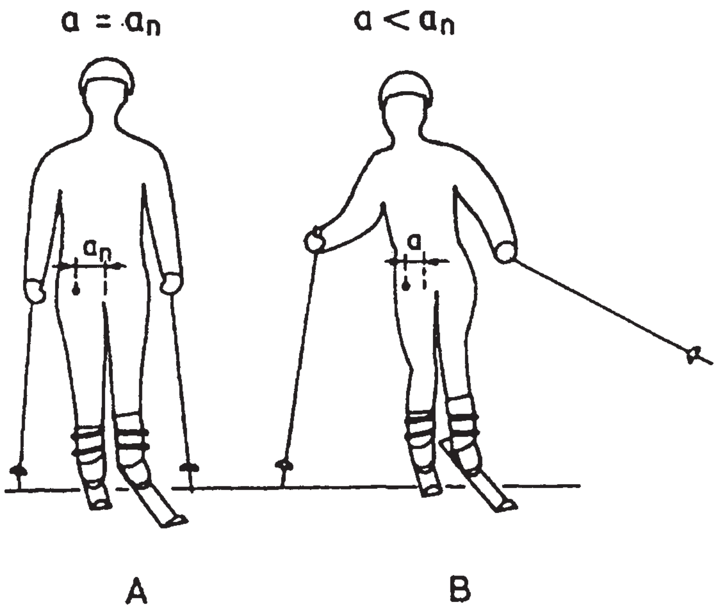

Fig. 1. Schematic presentation of two different characteristic body positions in the one-legged stance: reference ($a=a_n$) and inclined ($a<a_n$), where the center of body mass is displaced towards the hip-joint center of the supporting leg.

Fig. 3 indicates that the decrease of stress after the shifting of the upper part of the body towards the supporting leg is more effective in the case of larger φ_0, i.e. in the case of large inclination of the pelvis during the shifting of the upper part of the body towards the supporting leg. In cases of severe acetabular dysplasia (ϑ_{CE}=2° Fig. 3B) the maximum hip-joint contact pressure is increased even when the upper part of the body is shifted towards the weight-bearing leg with no pelvic tilting.

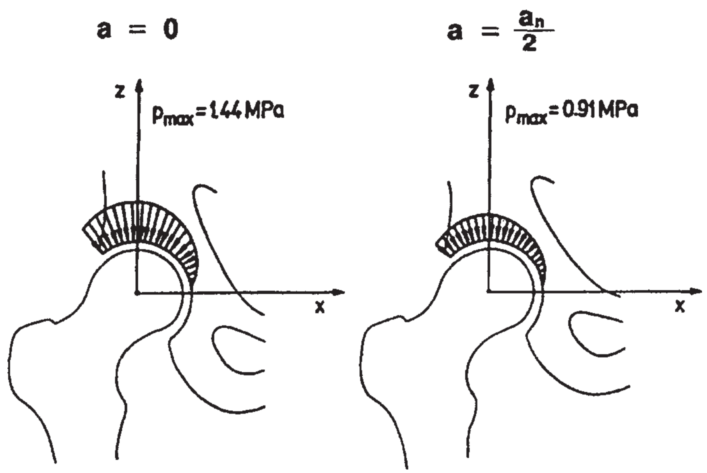

Fig. 2. The calculated distribution of stress on the human hip-joint articular surface in reference (a=0) and inclined ($a=a_n/2$) position of the upper part of the body in the one-legged stance for the initial values of W iberg angle $\vartheta_{CE,0}$= 40°.The values of the model parameters used are: W_B=800 N, D=8.45 cm, r=2.7 cm and f_0=15°

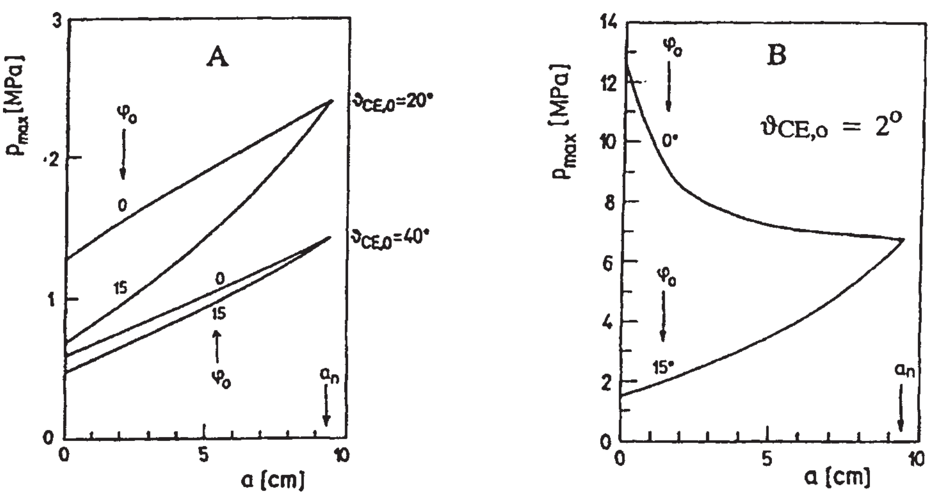

Fig. 3. The maximum value of stress in the human hip-joint articular surface p_{max} as a function of the magnitude of the lever arm a of the force **(W_B—W_L)** for (A) and (B). In all cases, the results are shown for two values of f_0=0° and 15°. The values of the model parameters used in calculations are: W_B=800 N, D=8.45 cm, r=2.7 cm.

4 Discussion and conclusion

During skiing straight downhill, weight is borne on both legs, while during turns it is borne on one leg only. During turning, the upper part of the body shifts towards the weight-bearing leg, the extent of the shift depending on the ground configuration, the speed of skiing and some other factors. The shift of the upper body towards the weight-bearing leg unloads the hip joint.

The extent to which the hip is unloaded depends on the degree of pelvic tilt occurring during turning. The pelvis can be relatively parallel to the horizontal plane of the body ($\varphi=0$), or slightly elevated on the non-weight-bearing side (phi>0). The unloading of the dysplastic hip by shifting the upper part of the body towards the weight-bearing leg is less pronounced with lesser degrees of pelvic tilting (Fig. 3). With large centre-edge angles, the extent of pelvic tilting does not seem to depend noticeably on the degree of hip unloading for a given upper-body shift. Yet, the smaller the centre-edge angle, the greater the effect of the degree of pelvic tilt on the hip unloading for a given upper-body shift. We have shown that in individuals with severe acetabular dysplasia, i .e. with an extremely small centre-edge angle, the hip-joint contact pressure decreases, or even slightly increases during the shifting of the body towards the weight-bearing leg with small pelvic tilting. These findings suggest that skiing may increase the probability of early arthrosis in individuals with dysplastic hips.

In keeping with the results of this theoretical study, subjects with borderline hip dysplasia should be encouraged to use the following skiing technique of swing turns: turning with an increased pelvic tilt on the side of the non-weight-bearing leg with a simultaneous shift of the upper body towards the weight-bearing leg. Thereby the dysplastic hip is unloaded to an optimum degree, and the risk of the development of early arthrosis is markedly reduced.

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16

SENSOR PLATES DESIGNED FOR MEASURING FORCES BETWEEN SKI AND BINDING—A DEVELOPMENTAL SUMMARY

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Keywords: sensor plate, ground reaction forces, biomechanics, alpine skiing.

After an evaluation comparing different models in laboratory based on special criteria, we developed a new force-sensor plate (Fig. 1) for measuring forces in z-direction between ski and binding with sensitive-to-pressure, electrical-resistance layers, designed for a range up to 10 kN. It can be easily installed between ski and binding, mechanically preloaded and measures both statical as well as fast-changing dynamic forces affecting vertically onto the surface. The sensor has a thickness of less than 5 mm and its base corresponds to the bases of the toe-units of bindings.

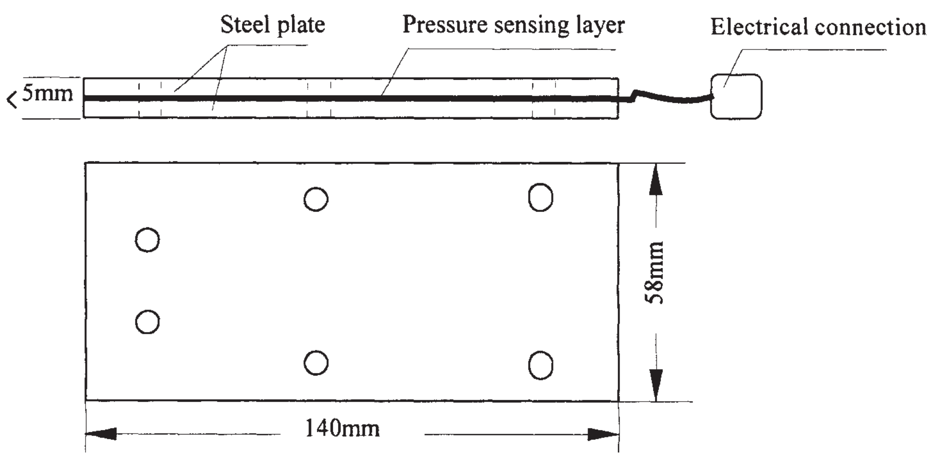

Fig. 1. Force-sensor plate.

1 Introduction

As studies on models have shown—see the exposition under the title, *Different possibilities for measuring force transmission between ski and binding*— not all designs of force-sensor plates are sufficient for the criteria that are demanded when measuring ground reaction forces while skiing. On one hand, the force-sensor plates should simultaneously measure the static as well as the dynamic forces that exceed the static forces many times over. Furthermore, it is to be determined if that method can measure the sheared forces in x- and y- direction as well. On the other hand, it is requested that the driving performance of ski and binding, particularly during curves, is not impaired by the force-sensor plate. Because of this, the construction is restricted to hard (rigid) materials with high solidity, because soft springy materials infringe upon the utilization of edges during curves.

2 Sensor Plate

2.1 Mechanical construction

Both bending beams and bending plates allow force measurement (as with adherance strain gauges) only if truly a measurable bending occurs. Therefore, they are not suitable for solving the problem described above, because they change the skiing performance during curves through additional cushioning effect. For that reason we developed a new measuring principle with sensitive-to-pressure, insulated layers so that bending is no longer necessary. The forces from the binding, working on the steel top plate, will rather be passed directly by means of two intermediate layers of extremely hard (i.e., practically non-compressable), insulating material to the strip-like, electrical-resistance layers (see Fig. 2).

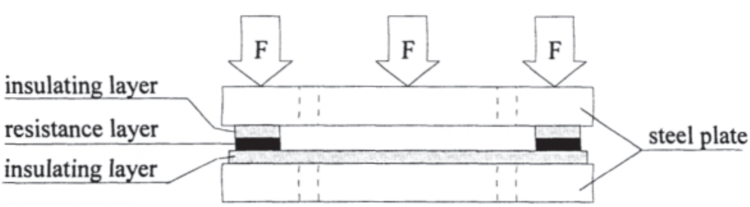

Fig. 2. Measure plate with electrical-resistance layers.

The resistance layers extend closely to the outer edge of the sensor plate parallel to the steel edges of the ski. They are attached to the lower insulated layer that itself is applied to the lower steel plate. The resistance layer and the lower insulated layer consist of hard ceramic. Because the intermediate, resistance and insulated layers are overall merely 0.5 mm thick and are made of extremely hard materials, their compression by force introduction is minute. Consequently, the application of force to the steel edges is not handicapped by cushioning effects. Insulation, resistance and its terminations are realized by a technique of screen printing to the steel plate. This technique allows the design of several forms and dimensions of pressure-sensing resistance layers at a minimum of cost and expense (see Fig. 3).

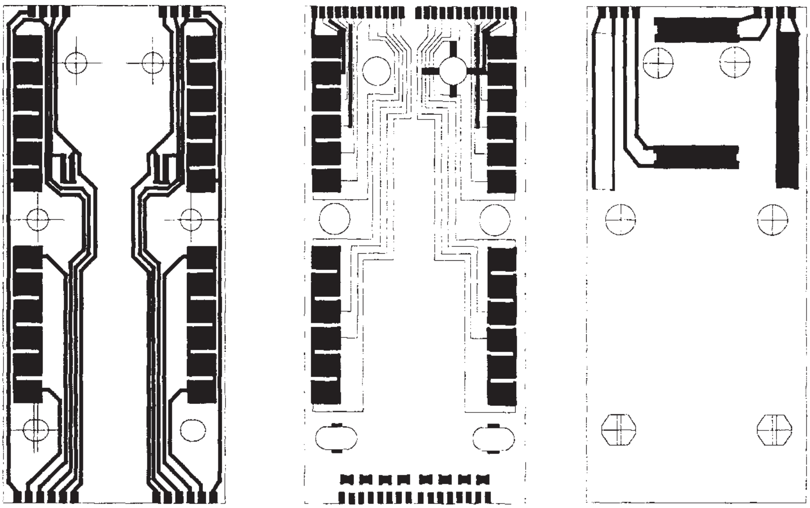

Fig. 3. Examples for pressure-sensing resistance layer.

2.2 Electrical function

It is important to mention that area forces of the intermediate layer affecting the resistance layer are not necessarily distributed regularly on the resistance layer. Within approved load limits, the change of resistance of parts of the resistance layers is approximately proportional to the affecting pressure. Thus, the local change of resistance in areas of larger pressure is higher and areas of smaller pressure lower. As a whole, the effect of the local pressure difference is in a way summed up by the resistance layer, so that the total force introduced through the insulated layers is actually measured.

Our laboratory measurements have proven that pressure-caused changes of resistance are strongly dependent upon the special mixture of the resistance material. We used predominantly one resistance material showing a change in resistance of about 10%/kN for one single strip with a length of 36 mm and a width of 6 mm (see Fig. 4–6). At the same time, the resistance value decreases with increasing area force almost linear.

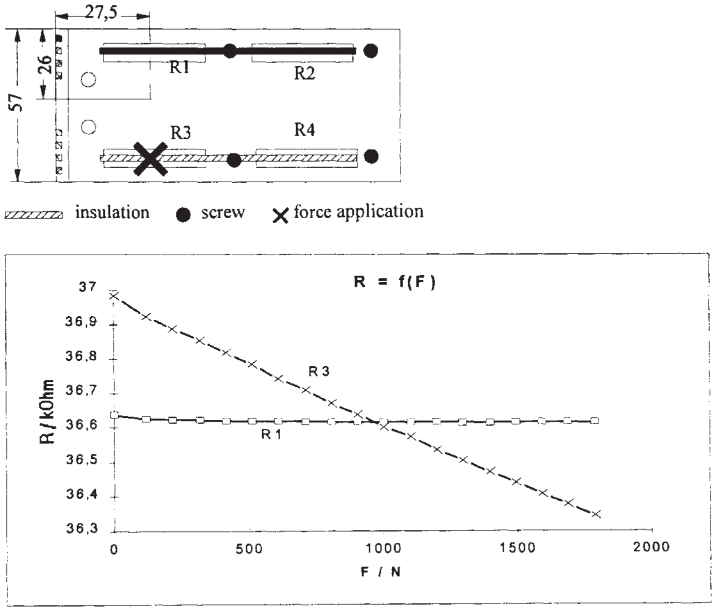

Fig. 4. Resistance change during application of force on the left edge.

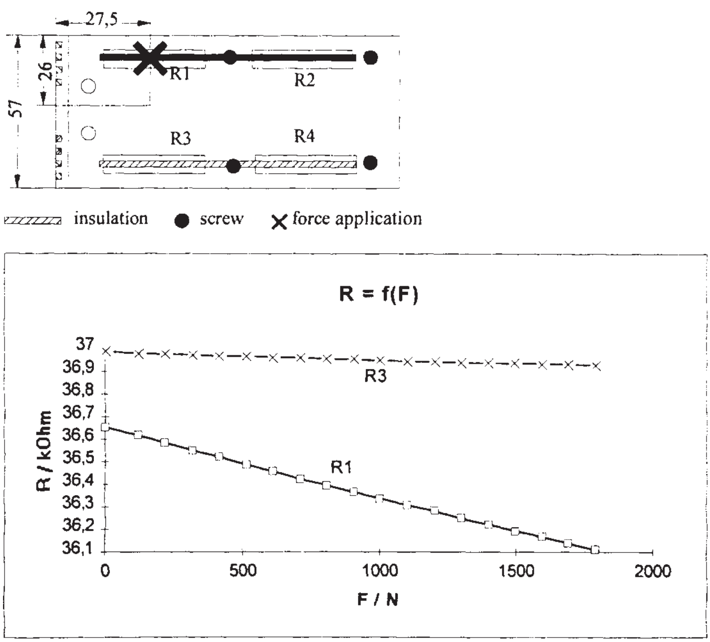

Fig. 5. Resistance change during application of force on the right edge.

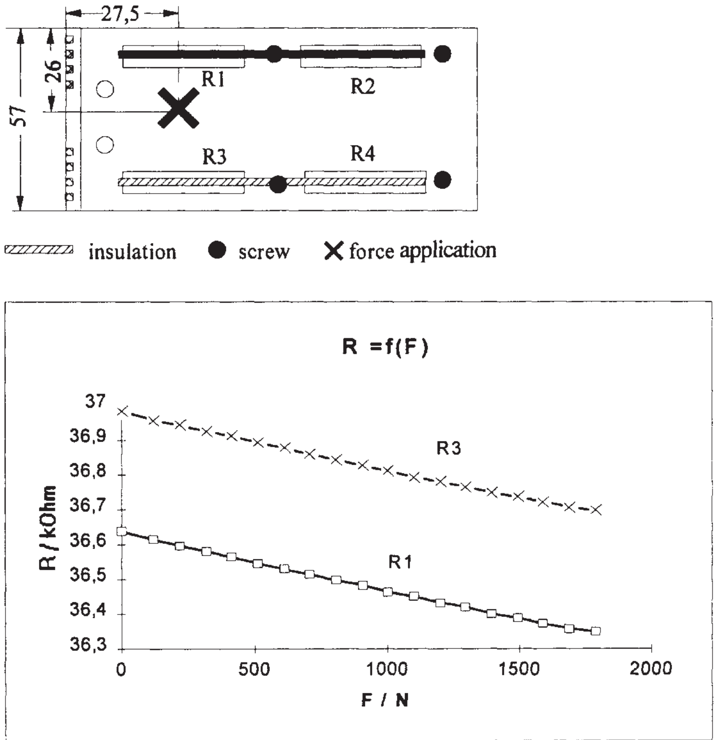

Fig. 6. Resistance change during application of force on the center.

2.2.1 Electrical measuring

On the force-sensor plate, several resistance layers are placed and connected so that pressure forces on the left and the right side of the steel edges and the center of the ski can each be measured and evaluated separately. The outward connection of the three measuring channels as well as the connection of the power supply is made through a multi-pin plug. Connected to a power supply of a 5V-battery the sensitivity without aamplifier amounts to about 1 to 2 mV/ 100N, dependent on the mixture of the resistance material. The dependency on force is almost linear. According to first laboratory measurements the linearity and hysteresis error is less than 3%. The electrical consumption of the entire force sensor plate we dimensioned is less than 5mA.

The Table (1) shows the voltage values which were measured on a sensor plate with interconnected resistance layers to a bridge. The force was during applied to the centre of the sensor plate. The two pressure-sensitive resistance layers on the left and right edge of the sensor plate measure in each case the half of the total force applied. This is shown in the voltage drops of the three bridges. The voltage drop of the bridges on the left and right edge is nearly half of that of the centre bridge (see Fig. 7). Supply voltage of the bridges 5VDC.

Table 1. Voltage values measured on a sensor plate with interconnected resistance layers to abridge.

Force / N	Left edge bridge U/mV	Right edge bridge U/mV	Centre bridge U/mV
0	0,7	0,02	0,4
120	1,8	1,3	2,8
218,1	2,26	1,74	3,7
316,2	2,67	2,17	4,5
414,3	3,09	2,6	5,4
512,4	3,48	3,06	6,2
610,5	3,88	3,52	7,1
708,6	4,26	3,94	7,9
806,7	4,67	4,39	8,8
904,8	5,05	4,83	9,6
1002,9	5,41	5,25	10,4
1101	5,78	5,69	11,2
1199,1	6,14	6,12	11,9
1297,2	6,5	6,5	12,7
1395,3	6,86	6,89	13,4
1493,4	7,2	7,24	14,1
1591,5	7,57	7,6	14,9
1689,6	7,96	7,96	15,6
1787,7	8,32	8,3	16,3

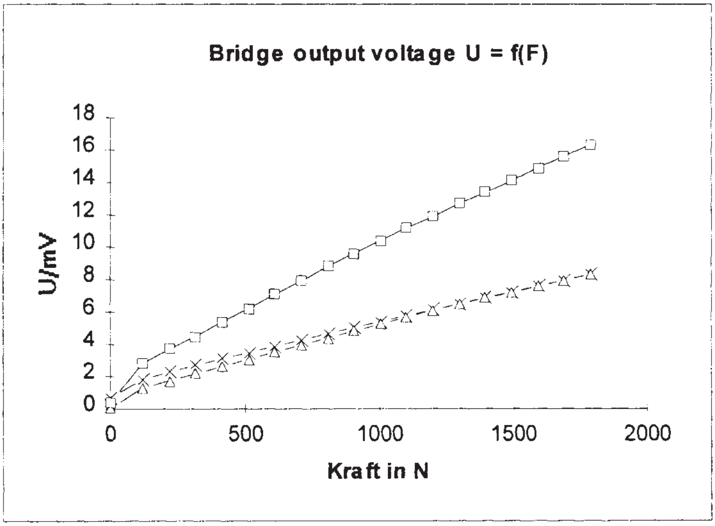

Fig. 7. Bridge output voltage.

3 Results

Because of the rigidity and the low construction height of the sensor plates presented, the driving performance of the ski, particularly during curves is not or only insignificant impaired. The application of the sensor plates during the process of mounting the bindings allows the measuring of the mechanical preloading, which differs from manual mounting (see Table 2).

Table 2. Resistor change before and after mounting the bindings.

Nominal resistance before mounting	Nominal resistance after mounting
R1 = 36,696kOhm	R1 = 36,638kOhm
R2 = 37,017kOhm	R2 = 36,985kOhm
R3 = 37,017kOhm	R3 = 36,912kOhm
R4 = 38,363kOhm	R4 = 38,214kOhm

If two or four sensing resistors are interconnected in a bridge configuration in the conductor layer, it is possible to adjust the three channels of each sensor plate to zero after mounting the binding. Additionally, the influence of the body weight of the skier can also be adjusted to zero. The pressure and the tractive force to the toe-unit of bindings, as well as to the left and right ski edge, are, therefore, recorded from the bridges as a positive and negative voltage drop.

Connection to telemetric systems and analysis through PC and Laptop represent no problem.

The total weight of the force-sensor plate is less than 250g. The complete equipment for a pair of skis consists of a set of four sensor plates to install a measuring system with 12 measuring channels.

4 Discussion

According to our considerations, the measurement of sheare forces in x-and y-directions with force-sensor plates would demand a different construction, but measurement would be imaginable by the same principle of changing through pressure dependent resistance layers.

When the sensor plate is connected to an electric measuring and controlling system, the skier's shift of power can be shown by 12 channels (6 for each ski) on a screen-for example, as beam diagram. Because of getting the influence of force of the toe-unit bindings separate, it is also possible to calculate the torques around the x- and y-axes (see Fig. 8).

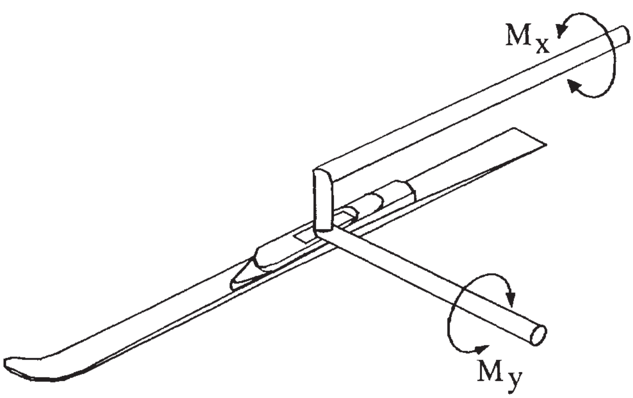

Fig. 8. Torque around x- and y-axes.

The complete measurement of torques should be evaluated by a measurement processing and controlling system, which we have to develop in the future.

5 References

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17

DIFFERENT POSSIBILITIES OF MEASURING FORCE TRANSMISSION BETWEEN SKI AND BINDING

A comparative test of some newly developed sensor plate models in laboratory

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Keywords: force transmission, sensor plate, ground reaction forces, biomechanics, alpine skiing.

In the comparative evaluation of different new force-sensor plate models, a sensor with piezoresistive electrical resistance layers, as shown under 2.2.2, offers the best results for these application environments, because it has the smallest effect on the reaction of the ski when changing direction. This measure plate is distinguished by a minimal yield and height, needs simple following measurement equipment, and a small current consumption only. They have to be mounted between ski and binding (Fig. 1).

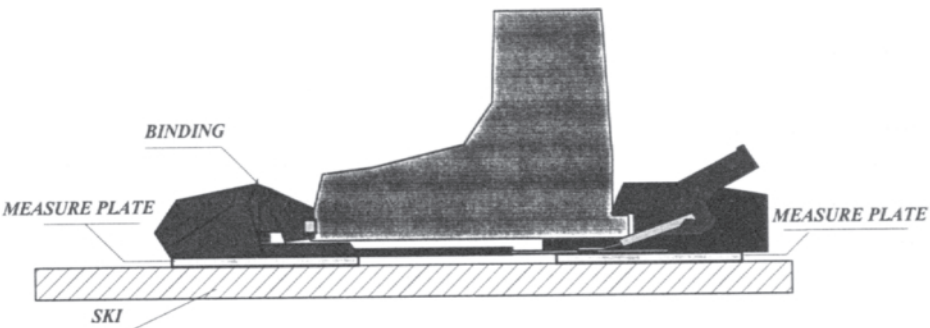

Fig. 1. Measure plates between ski and binding.

For more details and results of developing this piezoresistive sensor plate, see the exposition under the topic: sensor plates designed for measuring forces between ski and binding.

1 Introduction

Force-measure plates following the bending-beam principle (Fig. 2), developed by the *Institut für Trainings- und Bewegungslehre* in Cologne (directed by Prof. Dr. Mester), have been very successful in measuring the force reaction of skiing straight ahead or in gliding passages for many years.

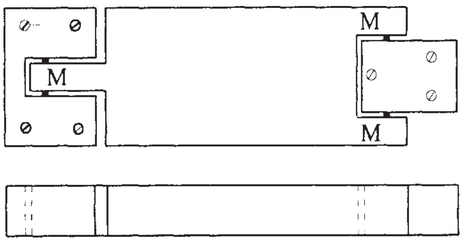

Fig. 2. Measure plate for one binding (like Mod. MESTER, 1988), [1], Measure points with strain gauges M.

The mechanical principle of this measurement is the three-point support. Under each toe-unit of the binding, an aluminium plate 1.5 cm thick is mounted by three square journals, thus hanging in supports, so that it is free to rotate round the y-axis. Because forces in z-direction effect the bending of the square journals (Fig. 2), you can use strain gauges M adhered onto the journals for measuring [1].

It is advantageous that both tensile and compressive forces can be measured. But these measure plates effect the reaction of the ski when changing direction. With it the measure plates distort as well as the journals [2], and so in measuring with simple strain gauges on the distorted surface area you have additional faults (Fig. 3).

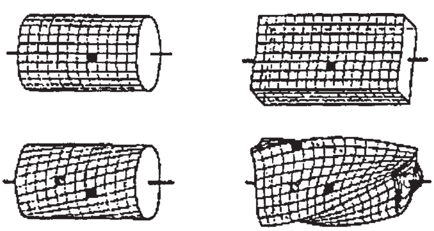

Fig. 3. Distoreted round and square journals.

So Prof. Master asked me for cooperation in developing further methods and new models of force sensors, that do not effect the reaction of the ski when changing direction. To assess the different possibilities in measuring the power transmission between ski and binding, I carried out an investigation to compare different models of sensor plates in the laboratory. At first the possibilities and the principle arrangement (Fig. 1) were discussed in a group and then I specified the criteria of comparison as following:

1. The sensor plate should interfere as little as possible with the performance of the ski and binding system.
2. The distribution of (statical and dynamic) forces in z-direction should be measured separately on the center, on the right edge and on the left edge of the ski under each toe-unit.
3. The measurement should be easily taken and recorded by an electrical measurement system.

2 Methods of measuring

2.1 Measure plates according to the principle of bending plates

2.1.1 General

A mechanical construction following the double-T-girder principle would provide a solution (Fig. 4).

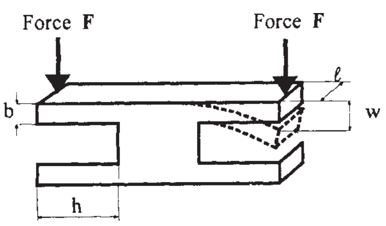

Fig. 4. Bending of an overhanging plate.

Though the double-T has to be an extremely flat one, to achieve as low a height as possible under the binding. The double-T has to be assembled axial-parallel to the x-coordinate of the ski under each toe-unit with the lower plate firm to the ski.

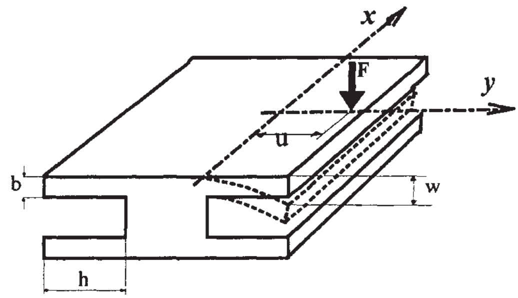

Fig. 5. Deflection of an overhanging plate with force F in a certain point (0;u)

The binding should be screwed onto the upper plate with washers used at the fixing points to provide definite force introduction. The left and the right half of the upper plate operate mechanically like a so-called overhanging plate. As shown in [3], the deflection w(x,y) is calculable as a function of x, y and of the force F (Fig. 5). For instance, if you have a force in a certain point with a distance u, then

$$w(x,y) = \frac{F}{8 \pi K} \{2xu - \frac{1}{2} [(x \ u)^2 \ y^2] \ \ln \frac{(x + u)^2 \ y^2}{(x - u)^2 \ y^2} \}$$

But in these application environments, I determinated the deflection of the half-plates by measurement in experiment (Fig. 6) with a force F introduced from above and spread through a crossbeam, because I think it is more similar to the force transmission of the binding.

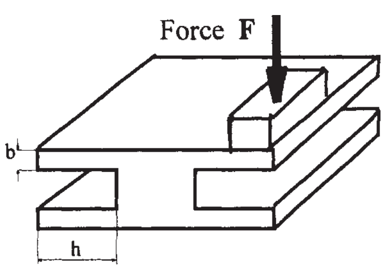

Fig. 6. Force introduction in experiment through a crossbeam 15×15 mm, 70 mm long.

2.1.2 Measure plates with strain gauges and electrical measurement system
The forces are being measured here by compression of the underside of the upper halfplates through strain gauges (Fig. 7).

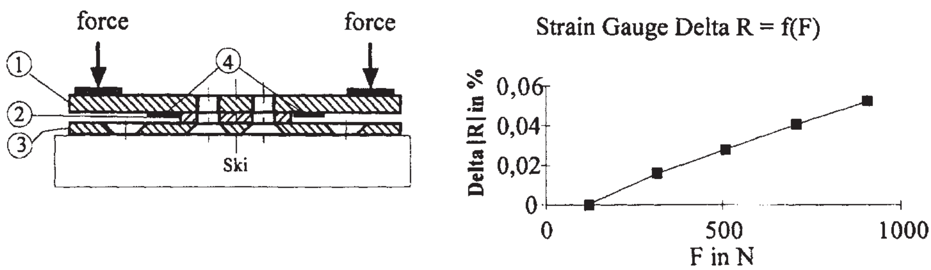

Fig. 7. Measure plate with strain gauges (4).

The measured electrical quantity is the resistance R of the strain gauges. A 750 N measurement range of force F results in a range of about 0,04% Delta R. Here the Delta means the relative change in relation to the starting value.

The evaluation by suitable strain gauge measurement systems is normal and easy.

2.1.3 Measure plates with inductive electrical measurement system
The bending of the upper halfplate is used to change the airgap of an electrical coil, so-called inductivity L (Fig. 8).

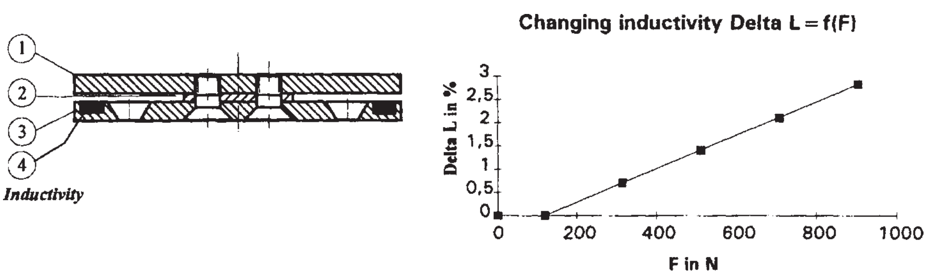

Fig. 8. Inductive measure plate.

In a force range of 750 N, I have found a change of about 2, 3% Delta L. By measuring this inductivity, the affecting force can be evaluated with suitable electrical measurement equipment.

2.1.4 Measure plates with a capacitive electrical measurement system
Here the bending of the upper half-plate is used to change the capacity C of a so-called capacitor—by variation of the distance between two electrode plates. Here a 750 N force F results in an range of about 1 % Delta C (Fig. 9).

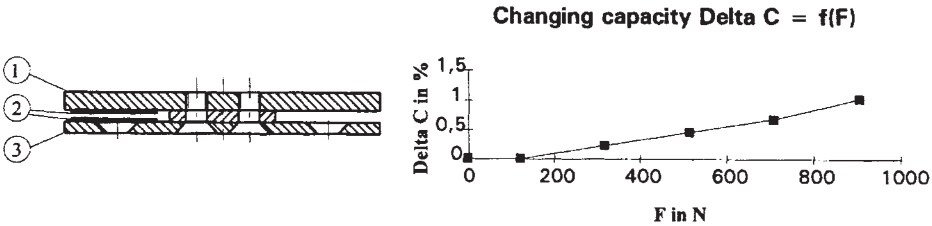

Fig. 9. Capacitive measure plate with electrodes (2).

The force can be represented by a suitable electrical circuit, that is sensitive to the capacity C.

2.1.5 Summary
The electrical circuits of 2.1.3 and 2.1.4 are not so easy to realize as that under 2.1.2. Now it is an advantage of the possible solutions presented under 2.1.2 to 2.1.4, that tensile and compressive forces can be distinguished and the force introduction is definite.

I measured the deflection of a 2 mm thick plate as well as of a 3 mm one (Fig. 10).

Of course, the thicker the plate is, the smaller the deflection will be. That means the yield is less as well as the interference with the ski and binding system. But the height and the weight increase over all. What is better for the piste performance? In addition, to utilize the electrical effects as under 2.1.2 to 2.1.4, you need deflection. A 2, 5 mm plate should be a compromise solution.

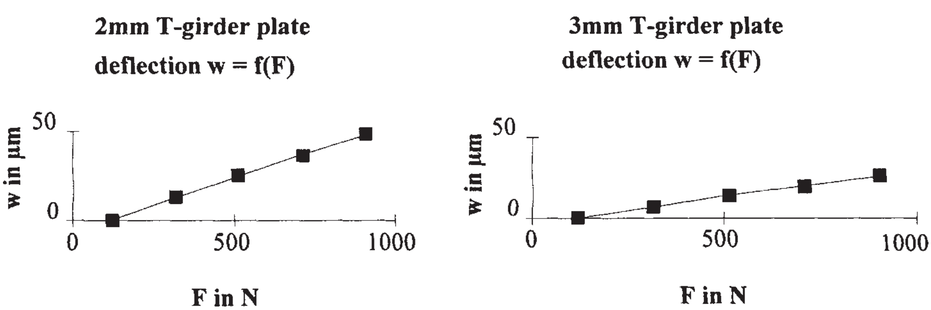

Fig. 10. Deflection of a 2mm and a 3mm T-girder plate.

But on the other hand the disadvantage lies in the considerable bending of the measure plate that interferes with the driving performance: therefore, I refrained from a further development of these models.

2.2 Measure plates with force-pressure transmission and preloading

2.2.1 General

In this design the sensor plate will be fixed and screwed between toe-unit and ski, directly while mounting the toe-units under mechanical prestressing equivalent to the manual assemblage (Fig. 11).

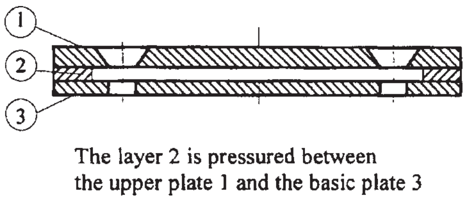

Fig. 11. Measure plates with force-pressure transmission and preloading.

That leaves the force introduction not as destinctive as in the models presented under 2.1 and so there are some mechanical problems due to the preloading forces while the binding is screwed.

But the deflection or compression (Fig. 12) is minimal in comparison to the T-girder construction under 2.1 as well for the mechanical construction used under 2.2.2 with 17 m as for the plates structure 2.2.3 with 14 m.

Because of that, the yield is minute and the interference with the performance of the ski and bindung system is very small.

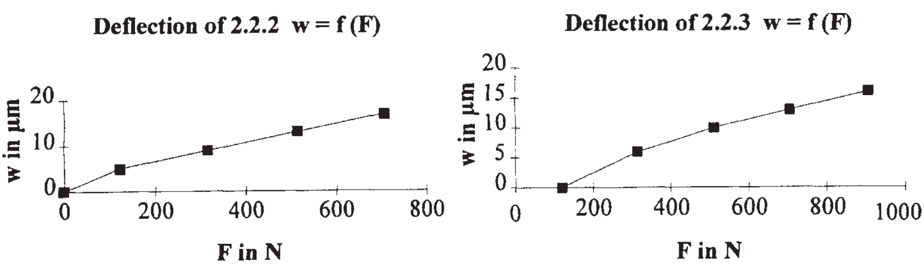

Fig. 12. Deflection of the force-pressure transmission sensor plates.

2.2.2 Measure plates with discrete miniature pressure sensors
In this solution miniature pressure sensors will be swimming embeded in permanent flexible silicon into a so-called dead-ended hole in the lower plate (Fig. 13).

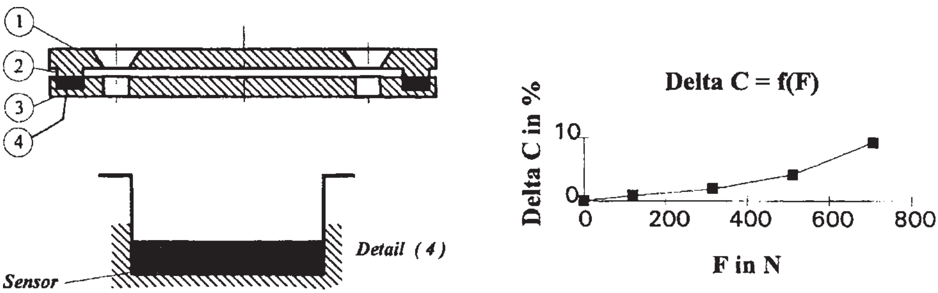

Fig. 13. Measure plate with discrete capacitive pressure sensor.

Suitable, columnar stamps of the upper plate press into the holes and therefore the force is transfered to pressure measurement. I have supplied the laboratory model with four pressure sensors (4-point bearing application) featuring a considerable sensitivity.

In a 750 N range of the force F, the diagram (Fig. 13) shows a changing Delta C of about 9%. Unfortunately it is necessary to supply a separate evaluation circuit for each pressure sensor. In addition to this the softness of the swimming bearing application seems problematic and so I stopped further developement for the present.

2.2.3 Measure plates with piezoresistive electrical resistance layers
In these sensor plates there are sensitive-to-pressure, electrical resistance layers, for instance layers of ceramic as described in [4] or synthetic materials or compounds. These layers are embedded between two insulating layers, sandwich-like (Fig. 14). The insulating layers themselves are embedded between the two steel plates that serve the force introduction and mechanical protection outwards like in the models described above. The force passes through the upper plate and the strip-like insulated layers into the resistance strip as an area force or surface pressure. The change of resistance in the Delta R range of about 0,9% is a measure of the affecting forces F in the range of 750 N (Fig. 14).

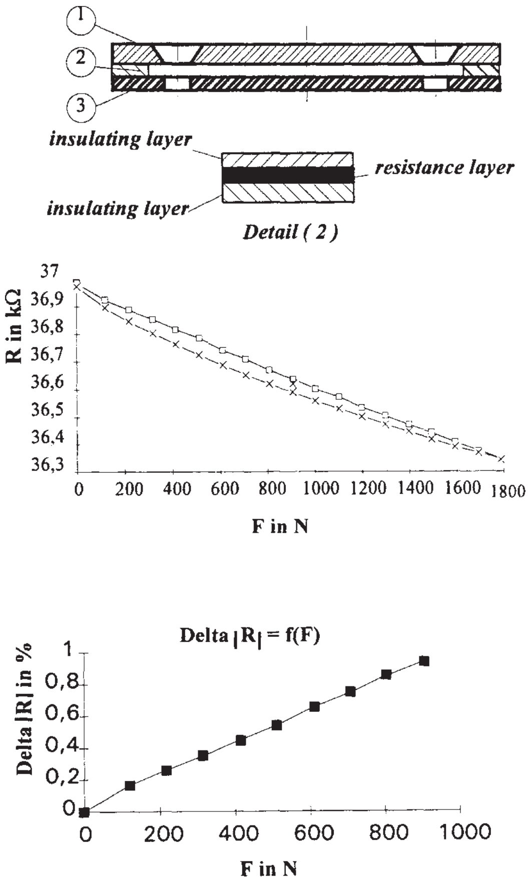

Fig. 14. Measure plate with piezoresistive electrical resistance layers.

The relatively low sensivity as well as some possible problems with so-called resistance noise should, in any case, be compensated by a suitably determined electrical circuit. In the electrical evaluation circuit there is even a smaller current consumption than in strain gauges.

Through utilisation of ‘hard’ materials both for the resistance layers and the insulated layers, the rigidity allows using the edges for changing direction, similarly as if only a hard metal plate of 5 mm thickness alone were mounted between ski and binding. This model was picked out for further development according to the criteria in the summary.

3 Results

All the models of the laboratory serve criteria 2 and 3, at which the costs of measurement circuits of the 2.1.2 and the 2.2.3 are lowest.

Now it is an advantage of the possible solutions presented under 2.1.2 to 2.1.4 that tensile and compressive forces can be distinguished and the force introduction is definite. On the other hand, the disadvantage lies in the considerable bending of the measure plates 2.1.2 to 2.1.4. Comparitively, the measure plate under 2.2. has a suffer force introduction. But best of all, criterion 1 is realized by the measure plate under 2.2.2. Because I employed very stiff materials both for the resistance and the insulating layers with a thickness of 0.5 mm only, there is practically no interference with the ski and binding system. This measure plate is distinguished by a minimal yield and height, it needs a very simple following circuit and a small current consumption only. Therefore the model 2.2.2 was picked out for further development according to the criteria in the summary.

4 Discussion

As force introduction at the 2.2.2 model is more complicated than at the 2.1, measurement calibration and evaluation are not simple. Next we work for a corresponding measurement processing.

Furthermore it is clear, that the criteria 1 to 3 do not subsume all problems. Of course, there is a possibility of measuring the ground reaction forces in the shoe or between the sole and binding. But even if restricted to the section between ski and binding, not all of the problems can be covered by the criteria explained in the summary under 1. to 3. Measuring the shearing forces in x- and y-direction for instance is not subsumed under these criterias. Another problem is the fact that both statical and fast changing dynamic forces, which could exceed the static forces many times over, should be measured as well.

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18

GROUND-REACTION FORCES IN ALPINE SKIING, CROSS-COUNTRY SKIING AND SKI JUMPING

Measurement methods and declaration possibilities

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Keywords: biomechanics, ground-reaction forces, vibrations, alpine skiing, ski jumping, cross-country skiing.

1 Introduction

In the three different disciplines of alpine skiing, cross-country skiing and ski-jumping there are a variety of forces, but this paper will only concentrate on ground-reaction forces [4]. As shown in Fig. 1, the data aquisition is also restricted to the share of the normal forces that are measured by the measuring binding. There are three interesting aspects, namely

- the absolute ground-reaction force (F_G),
- the center of force (COF),
- frequency analysis of the ground-reaction forces *(f)*.

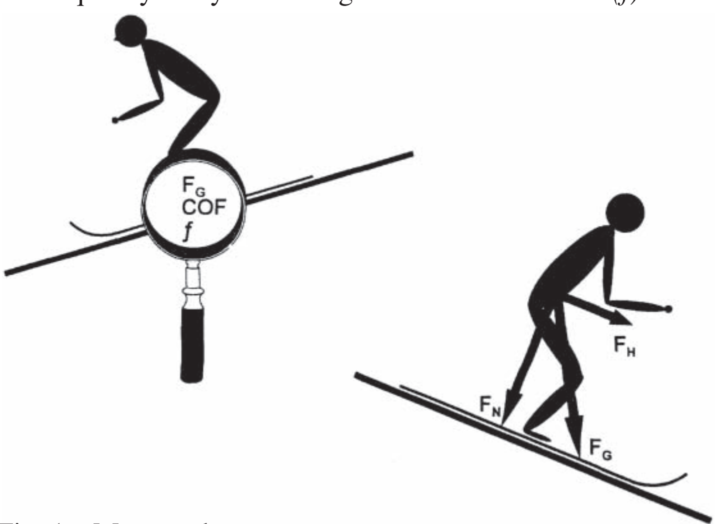

Fig. 1. Measured parameters.

Several special force platforms were developed to determine the ground-reaction forces of these three disciplines. With the assistance of these measuring bindings, we can gather information about forces that are found in skiing activity. All of these measuring systems are constructed with strain gauges and give precise information about the skier's force. It is recommended that a measuring sole (e.g. emed-system) not be used because of the non-measurable forces which could be transfered via the shaft to the ski (especially in Alpine skiing). In all measurements, it is necessary to find a compromise between the measurement accuracy and a possible handicap for the athlete. The measurement methods presented are highly precise in the expected vertical forces, but, nevertheless, hardly hamper the athlete.

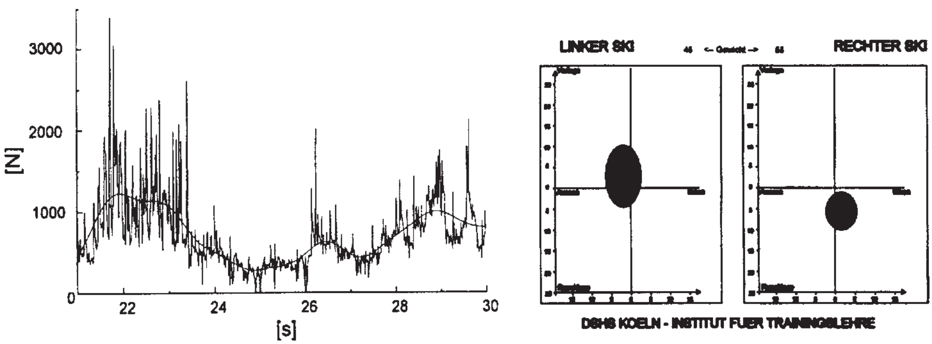

Fig. 2. Ground-reaction forces and their feedback.

Fig. 2 shows two examples of measuring the ground-reaction forces and two different ways of an individual feedback. The left graph demonstrates a normal force-time curve which displays the peak values of about 3000 N each leg. This graph shows the absolute height of forces that will be produced by the skier. The right graph is an example of a specific feedback procedure that illustrates the center of force (COF) [7]. This gives both athlete and coach a clear picture what the athlete is doing with regard to forward or backward load and stress of inside or outside edge.

2 Effects of vibration on the human body

In addition to the active contribution of the athlete in order to create forces, the possibility of "variable damping" as an answer to external forces must be emphasized. This will enable the athlete to maintain dynamic balance in the actual situation. Besides the permanent gravitational force, there is a dynamic ground-reaction force resulting, for instance, from crossing uneven ground. As a rule, these frequencies are not of a periodic nature, but appear indiscriminately. The effects of these vibrations range from annoyance, fatigue and reduced comfort, to safety and even health hazards [2][5][11].

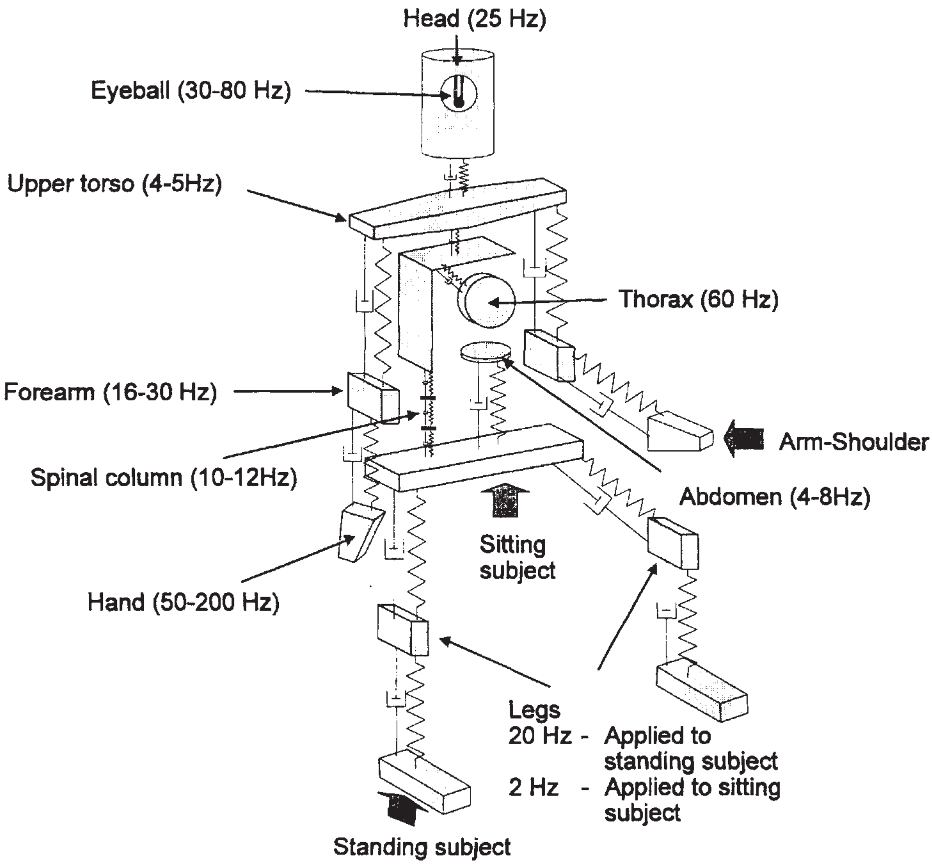

Fig. 3. Simplified mechanical system representing the human body.

Most of these vibration problems are related to resonance phenomena. Resonance occurs when the dynamic forces in a process excite natural frequencies, or modes of vibration, in the sourrounding structures. These different frequencies and amplitudes react on the athlete, but are dampened by the human locomotive apparatus and reach the particular body segments with differing intensity. The human organism can only be imagined approximately as a spring-mass-system with simple mechanical attributions (see Fig. 3) [2] [3]. This actual "human dampening system" can be widely influenced by using the muscle stiffness. Therefore, the human body is a more variable and adaptive dampening system in comparison to a mechanical model and can be optimally adjusted to the actual situation [10].

3 Measured F-t-curve and corresponding FFT in the three disciplines

In Fig. 4 the force-time curve produced by a ski jumper is divided into four phases:

- gliding phase down the ramp,
- passing through the radius,
- take-off phase,
- landing phase.

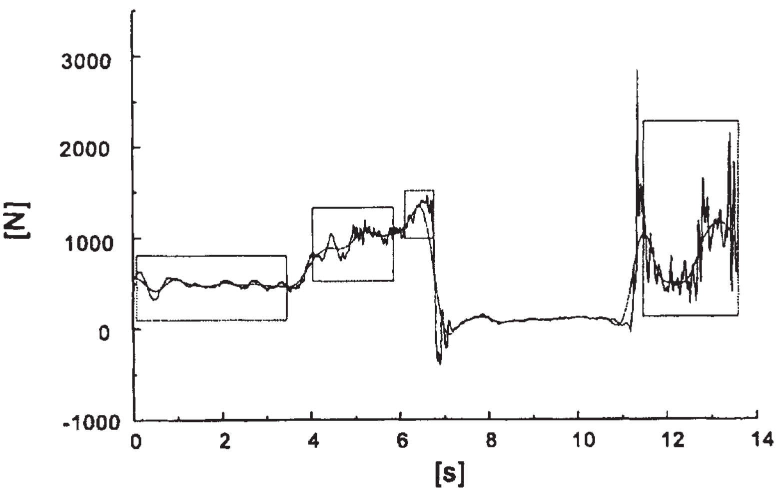

Fig. 4. F-t curve in ski-jumping.

Comparing the corresponding results in Fig. 5, one can see a frequency analysis calculated by a Fast Fourier Transformation (FFT). There is a clear peak in the gliding phase of 1 to 2 Hz, which may be a result of the skiers effort in taking his crouch position (see Fig. 5/Graph A). This entire body regulation is also pronounced in the phase of passing through the radius (see Fig. 5/Graph B) plus additional frequencies in this spectrum in the range of 10 to 15 Hz. In the stand-up phase, there are only vibrations of about 1 to 2 Hz in the absence of significant other peaks (see Fig. 5/Graph C). In contrast, there is a very wide spectrum in the landing phase of up to 15 Hz (see Fig. 5/Graph D).

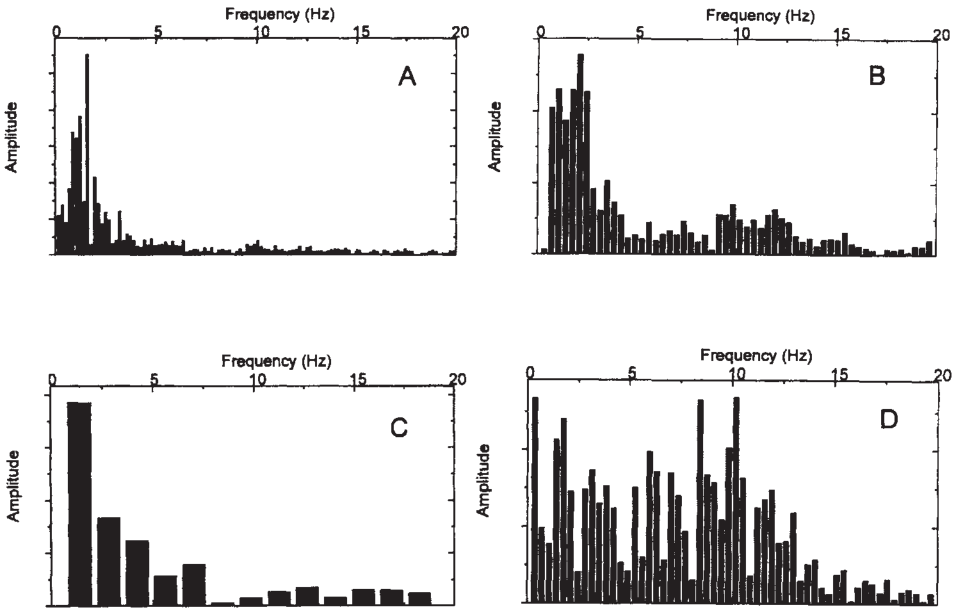

Fig. 5. FFT in the four phases of ski-jumping.

Fig. 6 shows the force-time curve of the inside edge of the left (LiIn) and right (ReIn) ski on the upper, and the resultant FFT (Figure below) as an example of Alpine skiing during men's slalom. There is a conspicuous alternating shape of the curve corresponding to the rhythm of the skier passing between the slalom gates. Subjecting the forces to frequency analysis, one can observe a similar picture to the case of ski jumping with the entire body regulation of 1 to 2 Hz plus additional parts between 15 and 30 Hz. This gives an accurate picture of the skier indicating his individuality.

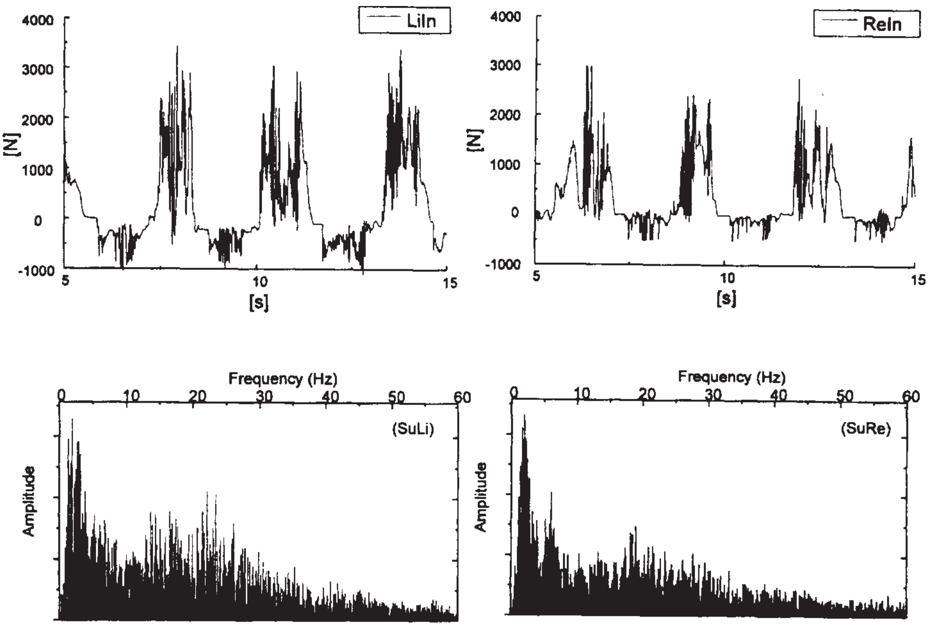

Fig. 6. F-t curve and corresponding FFT of am men’s slalom.

Fig. 7 illustrates a force-time curve of cross-country-skiing in the skating technique and the corresponding FFT. The two upper graphs indicate the entire force of left (SuLi) and right (SuRe) leg and the bottom graphs are the corrresponding FFT. The force-time curve shows the rhythm between loading the left and the right ski and movement regulation from backward to forward (see f-t graph “SuLi”). This movement regulation is also measurable in the bottom FFT, and again, there is a peak of 0.75 Hz, which represents the body movement from left to right ski. The second peak of 1.5 Hz, especially in the left graph, can be assumed as a movement from backward at beginning to forward at the end of the gait. Again, there is a difference between the left and the right ski, both in the real force-time curve and also in the FFT. The reduced absolute value in the force-time curve can be explained by a slight slope of the ski course. The skier, therefore, must empasize the take-off phase by the left leg. This of course has an effect on the frequency spectrum and determines the differencies between left and right ski.

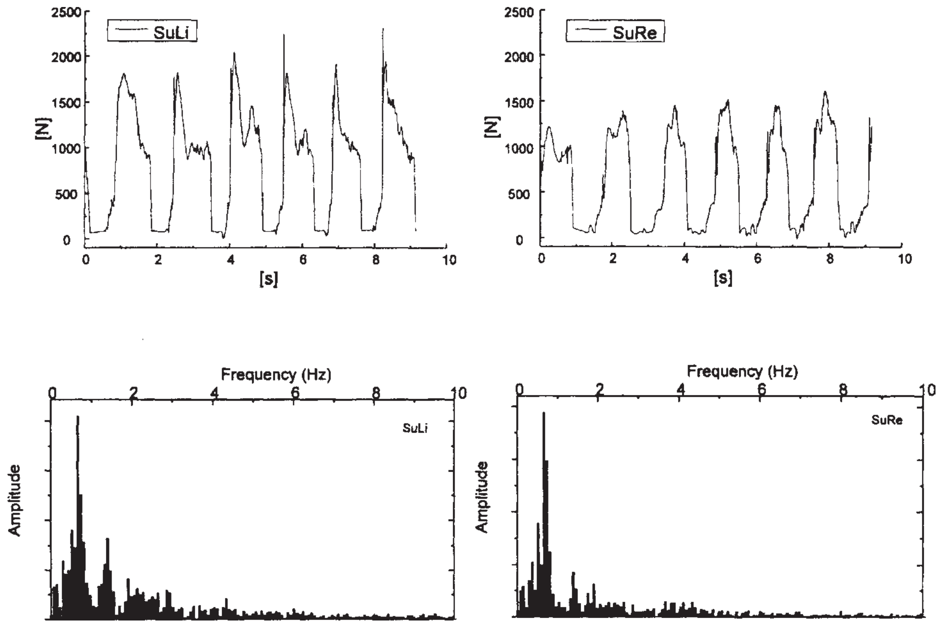

Fig. 7. F-t curve and corresponding FFT in cross-country skiing

5 Summary

We conclude that in all three disciplines, there are similar frequency ranges for the entire body regulation; however, we have differences in absolute and maximum force peaks. This is especially true for Alpine skiing, where the forces can become very high up to 6 kN/leg.

Of a special interest is the frequency spectrum in Alpine skiing. In accordance with the “variable damping” of the athlete, it is important “how” he or she can reduce the vibration under the ski. There are many possibilities for adjusting the “human dampening system” (e.g. muscle stiffness) and this can be regarded as a fingerprint for every athlete.

6 References

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19

CONSTRAINT FORCES MAY INFLUENCE THE MEASUREMENT OF VERTICAL GROUND REACTION FORCES DURING SLALOM SKIING

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Keywords: constraint forces, ground reaction forces, measurement devices, ski deflection, slalom skiing, alpine skiing.

1 Introduction

In most sports activities, motion is the result of muscular activity alone. In downhill skiing, two sources of energy are involved in the dynamics: gravity provides speed and forward motion while muscles allow the body segments to maintain equilibrium under external forces. For the athlete to remain in balance constant movement and adjustment is necessary. The ensemble of these complex movements in combination with forces and resistances involving edge control, pressure control and pivoting constitutes the mechanics of skiing. A world class skier has to handle this matter when skiing along a given course and at the highest speed possible. In order to ski faster, they must conserve kinetic energy and perform balancing movements in total harmony with forward motion.

Analysis of the important factors in skiing mechanics is useful for the comparison of different techniques. In this respect, the analysis of ground reaction forces is a particularly useful tool in biomechanical investigations of turns in slalom skiing. The following questions may be addressed:

- Magnitude of force with respect to time along the course
- Force control and equilibration of the athlete experiencing bumps, turns, etc.
- Force distribution between left and right ski
- Influence of equipment

Several devices to measure ground reaction forces have been reported [1]. However, the systems presented are not well-suited to measure carved turns in slalom skiing. While a stiff measuring device changes the longitudinal bending stiffness of the ski and therefore disturbs the performance of the athlete, a flexible device might deform too much and measure erroneous forces. During carved turns, the bending deflection of the ski below the boot is in the range of centimeters, depending on the radii of the slalom, the properties of the ski, and the technique of the athlete [2]. In addition, the ski might bend due to bumps in the slope or natural frequencies of the ski [3]. These bending effects will cause a dynamic change of the distance between the binding heads and, since the boot does not follow, cause internal forces at the interfaces between ski, binding, and boot. These forces are referred to as constraint forces.

The purpose of this study was to develop a measuring system which is not sensitive to constraint forces, and at the same time keeps the longitudinal bending stiffness of the system ski/binding/boot unaffected.

2 Material and Methods

2.1 Measurement devices

Two devices measuring vertical ground reaction forces were built. System A was attached between binding heads and ski, system B was fixed between boot and bindings. Both systems used beams supplied with strain gauges as the principle of force measurement, but coupling between boot and ski was different (Fig. 1). The beams in both systems were arranged in a manner ensuring the measurement of all vertical forces. The use of strain gauges as sensor elements provided the possibility of a dynamic analysis.

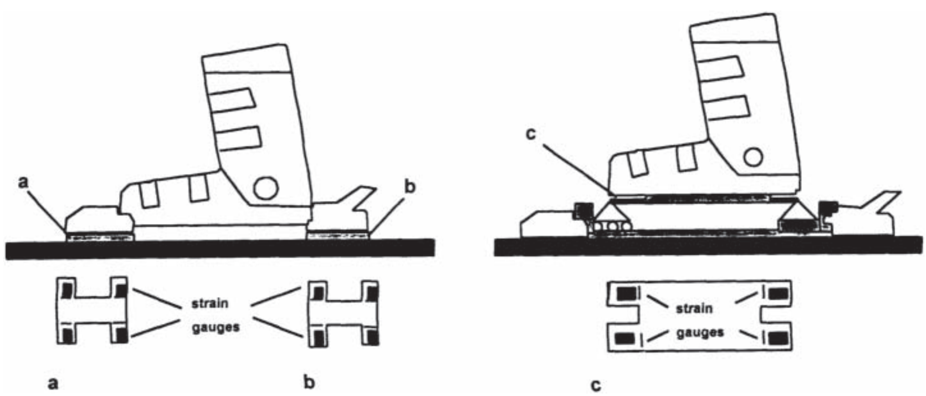

Fig. 1. Mechanical principle and coupling of device A (left) and B (right).

2.1.1 Device A

Device A consisted of two sensor plates (height 7 mm, weight 450 g), with four laterally directed beams each (Fig. 2). The front and the rear binding heads (MARKER M48) were mounted on top of the force transducers. Normal forces occurring between binding and ski generated a bending of the beams, while constraining shear forces generated torques. The strain gauges were arranged in a full Wheatstone bridge to electrically compensate for those torsional momenta as well as shear forces and temperature (Fig 3).

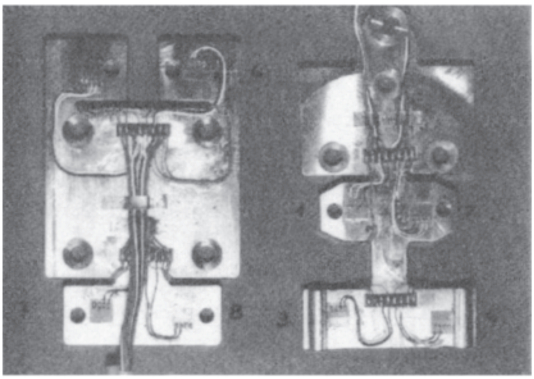

Fig. 2. Rear and front sensor plate of device A.

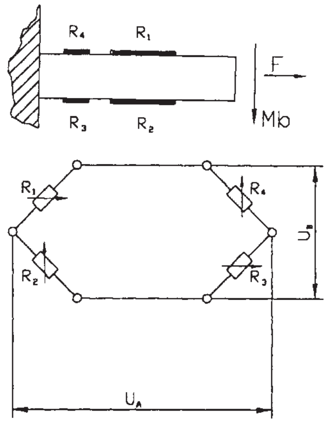

Fig. 3. Wheatstone Bridge compensating torsional momenta.

2.1.2 Device B

Device B used a different approach to eliminate constraint forces. The internal forces were neutralized mechanically rather than electrically. One sensor plate with four longitudinally directed beams was attached underneath the boot (NORDICA GRAND PRIX), while a special sole plate was used to fix the system to the bindings (Fig. 4). The force transfer between sole plate and sensor plate was arranged by using a statically determined fixation: A fixed bearing at the heel and a movable bearing at the toe (Fig. 5) allowed relative motion between the binding heads, thereby avoiding constraint forces within the four longitudinally directed transducers. A half bridge was applied on each sensor, compensating for longitudinal shear and temperature. The whole measuring device had a height of 16 mm and, using aluminum as material of the sole plate, a total weight of 990 g.

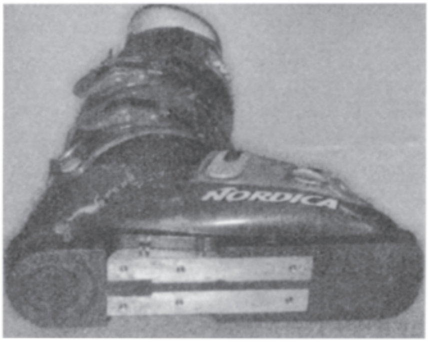

Fig. 4a. Boot with fixed adapter bars.

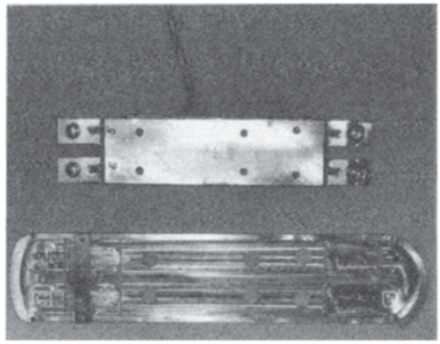

Fig. 4b. Sole plate (above) and sensor plate.

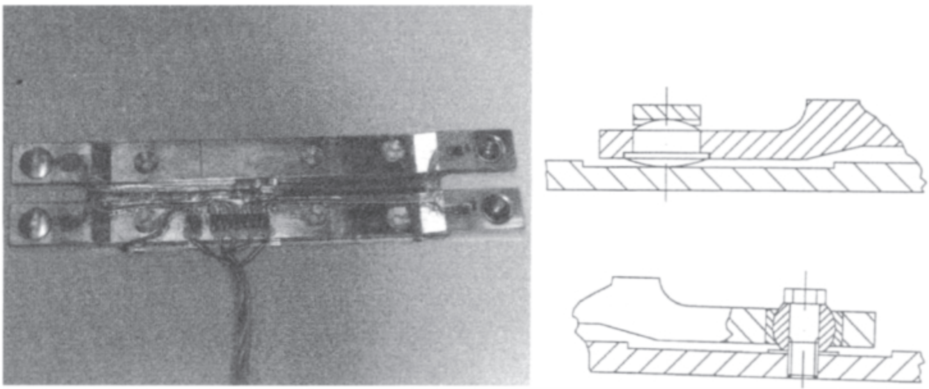

Fig. 5. Movable bearing (ball on flat) at the toe; fixed bearing (ball and socket) at the heel.

2.2 Testing protocol

Two tests were performed to examine the sensitivity of the two devices to constraint forces, a flexion test and a weight test.

2.2.1 Flexion test

In the flexion test, the ski including the binding and the boot was submitted to three-point-bending with a base of 2.0 m. The forces were applied directly to the ski, generating a longitudinal bending radius of 6.3 m. This test was selected to deform the ski in a manner comparable to slalom turns, but without external forces transmitted through the system. Therefore, the transducers should not generate a force reading.

2.2.2 Weigh test

In the weight test, one subject (75 kg) moved its center of gravity in a single-leg stance to five different static positions while the ski was fixed to the ground. By standing upright, leaning forward, backward, to the left and to the right, the body weight of the subject, plus additional frontal and sagittal momenta were transmitted through the measurement device. In each position, three measurements were performed. Each time, the transducers should measure the weight of the subject.

3 Results

3.1 Flexion test

In the flexion test, device A showed large values at all rear force transducers (up to 300 N per sensor) and also considerable values at two of the four front sensors (Fig. 6a), even though no vertical force was transmitted through the boot. In contrast, device B did not indicate sensitivity to the bending applied to the ski (Fig. 6b).

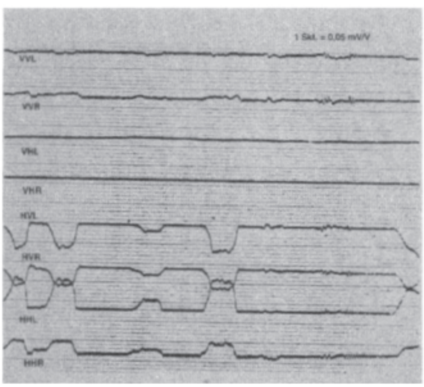

Fig. 6a. Force readings of device A during flexion.

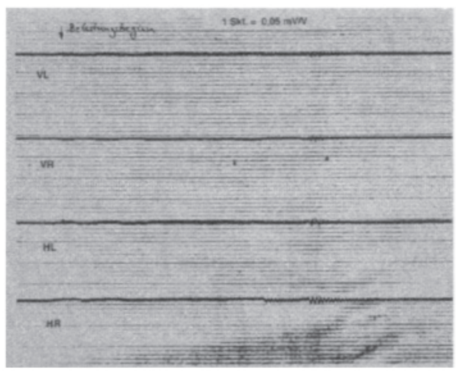

Fig. 6b. Force readings of device B (arrow indicates start of three-point bending).

3.2 Weigh test

In the weight test, the vertical force recordings under the condition of applied sagittal and frontal momenta were as follows:

Table 1. Results of weight test (in percentage of body weight).

Position of CG	Force in % BW (mean ± s.d.)	
	Device A	Device B
neutral	92.6 ± 5.6	101.4 ± 1.4
forward	127.3 ± 14.5	97.1 ± 1.6
backward	70.4 ± 13.7	88.4 ± 6.7
inward	80.1 ± 9.8	95.4 ± 7.9
outward	82.5 ± 11.1	97.9 ± 2.1

4 Discussion

Both systems were built to be non-sensitive to constraint forces. However, only device B provided reasonable data.

The poor results of device A were due to a specific constraint mechanism present during bending of the ski in the flexion test. The skiing boot does not only prevent relative displacement of the binding heads parallel to the ski but also inhibits their rotation when following the bending line of the ski (Fig. 7). The relatively stiff boot keeps the binding heads parallel and therefore applies an additional momentum to the sensor plates. This momentum causes a deformation of the transducers similar to that caused by normal forces. The values measured at the rear sensor plate are larger than those at the front plate because the fit between boot and binding is more constraining there. A similar mechanism was found to explain false measurements in the weight test.

Device A was also tested with a binding (ESS VAR) allowing longitudinal displacement. However, the improvement was marginal [4], because this binding also transmitted rotary momenta influencing the axial force measurement.

The movable bearing of device B allows free adjustment of the sensors, independent from displacement and rotation of the bindings. The device therefore provides reasonable data in both tests. The large offset in backward position (Tab. 1) is due to mechanical adhesion of the movable bearing in this position. The momenta applied during the weight test were static and therefore adhesion became important. The dynamic momenta and natural frequencies [3] occurring during skiing prevent the bearing from adhesion. These speculations were confirmed by later field tests [5].

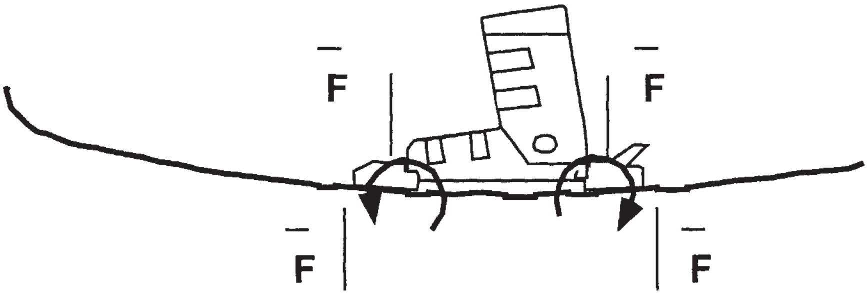

Fig. 7. The constraint mechanism: The boot inhibits the rotation of the bindings during ski bending.

The findings in this paper demonstrate the importance to test measurement devices under realistic conditions. Although both systems had been shown to measure accurately and reproducibly [4, 5] in a test set-up *without* constraint forces (Fig. 8), only one device qualified for dynamic measurements on skiing slopes. Device A indicated errors up to 300 N per sensor during the flexion test, and adds to more than 1,000 N if the value of the ground reaction force vector from the eight sensors is calculated. This may be up to 50% of the peak ground reaction forces measured during slalom skiing. In addition the direction of this vector is misleading, too.

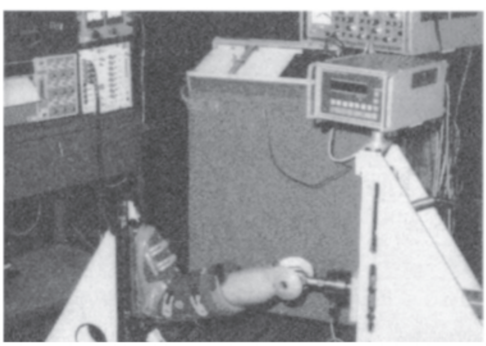

Fig. 8. Apparatus to test reliability and validity of the two measurement devices *without* constraints.

5 Conclusion

It has been illustrated by Howe [2] that the bending deflection of the ski is in the range of centimeters during a carved turn. In addition, it has been shown [6] that under extreme conditions significant sagittal and frontal momenta will apply. Hence, the established tests presented in this study seem to be a reasonable and useful tool in evaluation of ground reaction force measurement devices.

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STRUCTURAL DYNAMIC ANALYSIS OF ALPINE SKIS DURING TURNS

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Keywords: friction, natural frequencies, modes, trajectory, alpine skiing.

1 Introduction

In alpine slalom races, it is recognizable that competitors only rarely perform carved turns. Carving is regarded as the quickest possibility to change direction in alpine skiing. Instead of this, most alpine skiers are not able to stand on their optimal trajectory and they drift transverse to the gliding direction of the ski in short successive intervals of stick and glide phase, which is also called chattering. This effect is encountered particularly at the inner edge of the downhill ski, because at this location the greatest imbalance occurs between centrifugal force and adhesive friction at the edges acting in the opposite direction during the periods of transverse drift. In addition to the negative consequences for the trajectory it is highly probable that chattering has a fatiguing effect on the leg musculature. In order to make improvements, the classification of the effects causing chattering must be clarified. Depending on whether the chattering problem is caused by a cyclical force production of the skier or in the self-induced vibrations of the ski, any actions for directing the training or steps for optimizing material can be initiated.

In the literature, one article can be found about the cushioning ability of a skier against vibrations appearing in vertical direction [4]. Other scientific papers [1] [2] deal with the dynamic behaviour of the ski, which they determine by modal analysis in experimental and calculatory ways (finite element method). One paper published a long time ago also deals with power spectral density calculations of signals recorded during skiing [3]. Nothing can be found in the literature about determining the natural frequencies and modes as well as the constraints which appear during downhill skiing. This questions are to be clarified in the following study.

2 Methods

In order to develop a procedure which helps to narrow down the outstanding questions about the periods of transverse drift, the possible reasons for this phenomenon are formulated hypothetically:

1. Hypothesis:
   If a limiting force is present, the skier drifts in a transverse direction just at that moment, when the zentrifugal force (F_z) exceeds the adhesive force ($F_R=\mu\times F_N$). At that very moment, the centrifugal force would decrease, since the curve radius would increase and the ski would have a new chance to stick. Hence the cycle would start all over again.
2. Hypothesis:
   As a second cause only the stochastic excitations could effect the loss of contact of the ski to the snow. The ski would be considered as a rigid body and would randomly lose ground contact in the same pattern of excitation. Consequently, the input signal X_e would not have any dominant harmonic frequency parts.
3. Hypothesis:
   Structural dynamic effects may cause the loss of ground contact of the ski, if it is possible to determine natural frequencies and modes by the measured ski response.

2.1 Field Test

In order to discuss the questions formulated hypothetically, a field test was outlined. It was important for a good comparability keeping trajectory and slope conditions constant during the entire testing period. For that the slope area for the tests (inclination 43%) was iced over. A course was set with four open poles, through which the trajectory of the skier was stanardized. The skier increased his speed continuously beginning from zero speed. Hence a probably existant limiting force could be determined. In order to record the bending oscillations working perpendicularly to the ski surface, eight one-dimensional acceleration sensors (ERNST) were fixed along the central axis from the rear to the shovel of the ski. It was important that all sensors were aligned to the same plain. Two measuring sensors were fixed near the binding, because at this location the influence of ski elasticity can almost be ignored. Therefore, it is possible to record a nearly undistorted exciting signal. The raw data of the eight acceleration sensors was recorded by data-memory equipment (BIOSTORE, sampling frequency 1000 Hz) carried along with the skier. For the determination of constraints the run was filmed with a high-speed camera (picture frequency 180 Hz). In consideration of the Nyquist-criterion (2½ oversampling) it would be possible to identify oscillations up to 70 Hz. In order to synchronize the data of the acceleration measurement with the filming data the skier did an air jump before and after the run.

Through these precautions, it was ensured that the following were realized: first, different speeds to clear up the existence of a limited force (Hyp. 1); second, an Exciting Signal recorded without structural dynamic actions of the ski (Hyp. 2); and third, an acceleration response that would be taken by length sections of the ski (Hyp. 2+3).

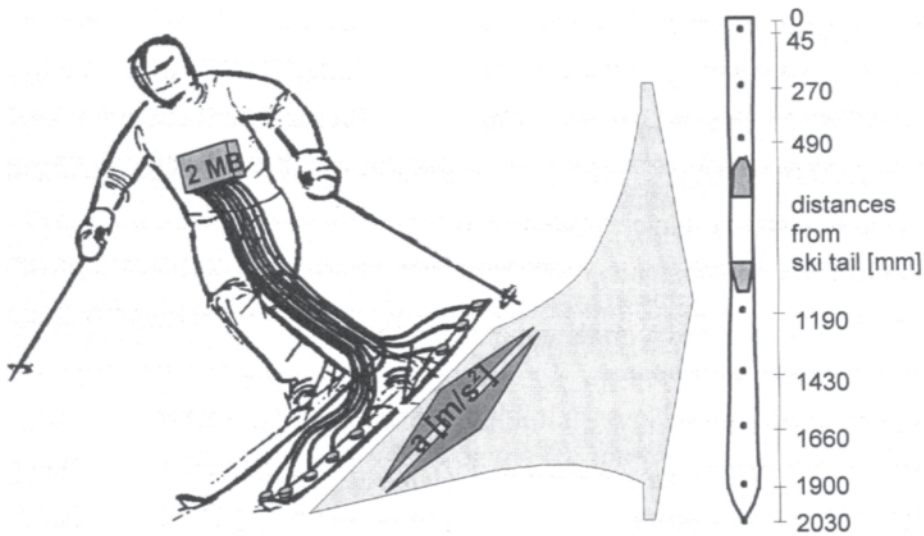

Fig. 1. Sketch of the experimental basis of the field test.

Results of the Field Test

At selected sections of the data a Fast-Fourier Transformation (FFT; Software: MATHEMATICA) was performed. This signal analysis showed that in slow as well as in fast skiing situations dominant harmonic frequencies, characterised by low values (36 and 45 Hz, respectively), can be determined. The evaluation of the parallelly connected channels revealed that these frequencies were dominant in complete sections of the ski (see Fig. 2a). For this reasons the existence of a limiting force as well as rigid-body behaviour can be excluded and it is therefore supposed that the oscillating response of the ski was measured here.

In a further step, the ranges determined from Fast Fourier Transformation were filtered in order to make possible a matching up the differentiated declarations regarding phase displacements of the separate channels to each other. High frequent and stochastic shocks and impacts were eliminated with a low-pass filter. The filtered acceleration-time diagrams are shown in Fig. 2b. The phase displacements of the channels were divided roughly into "in phase" and "inverse phase" to determine the mode of the ski. The result is the mode represented in Fig. 2c.

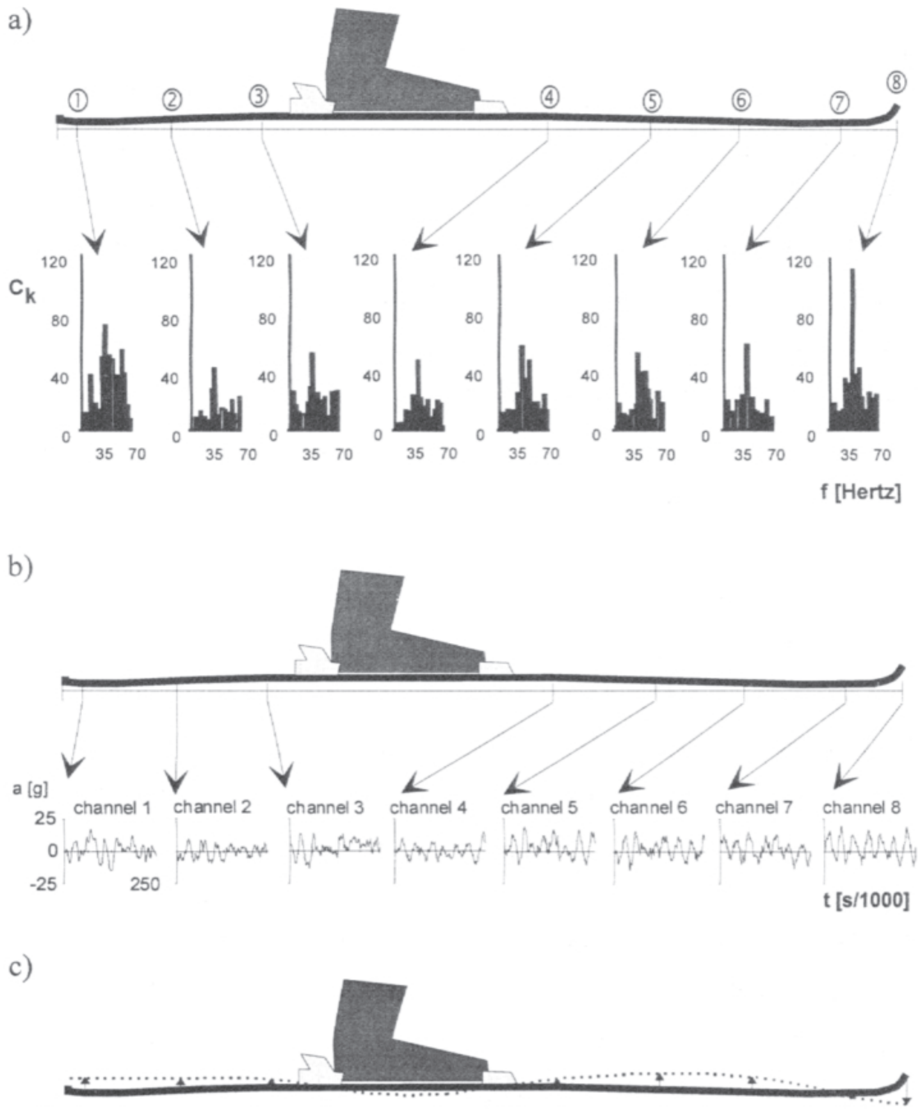

Fig. 2. Dominant frequencies and determined mode by the field test.

In a further step, the data was examined to detect a connection between the natural oscillations and the short successive drift intervals in a transverse direction. With the help of the video analysis, a time period, during which drift in the transverse direction as well as bending oscillations of 36 Hz were visible over the whole ski length, was used for an intensive signal analysis. By way of integrating the acceleration signal twice, the system function was determined. It followed, then, that the low frequency oscillation was the determining factor for the path. This can be derived from the undulating trend of the velocity signal and from the terraced trend of the path, both showing the frequency of 36 Hz (see Fig. 2b, 2c).

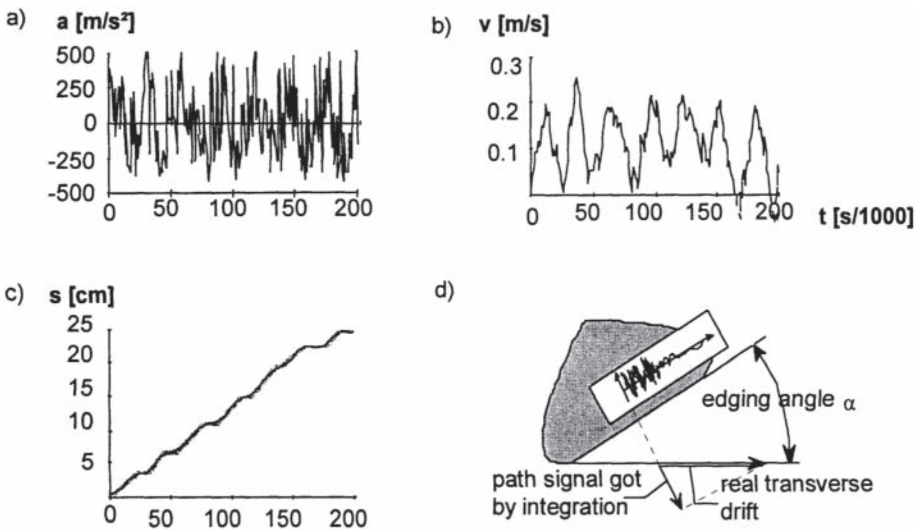

Fig. 3. a) Acceleration-, b) velocity- and
c) path-signal d) real transverse drift

The division of the path signal shown above through the sine function of the edging angle results in the real drift in the skier's transverse direction (see Fig. 2d). In the case of an edging angle of 30°, the drift increases with a factor of 2 as compared to the path calculated from the acceleration signal of 25 cm and amounts to half a metre (drift=measurement/sin a).

2.2 Experimental Modal Analysis

In order to verify the frequencies measured during skiing, an experimental modal analysis was conducted with the same pairs of skis (HEAD TR12 and TR16) at the IWB department of the Technical University in Munich, Germany.

Instead of disturbances on the ski caused by unevenness of the piste, a sine-wave-like signal, exactly defined in amplitude and frequency, was taken from the ski. The sine-wave force signal was sweeped up in ¼ Hertz steps from 8 to 80 Hertz and introduced near the binding at the rear section of the ski. This kind of dynamic excitement of the system and the thereby connected reading of the answering signal is generally called “frequency sweep analysis”.

The answering signal was recorded with a three-dimensional acceleration sensor. The frequency sweep reading was taken individually for each measurement point; i.e., the sensor was set from point to point, attached to the ski, and recorded the answering signal for each point of measure. The data accumulated from the acceleration sensor in analogue form was then fed into the A/D converter card of a measuring device. The frequency sweep of all 17 points thereby gathered were then in the form of ASCII files and could be further processed. The data of the excitement-force signal as well as the channels of the acceleration recorder were checked with oscilloscopes for their sine-wave character.

The natural frequencies are influenced not only by stiffness and mass, but also by load conditions. It is therefore necessay that load conditions occurring while skiing are imitated as closely as possible in the laboratory. For the simulation of a skiing situation, the ski is clamped at the front and rear as an experimental constitution. This corresponds to the bending stress of the centrally loaded ski while in use. As a control experiment, the natural frequencies of the ski without load conditions were taken. The goal was here to limit the general influence of the varying load conditions.

From both experiments, the frequency sweeps were recorded in the manner delineated above. In the accompanying sketch, the two experimental constitutions are illustrated.

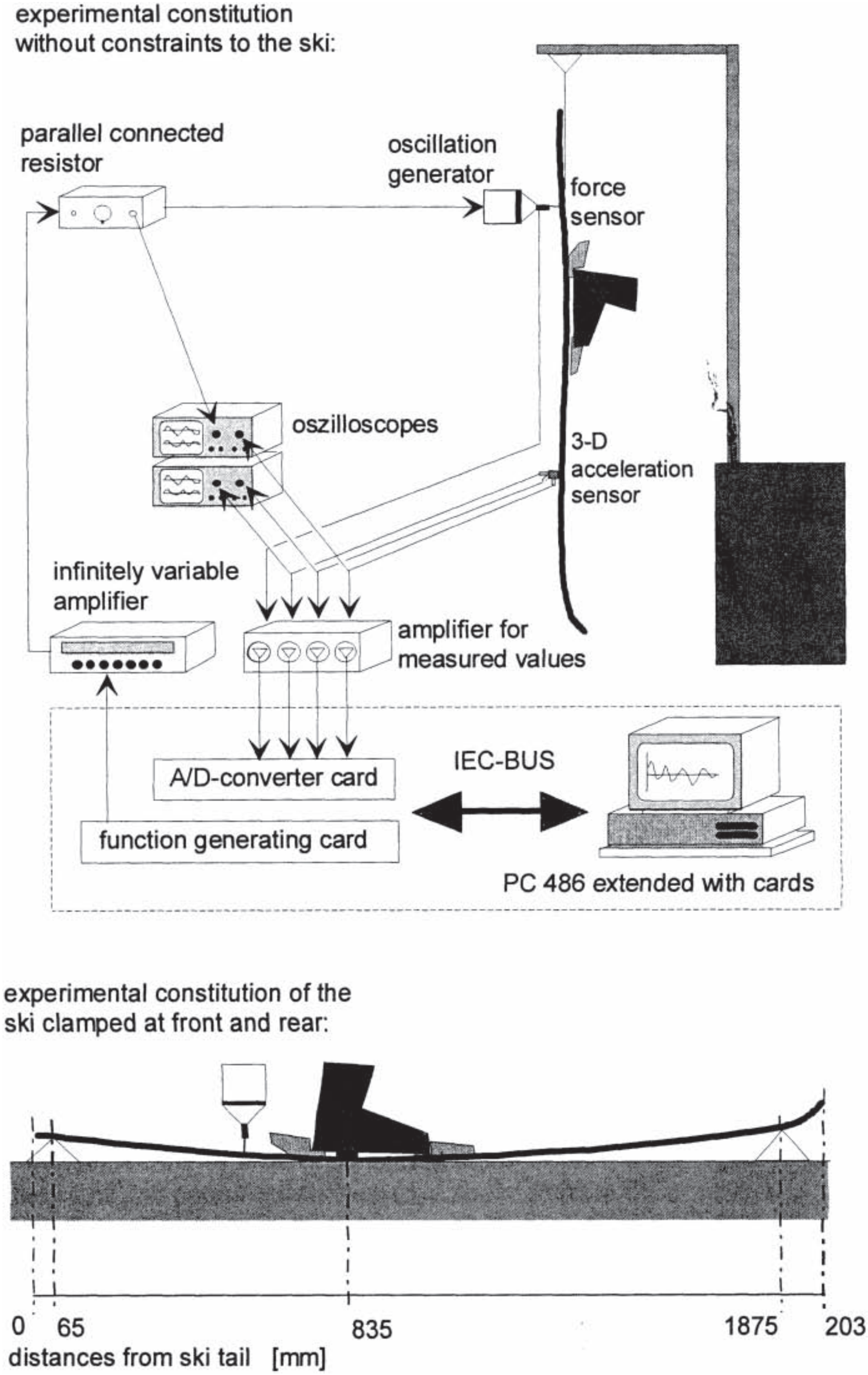

Fig. 4. Experimental constitutions of the experimental modal analysis.

Results of the Modal Analysis:
With help of all measured path-frequency sweeps, the characteristic modal flexibility roots of the system were determined. The characteristic flexibility roots established by the respective natural frequencies provided the mode corresponding to the natural frequency. Analogous to earlier investigations, the modes of the ski without load conditions were determined at the following frequencies: the first mode at 15.4 Hz, the second at 32.4 Hz, and the third at 50.3 Hz. The modes diplayed in Fig. 5 show the extreme situation as compared to the ski at rest, shown sketched in.

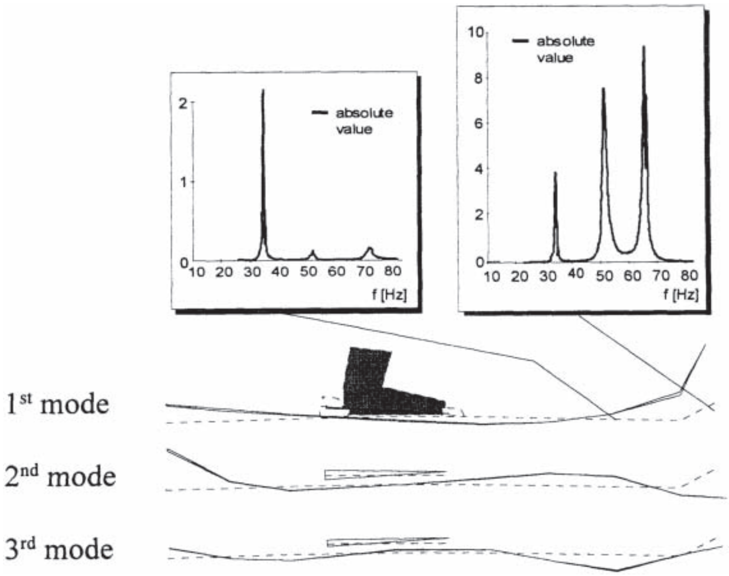

Fig. 5. Examples of two frequency sweeps and the modes of the situation without constraints.

With help of a video recording, a typical skiing situation with centrally loaded ski that usually occurs in the first part of the turning phase was specified from the manifold load situations during skiing. The ski was underlaid at both front and rear, and was screwed to the support base with help of a device in the middle of the ski at both sides. Thereby, the ski was loaded to bend in a way corresponding to the real situation while turning.

Because of the fact of clamping, the first determined mode is blocked in the situation *without constraints*. The first natural frequency of the clamp situation *front-rear* had the form of the second natural frequency in the test situation without constraints and was found at 35.4 Hz, the next highest at 52.8, and 73 Hz, respectively.

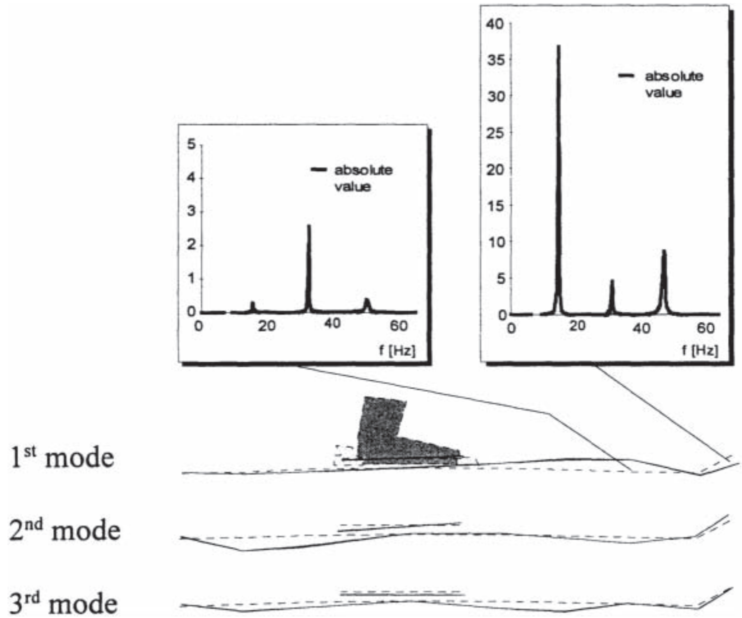

Fig. 6. Examples of two frequency sweeps and the modes of the situation clamped in the middle and supported in rear and front.

Looking at the frequencies and modes of the two investigated clamp situations, it can be determined that the second and third modes of the situation *without constraints* is almost identical to the situation *front-rear*. The insignificantly displaced nodal points effect a frequency displacement of a few Hertz (32.4 and 35.4 Hz, respectively, and 50.3 and 52.8 Hz, respectively).

3 Conclusions

In summation, the dominant frequencies determined while skiing, which were attributed to the dynamic behaviour of the ski, should be compared to the natural frequencies and modes ascertained in the laboratory. It should thereby be determined that the primary bending vibrations of the ski, measured in the situation *without constraints* at 15.4 Hertz, prove to be of little relevence to actual skiing. A good correspondence of the frequencies measured during skiing is attainable by taking load conditions relevant to skiing into consideration in the laboratory. Especially the dominant frequencies determined during skiing in the range of 36 Hertz could be ascertained in the laboratory under load conditions relevant to skiing as resonance vibrations of the ski. These vibrations do not have insignificant influence on the trajectory of the skier.

Investigations into trajectory have until now concentrated on the observation of a mathematically exact, calculable function as trajectory, which occurs as a result of active external forces. In the second part of the field-test evaluations, it was shown that the quality of the trajectory is also of decisive importance. This quality is influenced mainly by material. The central factor for the change of trajectory deliverately performed by the skier is the friction of the applied edges. In compliance with the normal preparatory measures, it was determined in the field test described above, that the dynamic behaviour of the ski influences the friction of the applied edges on hard pistes. Resonances of the ski have a detrimental effect on ground contact and lead to the inability of the skier to continue his or her carved turn and, instead, to chattering and cross-drifting.

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Part Two

Fitness Testing and Training in Skiing

21

EVALUATION AND PLANNING OF CONDITIONING TRAINING FOR ALPINE SKIERS *

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Keywords: alpine skiing, conditioning training.

1 Introduction

In alpine skiing competition as well as in many other sport disciplines, the most important characteristics for successful performances are represented by technical skills. However, specific ability cannot be expressed entirely without the contribution of factors such as courage and appropriate physiological properties. Training progress is based on two main factors, which are at the same time different and related: technical profile and physical conditioning. The improvement of technical skill is connected to neurogenic activity like inter- and intra-muscular co-ordination, activation and deactivation of agonist and antagonist muscles, interaction between proprioceptors (Golgi Tendon Organs vs stretch reflex), which are respectively inhibiting and maximising the potential of neurogenic output, etc. The second factor is related to energetic and metabolic aspects, to supply biochemical energy to the heavy demand required in competition. Cardiocirculatory and respiratory functions serve to transport oxygen to the muscle, while the metabolic profile reflects the enzymatic potential of the mitochondria and the anaerobic metabolism (alactic and lactic power and capacity). Concerning alpine skiing, no conclusive evidence has been reported regarding the role played by various physiological properties in obtaining the best physical conditioning. However, although the duration of the ski races seldom exceed 150s, aerobic power has been strongly connected to successful performance (Astrand and Rodahl, 1986). On the other hand, extensive observations on international-level Italian alpine skiers, suggested that the most successful characteristics were represented by speed-endurance capacity like continuous rebound jumps (Bosco et al. 1983a). Anaerobic power, measured during continuous jumps, has been shown to be the most predictive of alpine-skiing ability (Bosco 1991, White and Johnson, 1991). In addition, while jumping, the activity of torso and back has been shown to present similarities to the muscle requirements of skiing (Karlsson et al, 1978). Furthermore, it must be kept in mind that during skiing the behaviour of leg-extensor muscles follow the so-called "stretch-shortening cycle" activation. This type of muscular activity allows the storing and re-use of elastic energy, thus saving biochemical energy consumption (Cavagna, 1977). In light of the above observations, a new training method was planned for the athletes of The Italian National Alpine Ski Team, which took into consideration the individual physical and physiological characteristics as well. Therefore, at the beginning of the training season, the athletes were evaluated with a large test battery in laboratory and field conditions. These included aerobic and anaerobic (alactic and lactic power and capacity) assessment as well as neuromuscular and sprint performances.

2 Methods

Aerobic Assessment. Aerobic profile (Aer-Pr) was assessed by measuring the lactic acid concentration after (2, 4, 6, 8, 10 min) treadmill running for 6 min at 13 km/h.
Anaerobic Lactic Capacity tests. Three different diagnosis were used for assessing ALC.

a) Measurement of the time during 300 m×2 of running performance on track. The recovery time between the two trails was 3 min. The best time (TH-BST) was analysed.
b) *Continuous jumping for 45–60s (CJ).* Continuous jumping for 45s was performed on a capacitative platform (Ergojump). Average mechanical power (45–60 P) and height (45–60 h) were calculated.
c) *Continuous Jumping for 30 s with extra load of 0.5 times body mass (Cjbm).* Continuous jumping with extra loads were performed for 30s. Average height (30-h) and power (30-P) were recorded with Ergojump and average mechanical power (30-Erg-P) with Ergopower.

Before and 2, 4, 6, 8, 10 min after the performance of *a, b* and *c,* blood samples were collected from the fingertip for lactic acid determinations (TH-LA), (45-LA), (30-LA).

Anaerobic Alactic Power. Running 30m dash, and continuous jumps for 5s were applied. Time for 30m was measured (DASH), and height (5-h) and calculation of power (5-P) for jumping.

Neuromuscular and strength test. Jumping was performed from the squat position without (SJ) and with extra loads similar to the athlete's body weight (SJbw) and with counter movement (CMJ). In SJbw, mechanical power with Ergopower was also calculated.

Calculation for jumping test

Jumping performances during SJ, Sjbw, CMJ and continuous jumping for 5, 15, 45 and 60s were measured with Ergojump. The flight time (t_f) and contact time (t_c) of each single jump was recorded on a resistive (capacitative) platform (Bosco et al. 1983a) connected to a digital timer (accuracy±0.001s) (Ergojump®, Psion®, XP, MA.GI.CA. Rome, Italy). To avoid unmeasurable work, horizontal and lateral displacements were minimised, and the hands were kept on the hips throughout the test. Knee angular displacement was standardised in that the subjects were required to bend their knee approximately 90°. The rise of the center of gravity above the ground (h in meters) was measured from flight time (t_f in seconds) applying ballistic laws:

$$h = t^2_f \cdot g \cdot 8^{-1} \quad (m) \tag{1}$$

where g is the acceleration due to gravity (9.81 $m.s^{-2}$).

Calculation of the average mechanical power (P) was obtained using the equation introduced by Bosco et al. (1983a):

$$P = T_f \cdot Tt .24.06 \cdot (Tc)^{-1} \quad (W . kg_{bm}{}^{-1}) \tag{2}$$

where P is the mechanical power per kilogram of body mass, T_f the sum of the total flight time, Tt the total working time (5–60s), and Tc the sum of the total contact time. Average h and average power P for the total work performed during both 5s and 60s were computed. In 45–60s jumping performance, average h and P for separate 15s interval (0–15s, 15–30s, 30–45–45–60s) were also calculated.

Power measurements during 30s jumping

The vertical displacements of the loads were monitored with simple mechanics and sensor arrangements (Ergopower, Ergotest Technology A.S., Langensund, Norway). The loads were mechanically linked to a sensor which glided on a track bar. The sensor was interfaced to an electronic device. When the loads were moved by the subjects, a signal was transmitted by the sensor at every 3mm of displacement. Thus it was possible to calculate velocity, acceleration, force, power, and work corresponding to the load displacements (for details see Bosco et al. 1995).

The test battery was applied systematically from 1989 in order to evaluate the training progress of the athletes belonging to The Italian National Alpine Female and Male Ski Teams. In addition, the same test battery was utilised to evaluate the biological changes induced by training before and after two months of training.

Statistical analysis

Ordinary statistical methods were employed, including means and standard deviations. Coefficients of correlation between changes caused by training were tested using Pearson's product moment technique. Student's t-test for paired observations was used to compare means before and after the training programme.

3 Results

The correlation matrix of several changes of the physiological and biomechanical parameters, induced by eight weeks of training on nine female and fifteen male international-level alpine skiers, is presented in Table 1. No relationships were found between the changes of the aerobic capacity and the changes in speed-endurance variables and the correspondent blood-lactate concentrations (time to run 300m, 45s CJ, 30s Cjbm). On the other hand, changes in explosive-type characteristics (SJ, CMJ and 5s CJ) demonstrated positive relationships with the changes in sprint performance. The absolute values for both groups, observed before training, are shown in Fig. 1a, b. The male athletes demonstrated more statistically significant differences than the female counterparts for 300m running, rise of CG during 45s CJ, power during 30s CJbm, and aerobic assessment capacity (Fig. 1a). The same trend was noted for blood-lactate accumulation after 300 m running and 30s Cjbm. In contrast no gender differences were noted for blood lactate concentrations after 45s CJ and 6 min running on treadmill (Fig. 1b).

	Aer AL ns	Cm cm ⇑3	Das s ⇓1	45h cm ⇑1	451 AL ⇓1	45p w/k ns	5h cm ⇑2	5p w/k ⇑2	Sj cm ⇑1	Sjb cm ⇑2	TH s ns	TH AL ⇓3	30s cm ⇑2	30s AL ns	30s w/k ⇑1
Cm	ns	100													
Das	ns	54'	100												
45h	ns	ns	ns	100											
451	ns	ns	ns	ns	100										
45p	ns	51'	71"	ns	ns	100									
5h	ns	69"	56'	ns	ns	71"	100								
5p	ns	57'	58'	ns	ns	86"	72"	100							
Sj	ns	77"	79"	ns	ns	65'	70"	69"	100						
Sjb	ns	ns	ns	ns	ns	ns	ns	ns	ns	100					
TB	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	100				
TL	ns	ns	ns	ns	ns	ns	ns	-51'	ns	ns	ns	100			
30h	ns	ns	ns	ns	60'	54'	ns	ns	ns	60'	ns	ns	100		
30L	ns	ns	ns	ns	ns	ns	72"	ns	ns	ns	ns	ns	ns	100	
30p	ns	ns	ns	ns	ns	55'	ns	ns	ns	ns	ns	ns	86"	ns	100

Table 1. The matrix of different parameter changes, caused by systematic training performed by thirteen alpine skiers at an international level, was obtained using the Person's product moment correlation coefficient. Statistically significant levels are shown by: '=P<0.05; "=P<0.01; ns non significant. The arrow indicates the enhancement () or the decrease (), which has occurred comparing the results before and after the training period. The number indicate the level of statistical significance obtained by the changes: 1=P<0.05, 2=P<0.01, 3=P<0.001.

Symbol:

Aer=Aerobic assessment capacity, Cm=Rise of center of gravity during counter movement jump, Das=30m dash, 45h=Average height of center of gravity during continuous jumping for 45s, 451=Blood lactate concentration after continuous jumping for 45s, 45p=Average power (W× kg^{-1}) developed during continuous jumping for 45s, 5h=Average height of center of gravity during continuous jumping for 5s, 5p=Average power (W×kg^{-1}) developed during continuous jumping for 5s, Sj=Rise of center of gravity during Squat Jump, Sjb=Rise of center of gravity during Squat Jump performed with extra load similar to the subject's body mass, TB (s) =300 m running time, TH (LA)=Blood-lactate concentration after 300 m running, 30h=Average height of center of gravity during continuous jumping for 30s performed with extra load of 0.5 times the subject's body mass, 30L=Blood-lactate concentration after continuous jumping for 30s performed with extra load of 0.5 times the subject's body mass, 30p= Average power developed during continuous jumping for 30s performed with extra load of 0.5 times the subject's body mass.

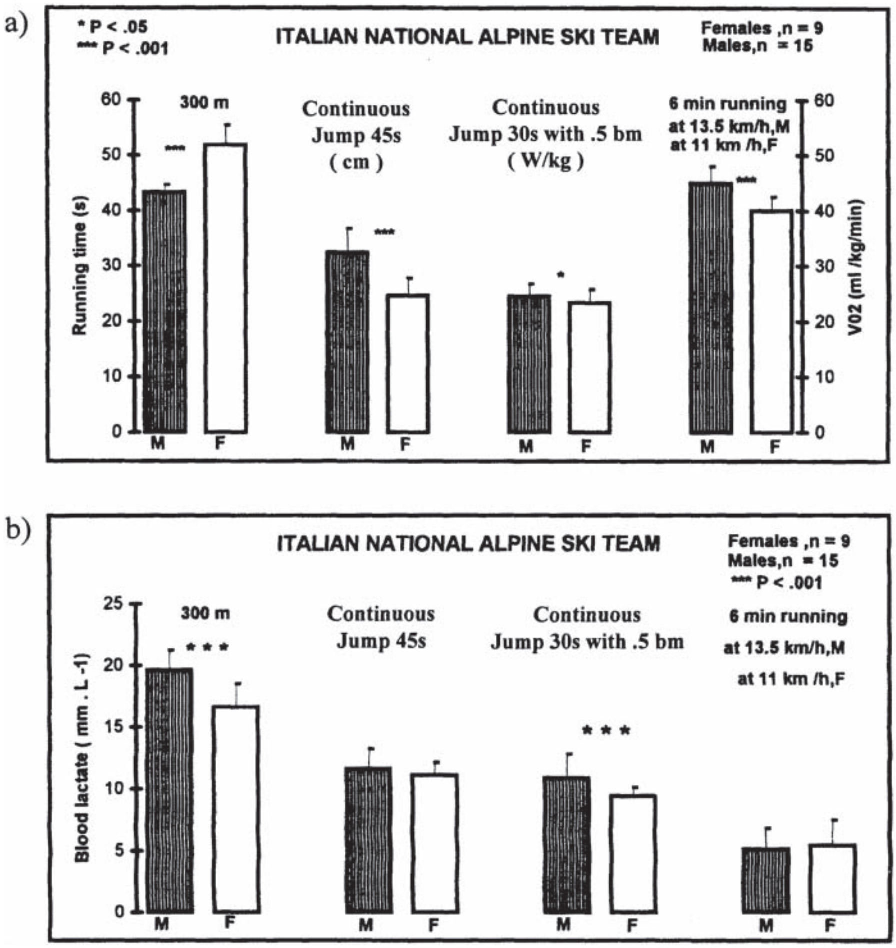
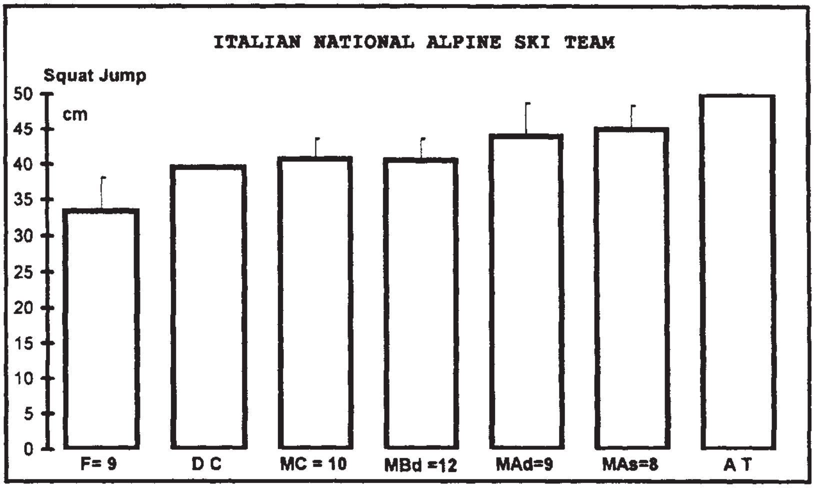


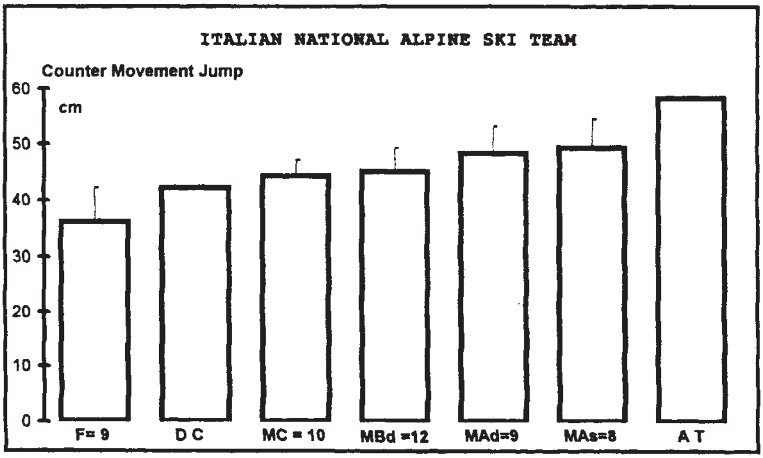
Fig. 1. Aerobic assessment capacity, 300m running time, average height (cm) during 45s CJ and average mechanical power (watt. kg-[1]) during 30s are shown for nine female and fifteen male international level alpine skiers in the upper panel (a). Blood-lactate concentration for the parameters are shown in the lower panel (b). Assessment for gender difference was performed using Student's t-test for unpaired observations. *P<0.05, ***P<0.001.

The rise of the CG measured in SJ, CMJ and 5s CJ are shown in Fig. 2a, b, c respectively for nine international-level females (F=9), one female Olympic gold medal winner (DC), ten males belonging to The Italian National C team (MC=10), twelve males belonging to The Italian National B downhill team (Mbd=12), nine males belonging to The Italian National A Downhill team (Mad=9), eight males belonging to The Italian National A Slalom team (Mas=8) and one male Olympic gold medal winner (AT).

a)



b)



c)

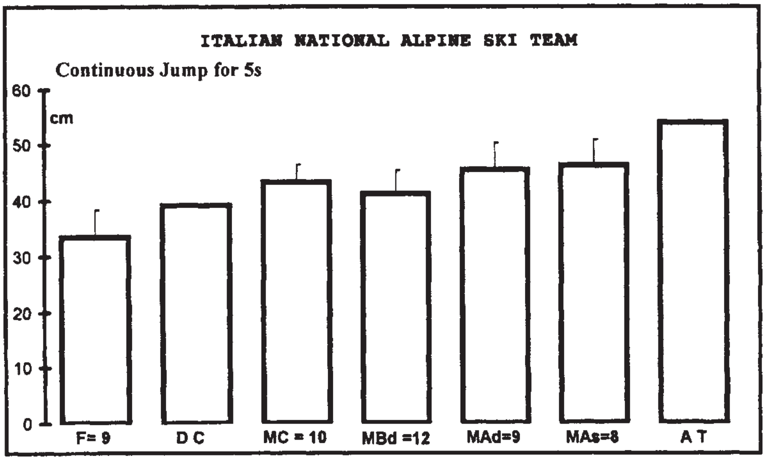
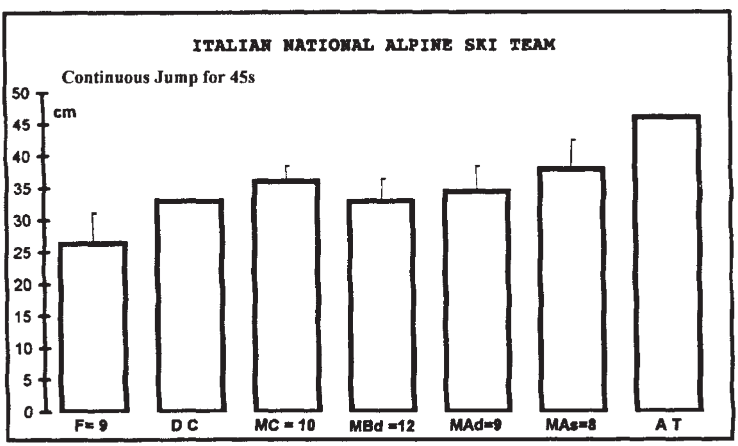


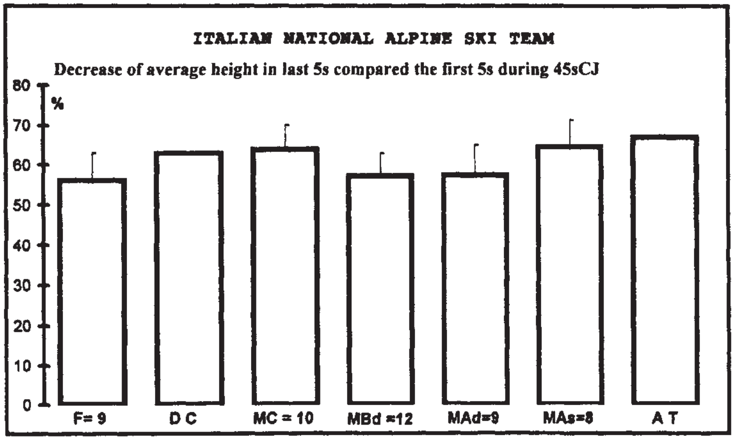
Fig. 2. The results of the rise of the center of gravity measured in Squat Jump (SJ) (upper panel: a), counter-movement jump (middle panel: b)and 5s CJ (lower panel: c) are presented for nine female international-level alpine skiers (F), one female international-level skier (DC), ten alpine skiers belonging to The Italian Men National C Team (MC), twelve alpine skiers belonging to The Italian Men National B Team (MB), nine alpine skiers belonging to The Italian Men National Downhill Team (MB), eight alpine skiers belonging to The Italian Men National Slalom Team (MA), and one male international-level skier (AT).

The results relative to speed endurance (average height in 45s CJ and decrease of average height in the same performance) and ratio between explosive power and maximal dynamic strength ($SJ \cdot SJbw^{-1}$), measured in the same subjects as in Fig. 2 are shown in Fig. 3a, b, c, respectively.

a)



b)



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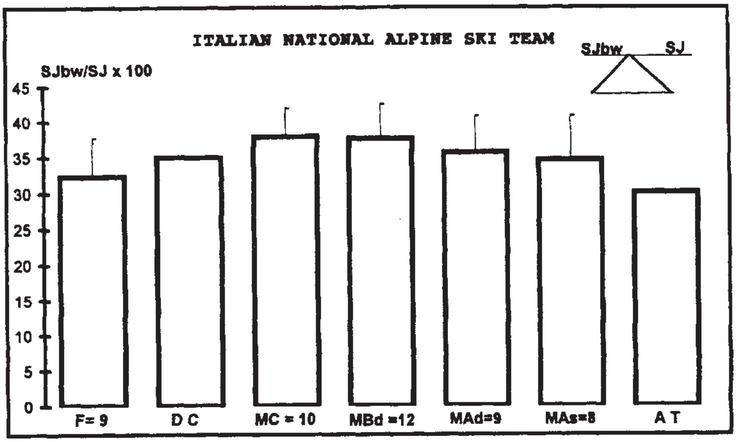


Fig. 3. The rise of the center of gravity measured during 45s CJ (upper panel: a), the decrease of the average height in the last 5s during 45s CJ (last 5s·first $5s^{-1}$·100) (middle panel: b) and and ratio between explosive power and maximal dynamic strength (SJ · $SJbw^{-1}$·100), (lower panel: c) are presented for nine female international-level alpine skiers (F), one female international-level skier (DC), ten alpine skiers belonging to The Italian Men National C Team (MC), twelve alpine skiers belonging to The Italian Men National B Team (MB), nine alpine skiers belonging to The Italian Men National Downhill Team (MB), eight alpine skiers belonging to The Italian Men National Slalom Team (MA), and one male international-level skier (AT).

The average increase in CG calculated every 5 jumps during 60s CJ was used to evaluate the speed-endurance capacity for thirteen male and eight female international-level athletes (Fig. 4). In the same figure the values of CMJ and 15s CJ are also shown.

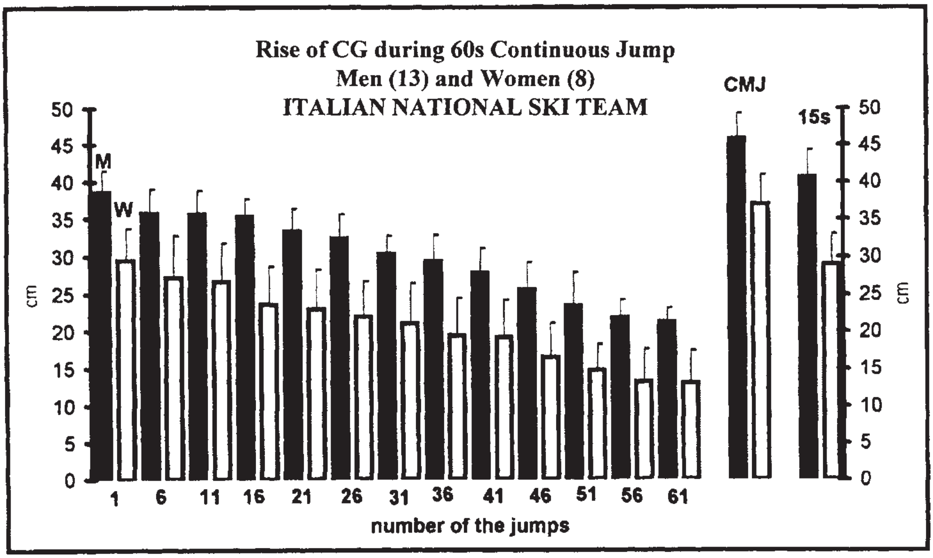


Fig. 4. The average values of the rise of center of gravity calculated every five jumps during 60s CJ, in Counter Movement Jump and during 15s CJ are are shown for thirteen male skiers (filled bar) and eight female skiers (empty bar).

Longitudinal observations on speed-endurance capacity, measured during the 45s continuous jump on seven female international-level alpine skiers (Fig. 5, left) and on one female Olympic winner (Fig. 5, right) expressed over a 15s period are presented before (June 1989) and after 5 years (June 1994). No statistically significant changes were noted for the seven female athletes after five years. In contrast, the female Olympic winner showed an improvement of around 20% of the average height for the first 15s period and around 10% for the other two 15s second periods.

Speed-endurance capacity, measured during the 60s continuous jump, on seven male international-level alpine skiers (Fig. 6, left) and on one male Olympic winner (Fig. 6, right) expressed over 15s period are presented before (June 1989) and after 5 years (June 1994). Statistically significant improvement (7–8%) of the average height of the center of gravity was noted for the seven male athletes after five years for the first (0–15s, $P<0.05$) and second (15–30s, $P>0.01$) periods, while no changes were noted for the last two periods (30–45s and 45–60s). In contrast, the male Olympic winner showed a drastic enhancement (>25%) for the first three 15s periods (0–15s, 15–30s, 30–45s) and about 13% for the last period (45–60s).

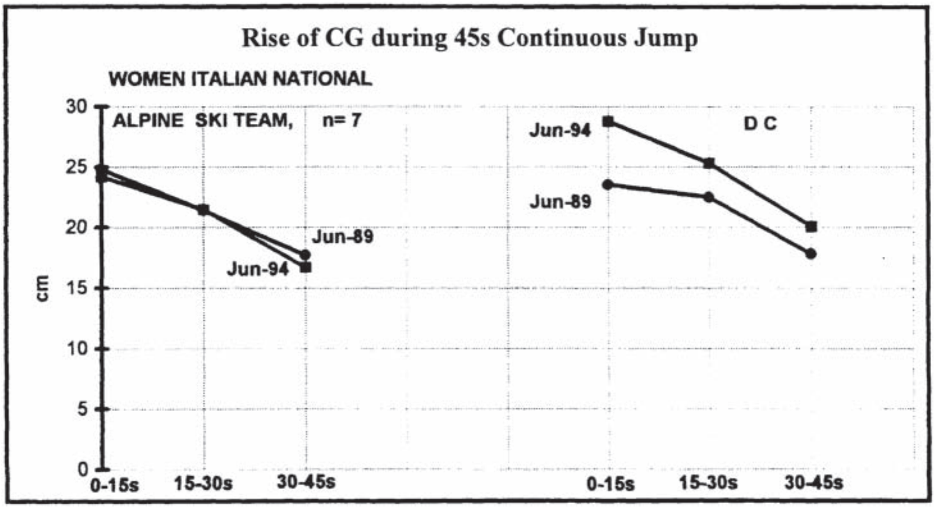


Fig. 5. The average values of the rise of the center of gravity measured during the 45s continuous jump on seven female international-level alpine skiers (left) and on one female Olympic winner (right) expressed over a 15s period are presented before (June 1989) and after 5 years (June 1994). No statistically significant changes were noted for the seven female athletes after five years. In contrast, the female Olympic winner showed an improvement around 20% of the average height for the first 15s period and around 10% for the other two 15s second periods. The astericks denote statistically significant difference, *<P 0.05; **P<0.01, Student's t-test for paired observations.

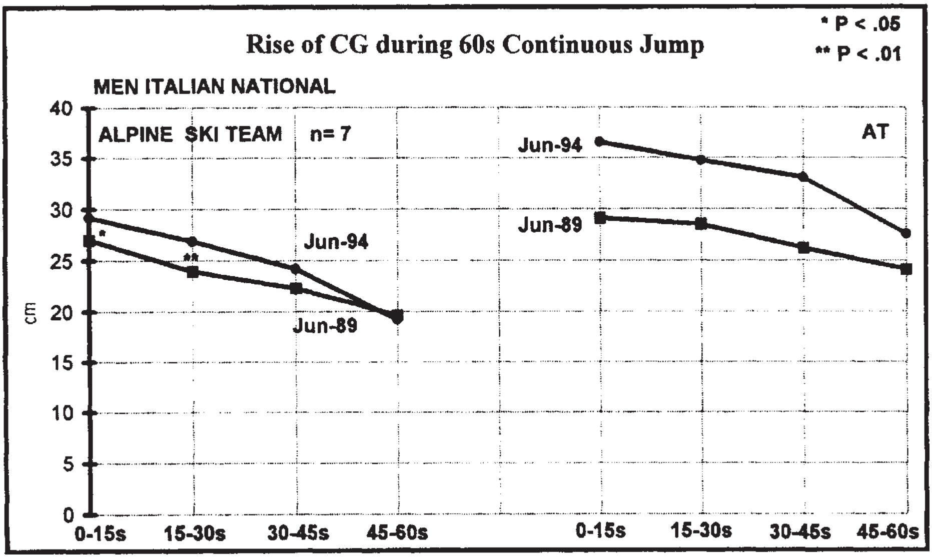
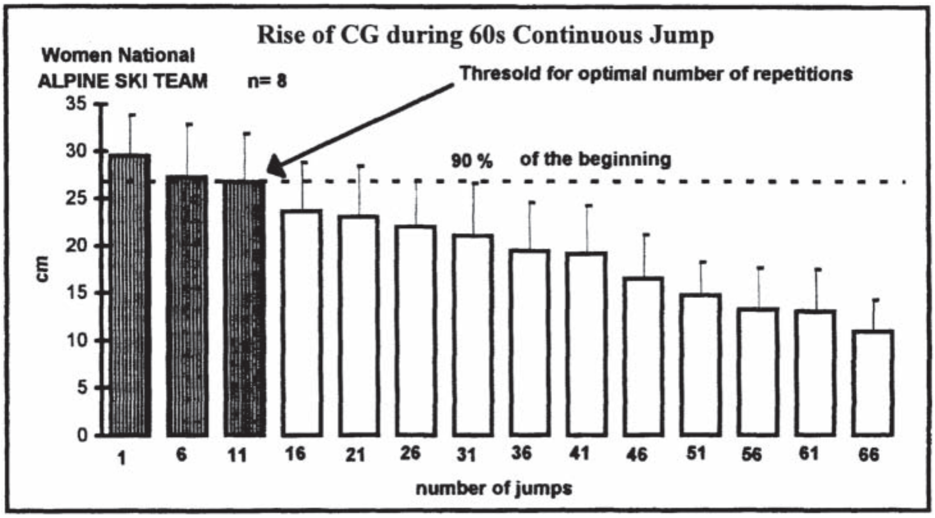


Fig. 6. The average values of the rise of the center of gravity measured during the 60s continuous jump on seven male international-level alpine skiers (left) and on one male Olympic winner (right) expressed over a 15s period are presented before (June 1989) and after 5 years (June 1994). Statistically significant improvement (7–8%) of the average height of the center of gravity, were noted for the seven male athletes after five years for the first (0–15s) and second (15–30s) periods, while no changes were noted for the last two periods (30–45s and 45–60s). In contrast, the male Olympic winner showed a drastic enhancement (>25%) for the first three 15s periods (0–15s, 15–30s, 30–45s) and about 13% for last period (45–60s).

The average values of the rise of the center of gravity every five jumps during 60s are presented separately for the eight female (Fig. 7) and the thirteen male alpine skiers (Fig. 8). The threshold indicating the optimal number of repetitions was settled at 90% of the initial-value level.



7. The average values of the rise of the center of gravity calculated every five jumps during 60s are presented for eight female alpine skiers. The threshold indicating the optimal number of repetitions settled at 90% of the level of the initial value.

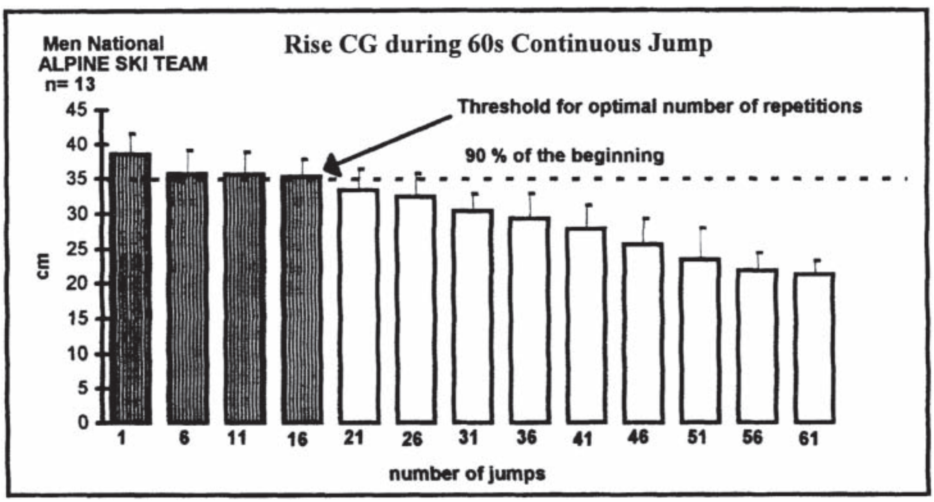


Fig. 8. The average values of the rise of the center of gravity calculated every five jumps during 60s are presented for thirteen male alpine skiers. The threshold indicating the optimal number of repetitions settled at 90% of the level of the initial value.

4 Discussion

Maximal aerobic power measured by maximal oxygen consumption (VO_2-max) has been used to assess fitness for alpine skiers (e.g. Saibene et al. 1985). On the other hand, White and Johnson (1991) demonstrated that VO_2-max did not exhibit any discriminating property when several groups of alpine skiers of different levels were evaluated. Based on the results of the White and Johnson studies, anaerobic power tests appear to be the most predictive of alpine skiers ability. In this connection several authors (Bosco et al. 1983a, Vandewalle and Monod 1987, White and Johnson 1991, Bosco et al. 1994a) have recommended the continuous jumping test (Bosco et al. 1983a) to assess the absolute power output for the specific nature of the effort demanded by the test. In alpine skiing, as well as in volleyball and basketball, the leg-extensor muscles are activated mostly in a stretch-shortening fashion, which is the specific characteristic of jumping-test performance. These suggestions are supported by the results of the present study. In fact, as shown in Table 1, the modification induced by eight weeks of systematic training demonstrated no relationships between the changes of the aerobic-capacity assessment and the change occurred in the speed-endurance profile (continuous jumping for both 30 and 45 seconds and 300 m running). In contrast, the changes observed in explosive-power characteristics (CMJ and 30 m dash) showed positive relationships with the modifications found for the speed-endurance profile. These findings suggest that both explosive power and speed-endurance capacities might possess a common biological pattern, which might be identified in the biological characteristics of the fast-twitch fibers. It should be kept in mind that it has been previously shown that there is a positive relationship between sprinting (Mero et al., 1981), single jump (Bosco and Komi, 1979), continuous-jumping performances (Bosco et al. 1983b) and FT fibers. This means that subjects rich in FT percentage are more favoured for anaerobic capacity than slow subjects. It is more likely that speed-endurance characteristics are connected with anaerobic capacity than with aerobic profile. In this connection it has been shown that anaerobic training improves the muscle’s capacity to tolerate acid that accumulates within them during anaerobic glycolysis (Wilmore and Costill, 1994). This is caused by improvement of the buffering capacity (Sharp et al. 1986) which is more pronounced in subjects rich in FT fibers and can be enhanced by anaerobic-type training. However, regardless of the intrinsic biological mechanism in which it has occurred, the results shown in Table 1 clearly demonstrated the relationship between explosive power and speed-endurance profile. This relationship might also be enhanced by the interruption of aerobic training

(Costill 1967, Ono et al. 1976). In fact, it should be pointed out that the training programme (Bosco 1994a) devoted to stimulate biological adaptation to speed endurance completely excluded aerobic metabolism. The programme was based mainly on strength training and the jumping exercise. In contrast to other regimes (e.g. Steadman et al. 1987) which emphasised aerobic conditioning as the basis for improvement of speed endurance (Fig. 9, left panel), no aerobic training was employed (Fig. 9, right panel).

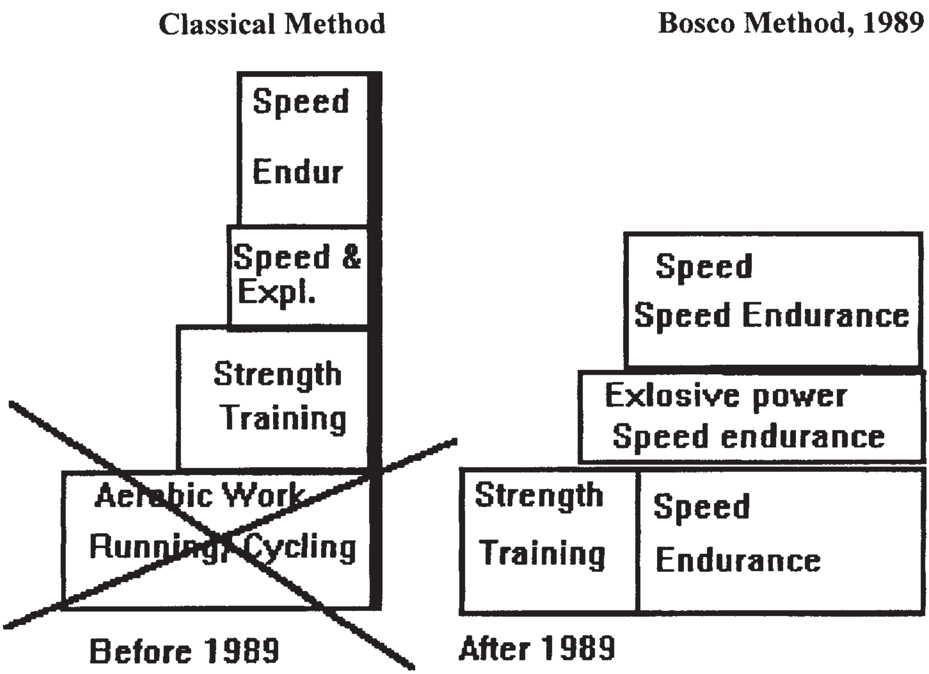


Fig. 9. Schematic representation of classical training method utilised for enhancement of speed-endurance capacity. The method which consisted of a block-period training system, was based on the supposition that biological adaptation could occur and progress separately in different physiological properties.

The classical method utilised for enhancement of speed endurance was based on a block training system. This training programme assumed separate and progressive biological adaptation. In contrast, speed endurance is considered in the new training method as a specific physiological property, which possesses its own identity and training strategy (Fig. 10, Bosco 1985, 1990).

One of the most specific training systems adapted for enhancement of speed endurance consisted of calculating the optimal number of repetitions which must be performed during each training series. For this purpose, the 60s CJ test was utilised to calculate the optimal number of repetitions for each athlete.

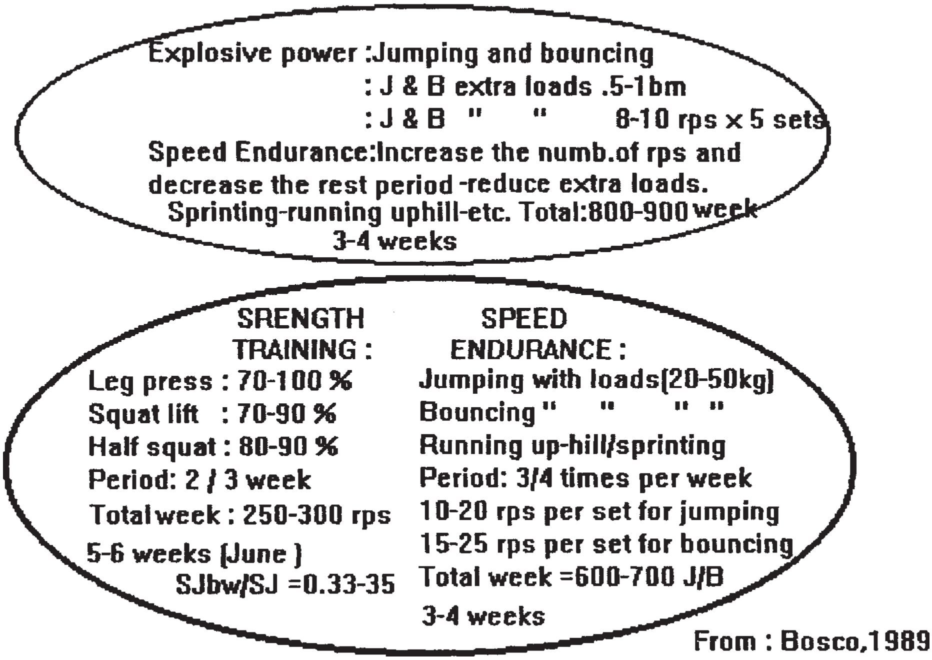


Fig. 10. Schematic representation of the new training method utilised for enhancement of speed-endurance capacity. The method has been utilised for team-sport athletes (Volleyball, Basketball, Bosco 1985) and individual sport (Alpine Ski, Bosco 1990). In contrast to the classical method, speed-endurance capacity was considered a specific physiological property, possessing ist own identity and therefore could be trained with specific drills and exercises.

To control that the subjects executed the exercises with maximal effort at beginning of the test, the initial values were compared to a single CMJ and to 15s effort performed separately (Fig. 4). If the initial values in 60s CJ were not much different than CMJ (20%) or 15s results (10%), than the test was considered valid. Once the test was accepted, the optimal number of repetitions was settled by counting the number of the jumps which reached not lower than 10% of the magnitude of the performance level obtained at beginning of the test. As shown in Fig. 7, the female skiers could not maintain the level threshold for more than 11 jumps, while the male counterparts were able to keep the height over the threshold (Fig. 8) for 16 jumps.

Longitudinal observations on biological adaptation for speed-endurance capacity also revealed strong gender difference.In fact, statistically significant ($P<0.05$–0.01) enhancement of the work output (rise of the center of the gravity) in the first 30s of 60s CJ test was noted only in male skiers after five years of systematic training. In contrast, no changes were noted in female athletes. Only for the female Olympic winner, as well as for the male Olympic winner, a dramatic improvement of speed-endurance capacity after five years of training was shown. It should be noted that at the beginning of the longitudinal observations (June 1989), no remarkable differences were noted between both Olympic winners and the counterpart international-level athletes. However, through the long training period, the speed-endurance capacity (Bosco's test, 1983) became the most predictive of alpine-skier ability, as previously suggested by White and Johnson (1991) (see also Fig. 3a). In this connection, it should also be reminded that maximal dynamic strength (SJbw) is not likely to be a discriminate characteristic between gender or between poor and elite athletes. In fact, when dynamic strength is related to explosive power (see Fig. 3c), no remarkable gender difference can be noted. Indeed, the ratio between the two characteristics in the male Olympic winner was lower than all the other skiers, including the female athletes. The ratio between SJbw and SJ has been assumed to represent the equilibrium between maximal strength and maximal explosive power (Bosco, 1992).

Since both properties are produced by the same muscles (leg extensors), the ratio may perhaps give indications on how much the explosive power can be improved by strength training. In addition, as shown in Table 1, high maximal dynamic strength is not related to speed-endurance capacity. Therefore, according to the present results, it is likely that the strongest gender difference can be found only for explosive power and speed-endurance capacity (see also Fig. 1–3). Gender differences in strength have been examined in function of neuromuscular co-ordination and body size (e.g. Wilmore 1974), training status (e.g. Morrow and Hosler 1981), etc. There is general agreement that women's lower extremity strength reach on the average 70% of men's. Although this difference could be associated to the ten-fold greater magnitude of Testosterone present in adult men, in leg strength, when body size is accounted for, women reach similar values to men (e.g. Wilmore 1974). However, no clear relationship has been found between the magnitude of strength and the level of testosterone. In this regard, it has been suggested that Testosterone might be connected to neural factors (e.g. Kraemer 1992), which in turn, could explain the positive relationship found between Testosterone and explosive power (Bosco 1993). The influence of training can demonstrate strong potential in adapting neuromuscular behaviour. In some cases, its effect can be stronger than that of the basic structural composition of skeletal muscle (e.g. Thorstensson 1976, Bosco et al. 1994b). It has been suggested that improvement of neuromuscular behaviour induced by high resistance training may result from an increased number of motor units and/or increase in their firing frequency and/or from possible adaptations in the recruitment pattern of motor units (Milner-Brown et al. 1975, Sale 1988). In this connection, Bosco et al. (1995) suggested that the effect of strength training on the male sex hormone might be one essential factor connected to such gender difference noted. The increase in serum Testosterone has been shown to be more pronounced in men than women, in both long-term training adaptation (Hakkinen et al. 1988, 1990), and after a single strength-training session (e.g. Weiss et al. 1983, Kraemer et al. 1990).

In this respect, more than an anabolic agent, it has been suggested that testosterone may cause a dramatic maximizing the potential effect on neural factors and may favour the transition of type two fibers to more glycolitic profiles (for a review see Kraemer 1992). Although no serum Testosterone concentration was analysed in both male and female skiers, it can be assumed that adaptive changes to training of sex hormones were more pronounced in male compared to female athletes. Thus greater amount of Testosterone might be connected to the greater capacity shown by male skiers in speed-endurance and explosive-power performances, compared to female counterparts. It should be noted that the speed-endurance capacity, evaluated during 60s CJ, demonstrated a positive relationship with the magnitude of the serum testosterone in sixteen soccer players (Bosco et al. 1996b). In addition, it can be suggested that the mechanical behaviour of muscular function might be an improved, high level of Testosterone.

Finally it should be pointed out that aerobic training, in addition to inducing muscle activation to work at low frequency, is likely to increase and stimulate b-endorphin release. This in turn may inhibit LH release, and consequently, testosterone production (Sapolsky, 1987). Recent studies, performed on soccer players, strongly support these suggestions. In fact Bosco et al. (1996a), noted that endurance capacity assessment was negatively and positively correlated with serum Cortisole concentrations, while a negative, statistically significant relationship was found with serum Testosterone concentrations.

Concluding remarks

According to Bosco's training programme (1985, 1990) the following conclusions can be drawn:

i) Speed-endurance capacity is likely to be the most important capacity for alpine skiers and team sport athletes (e.g. soccer, volleyball, basketball, handball, etc.).
ii) Speed-endurance characteristics are not related to high aerobic power.
iii) Maximal dynamic strength, although playing an important role for speed-endurance training, does not represent an essential capacity. However, since strength training enhances an increase in Testosterone circulation, which in turn, it is likely to be connected with transition of FT fiber to more glycolitic profiles and more efficient muscular behaviour, it must be included in the training programme.
iv) Speed-endurance capacity can be improved using a personalised training programme. It is possible to calculate the optimal number of repetitions using the method introduced by Bosco (1990).
v) It seems that the biological adaptations induced by systematic training are more effective for enhancement of speed-endurance capacity.
vi) Explosive-power characteristics are strongly determinated by genetic characteristics, therefore, training can partly influence its enhancement.
vii) Although strength training is included in the training programme, it should not be emphasised, since a certain equilibrium must be kept between maximal dynamic strength and explosive power.

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22

KINEMATIC AND KINETIC ANALYSIS OF SLALOM TURNS AS A BASIS FOR THE DEVELOPMENT OF SPECIFIC TRAINING METHODS TO IMPROVE STRENGTH AND ENDURANCE

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Keywords: slalom skiing, technique analysis, specific strength training, ski-specific-training equipment, biomechanics, alpine skiing.

1 Introduction

In recent years, the authors have worked intensively with technique analyses of ski races and the possible transfer of technique-specific interests in conditioning training through the development of special training equipment at the Institute for Sport Sciences at Salzburg University.

The science of training will, more than ever before, be called upon to contribute to the optimization of training methods in high-performance sport. In the future, improvements of athletic capacity will probably be better achieved through an increase of the quality of training rather than an increase in the amount of training [1].

The literature of training science contains numerous studies which prove that the training of general conditioning, valid for all forms of sport leads to considerable improvements of particular physical parameters; however, training of this kind hardly succeeds in increasing competitive capacity [2] [3] [4].

On the other hand, it could be shown in numerous cases that the use of technique-specific means of training—parallel to general conditioning training—leads to considerable improvements of performance also among athletes with many years of training experience [5] [6] [7].

Consequently, it is important to direct one's attention to the development of biomechanically relevant and, therefore, highly specific means of training. This mainly applies to what are called seasonal sports such as alpine ski racing. Alpine ski racing is one of those sports which make high demands on technical and physical abilities. This is made more difficult by the fact that technique-specific training can only be performed on snow. Because snow-training in summer is very problematic due to organizational and financial reasons, technique-specific training is of high importance.

In order to do justice to this demand, as detailed data as possible regarding the kinematic motor and dynamic load structure are necessary. Only then, building on this knowledge, can the development of skiing-specific training devices and methods be initiated.

2 Methods

As basis for the development of ski-racing specific simulation exercises, we give here descriptive biomechanical analyses of competition techniques in the slalom.

As test persons, one member of the Austrian national team and six up-and-coming young skiers of the skiing secondary school in Stams were at our disposal. They were each required to complete a slalom course with openly planted gates and a vertical three times on a permanent ski run. The slalom slope—that is to say, the preparation of the piste -was the equivalent of the usual standard for world-cup competitions.

For the kinematic analysis, the piste was marked out with 30 different high rigid calibration poles. The three-dimensional coordinates of each of the reference markers and the coordinates of the calibration points on a Peak Performance calibration frame, placed approximately in the centre of the piste, were obtained using a theodolite and standard surveying methods. The calibration frame was used to aid accurate computation of the internal camera orientations and DLT parameters.

Two video cameras mounted on platforms (recording frequency 50 Hz) could follow the racer in his movements through panning on one hand, and on the other, could guarantee a full-size picture of the test person from start to finish through the use of zoom lens. This has a positive impact on the exactitude of the measurements in the following evaluation using the peak 3D Software and the Panning programme developement by Drenk [8].

Drenk developed a computer programme based on Peak Software, which enables the user to obtain the tree-dimensional data of the body landmarks by using pannes, tilted and zooming cameras (panning-programme). If the filming conditions are strictly adhered to, the algorithms underlying the panning-programme guarantee the usual accurancy of fixed cameras in the whole range of filming.

Fig. 1. Racer during a test run.

The ground reaction forces and pressure distributions on the plantar surface were measured with the EMED system from the firm NOVEL. The racers had to ski with two specially adaped insoles with 85 capacitive sensors, placed between inside boot and plantar surface. The data were collected in the mikro-EMED, worn in a specially adapted belt around the skier's waist. The sampling was 40 Hz. Measurement errors occuring during the experiments as a result of the forces which are deflected over the leg of the ski boot and are, therefore, not registered, lie in normal slalom situations within acceptable parameters.

With a specially developed synchronizer, an exact synchronization of the kinematic and kinetic data could take place.

After the very time-consuming calculation and evaluation of the three-dimensional kinematic and the kinetic data any, desired course insightful for both trainer and racer regarding slalom technique could be represented and interpreted.

Table 1. Selected kinematic and kinetic parameters.

KINEMATIC PARAMETERS	KINETIC PARAMETERS
knee angle	ground reaction force from the outer leg
hip angle	ground reaction force from the inner leg
inward leaning angle	just the force of the heel
angle of the skis to the movement direction	just the force of the forefoot
angle of the shoulder and hip axis to the movement direction	force of the inside edge
edging angle	force of the outside edge
velocity of the center of gravity	movement of the weak point under the foot

The course of the ground-reaction forces from the outer and inner ski, including the inward-leaning angle of the skier calculated over the partial centres of gravity is here shown in an exemplary manner. A further diagram shows the shoulder and hip axes with respect to the racer's direction of motion.

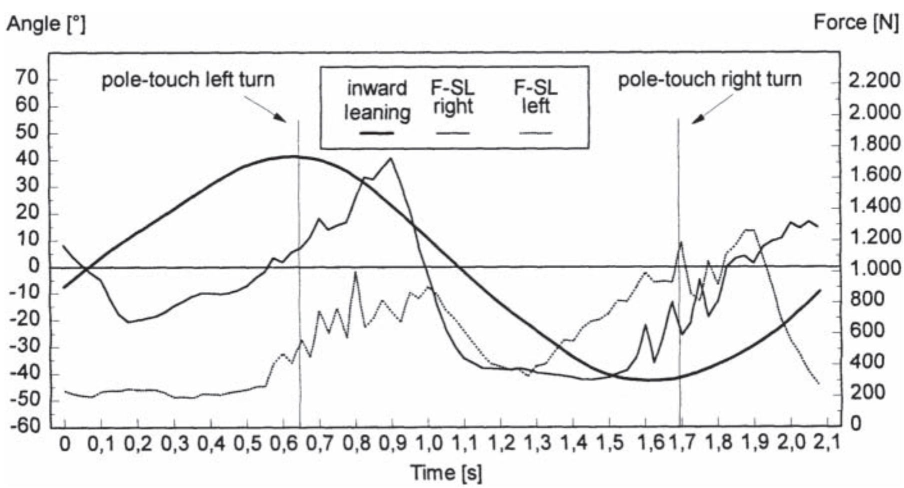

Fig. 2. Inward leaning angle of the skier with the force-time curves of the outer and inner leg during a left and right turn.

During a left turn, the maximum of outer-ski stress is approximately 2.5 times, the inner-ski stress approximately 1.5 times that of the body weight. A considerably more intensive co-stressing of the inner ski is, in comparison, observable in the following right turn. This also shows effects on the corresponding inward-leaning angles whose maxima occur approximately at the moment of pole clearance and measure circa 40°.

In Fig. 3, a relatively intense co-rotation of the shoulder axis until the moment of pole clearance is shown in both left and right turn. The hip axis in comparison remains relatively constant with the elite skier, as opposed to the up-and-coming skier.

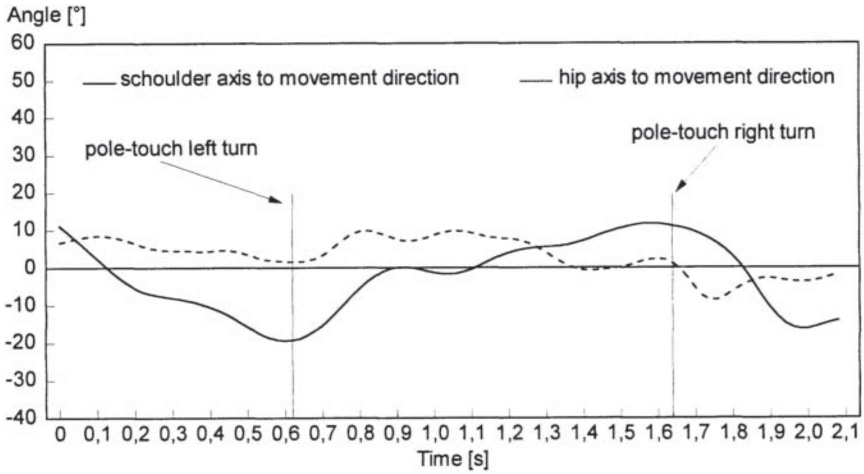

Fig. 3. Angle of the shoulder and hip axis to the direction of motion.

3 Results and Discussion

In the second part of the project, two pieces of training equipment were developed and built based on the knowledge gained from the earlier results. The goal was to realise the highest possible correspondence between the characteristics of slalom competition and the training exercises.

From the point of view of training methodology, the following demands are to be made on technique-specific conditoning training:

a) In the selection of the training exercises, one should try to come as close as possible to the dynamic and kinematic structure of the competitive exercise (simulation exercise).

On the one hand, the dynamic and kinematic affinity of training exercise and competitive exercise provides a training stimulus for the musculature mainly under strain in competition. On the other hand, special neuronal mechanisms are created which improve the technique-specific muscular innervation pattern.

b) The degrees of resistance used in the simulation exercise should be so chosen that they exceed or fall short of the strain specific to the competition only to a very slight degree.
On the one hand, in accord with the training principle of the variation of the strains in training, it is necessary to vary systematically the kinds of resistance and consequently the training exercise itself. On the other hand, several studies [9] [10] [11] have shown that great variations in the decrease of the resistance result in the emergence of structural alterations in the movements themselves. The extent to which degrees of resistance specific to competition may be exceeded or fallen short of is given as being between +/-5–15 percent in the relevant studies [12].
c) In the choice of motion frequency, the competition-specific nature of release of energy has to be taken into consideration (not maximum, but optimum motion frequency).
d) The duration of the exercise series should on the one hand cause exhaustion; on the other, the essential intensity parameters of the simulation exercise should also be retained at the end of the series.

The first training instrument—the ski-power hometrainer (SPH)—has been conceived as a ski-specific training device for the up-and-coming young skier, skiing clubs and for the at-home training of athletes, and is made to be transportable. The simulating motion, analogous to unweight during a racing turn, is executed by moving from one tilted surface to the other while wearing either ski jumping boots, ski boots or ski boots with short skis.

The resistance of the simulated angle of the slope can be adjusted according to body weight and jumping rhythm. The jump frequency and duration of the exercise series is given to the athlete through the presentation of a video-recorded slalom race. According to the training conditions and terms of reference, additional weight in the form of upper-thigh sleeves (up to 10% of the body weight) can be added.

Fig. 4. Ski-power-hometrainer.

To check the validity of the training device, the kinematic and kinetic features of the training exercises were analyzed using the measuring methods described above (Fig. 5/Fig. 6).

The forces of the outer and inner ski of a slalom turn of an up-and-coming racer displayed here show once again the familiar pattern of the strain relief *inner-ski/outer-ski*.

This is also recognizable in the motion of impression on the ski-power hometrainer. Correspondence between the measurements of the forces summoned up by the outer and inner leg and the temporal structure is also visible. Only the landing on the respective opposing side of the SPH brings about, expecially in the outer leg, a very steep increase in force and a generally double-peaked force-time duration.

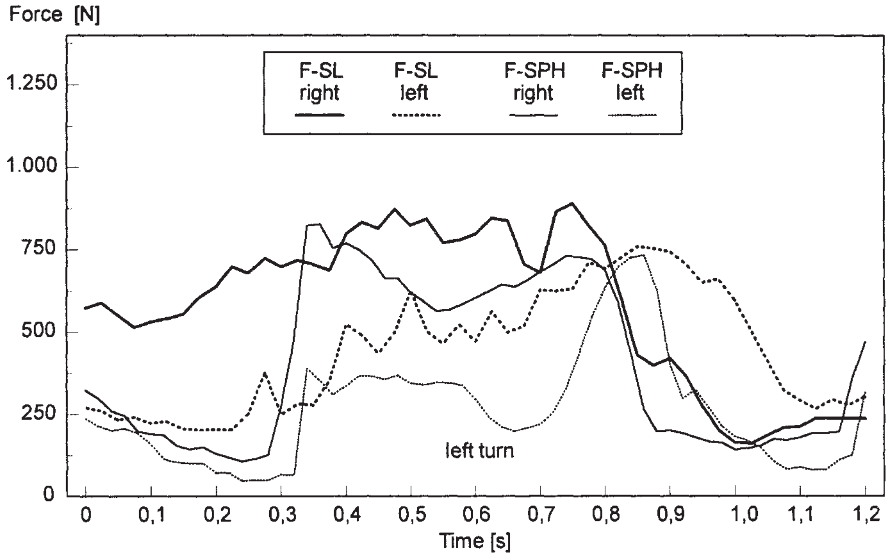

Fig. 5. Comparison of ground-reaction forces from an up-and-coming racer: slalom vs. ski-power-hometrainer simulation exercise.

The comparison of the two courses of the knee angle of the respective outer leg during the turn shows a satisfactory correspondence in the turning phase. During the turn release, the knee angle is significantly larger (up to 170°) than in the real slalom situation, bacause of the necessarily more intense motion of impression.

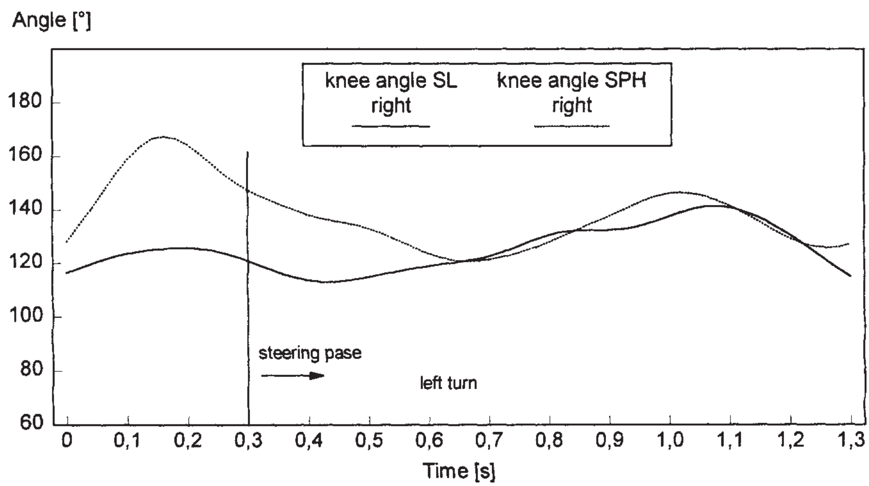

Fig. 6. Comparison of the knee angle from an up-and-coming racer: slalom vs. ski-power hometrainer simulation exercise.

Considerably more difficult was the development of a second ski-specific training device, the ski-power simulator. For this piece of equipment, the target groups to be kept in mind were schools which focus on skiing (e.g. the secondary school in Stams) and high-performance athletes.

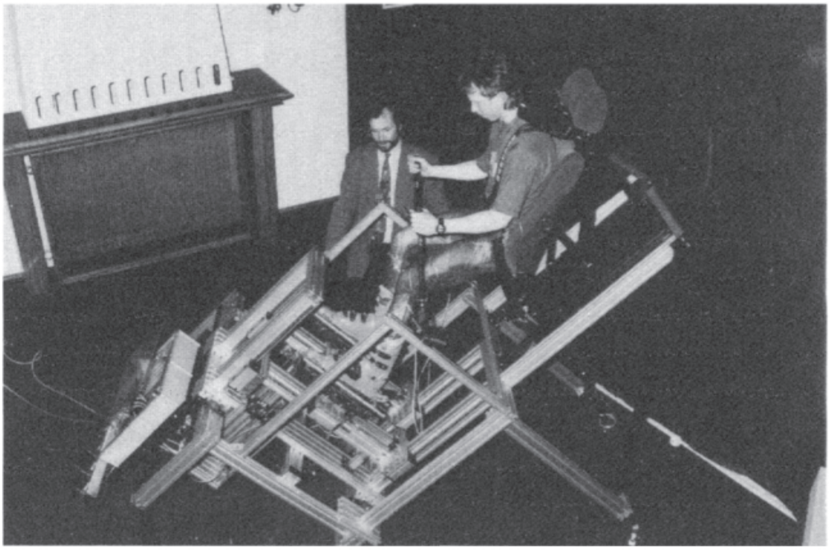

Fig. 7. Ski-power-simulator.

For the foundation of this strength- and stamina-training device, highly sturdy, precision treadmills make from aluminium of the ITEM MB System was used.

Generated by five dual-drive magnetic piston cylinders, the given movement is done along a linearly arranged support unit. Magnetic valves, throttle valves, motion-activated switches, as well as pressure release valves were interconnected for the purpose of making variable settings possible. The throttle valves and motion-activated switches make possible the simulation of more or less all gate combinations planted from the fall line. The pneumatic equipment was done by an automation instrument (S5–100U) from the firm SIEMENS. The results of the validity check of this training device are shown below:

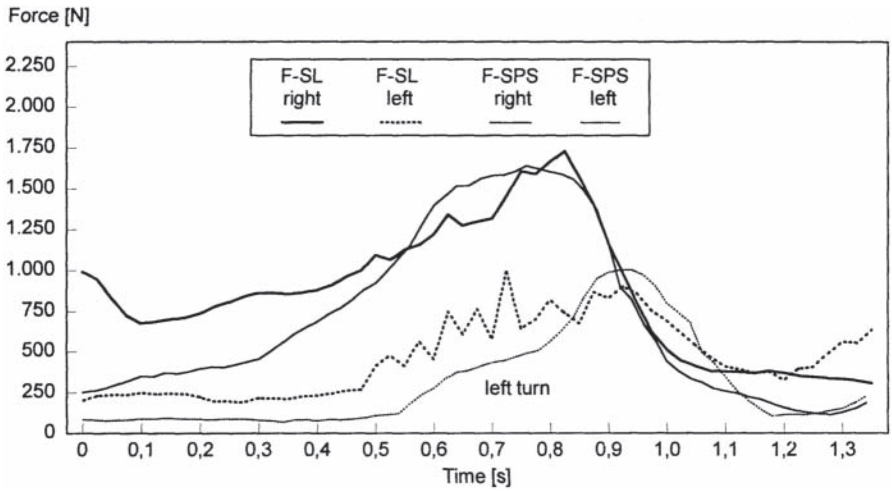

Fig. 8. Comparison of the ground-reaction forces from the elite athlete: slalom vs. ski-power-simulator simulation exercise.

Fig. 8 compares the ground-reaction forces in the slalom of an elite athlete with that of a turn simulation of the SPS. Very good correspondence in the range of the temporal as well as the dynamic (kinetic) structure has been attained.

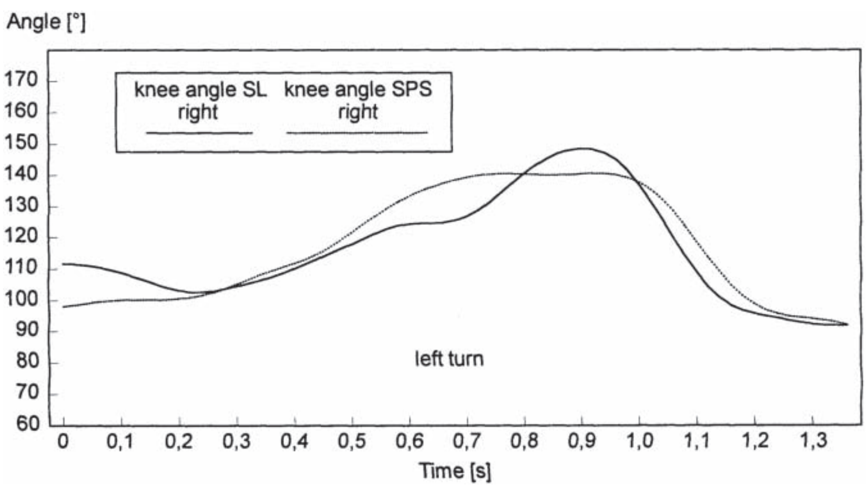

Fig. 9. Comparison of the knee angle from the elite athlete: slalom vs. ski-power simulator simulation exercise.

Also in the kinematic parameters, as in the knee angle of the outer leg, the demand for structural similarity could be fulfilled by the ski-power simulator in many areas.

In a future, third part to this project, it is planned that the efficiency of these devices in the training process will be verified and ski-specific strength-endurance tests developed.

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TYPES OF MUSCLE ACTION OF LEG AND HIP EXTENSOR MUSCLES IN SLALOM

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Keywords: concentric muscle action, eccentric muscle action, slalom skiing, stretch-shortening cycle, training device, alpine skiing.

1 Introduction

During preparation and competition periods, specific strength training and exercises which simulate the slalom turn, are used to prepare, maintain or enhance performance in slalom. Common skills for this purpose are one-and two-footed vertical and horizontal jumps. One-footed alternating lateral jumps with landing and push-off on the outside leg are particularly often used. During all these movements performance is generated mainly by leg-and hip-extensor muscles, acting in a stretch-shortening cycle (SSC). Stretch-shortening cycle is characterised by the immediate succession of two movement phases during ground contact. During the first phase, external forces usually exceed (internal) muscle forces. Therefore the joints (here: ankle-, knee-, and hip-joint) are bent in this phase and the corresponding active extensor muscles are stretched, working eccentrically. Immediately after compensation of the external forces the second phase begins: the joints are extended and the extensor muscles shorten, working concentrically. As indicated from several studies [1] [2] [3], SSC is a specific type of muscle action (MA). The reason for this is that during the eccentric phase, energy is stored in elastic structures of the muscle-tendon complex and reutilized during the concentric phase [4] [5] [6]. This leads to the maximization of performance potential and to an enhanced efficiency of movements using SSC, compared to movements with pure concentric MA [1] [2] [7]. The potentiation of performance as well as the efficiency of SSC depend mainly on the quality of the regulation of muscle stiffness. In SSC movements muscle stiffness is regulated essentially via three mechanisms: the muscle activation before ground contact (pre-activation), short-range elastic stiffness (SRES), and the stretch reflex activation. In movements with pure concentric MA, muscle stiffness is primarily regulated by voluntary muscle activation. High performance in movements using the same muscles but different types of MA than SSC (e.g. pure concentric MA) therefore, is not completely transferable to movements using SSC and vice versa.

In addition, it is well known that the amount of adaptation to training procedures depends on the type of MA used during the training exercise. For example, when a combination of concentric-eccentric MA is used in training, results from pure concentric and pure eccentric tests are improved, but this is significantly less than compared to those from the specific concentric-eccentric test [8].

Therefore, it should be assumed, that gains in strength training using a certain type of MA are only partly transferable to movements using a different type of MA. For that reason, the type of MA during training movement, should be the same one as of the specific sport movement of interest (here: slalom turn).

The aim of the study was to analyse which types of MA are used in slalom and to find guidelines for the construction of relevant training exercises.

2 Methods

One member of the Austrian national alpine skiing team and six junior ski-racers (international level) of a skiing secondary school in Stams, volunteered as subjects in this study. Their task was to complete a slalom course with openly planted gates and a vertical three times. The slalom slope (and preparation of the piste) was equivalent to the standard for world-cup competitions.

Fig. 1. Racer during the left turn.

Pressure distribution under the soles of the feet was measured inside the boots via an EMED-system (sampling-frequency=40 Hz). Based on this data one can calculate force-time-curves with sufficient accuracy. To guarantee a high resolution consistently, kinematic data was registrated using ‘pan’ and ‘zoom’ video camera systems (50 Hz). Kinematic data was analysed by means of a modified ‘Peak Performance System’.
More information about methodological aspects of the study are given in the previous article by RASCHNER et al. in this volume.

3 Results

As shown in Fig. 2, during the turn the force under the outside leg first increases continuously (about 2.5 times body weight) and thereafter decreases in a short time (about 200 ms). Until the pole is touched, the knee-joint angle increases, thereby extending the knee-joint angle and working the knee-extensor muscles concentrically. After this phase until the end of the turn, the knee joint is bent more and more and the knee-extensor muscles work eccentrically. In contrast, hip-joint angle stays nearly constant until pole-touch (small reduction), and is reduced significantly thereafter. The outside hip joint is bent and the hip-extensor muscles work eccentrically most of the time. *For that reason neither the knee nor the hip-extensor muscles of the outside leg use SSC!*

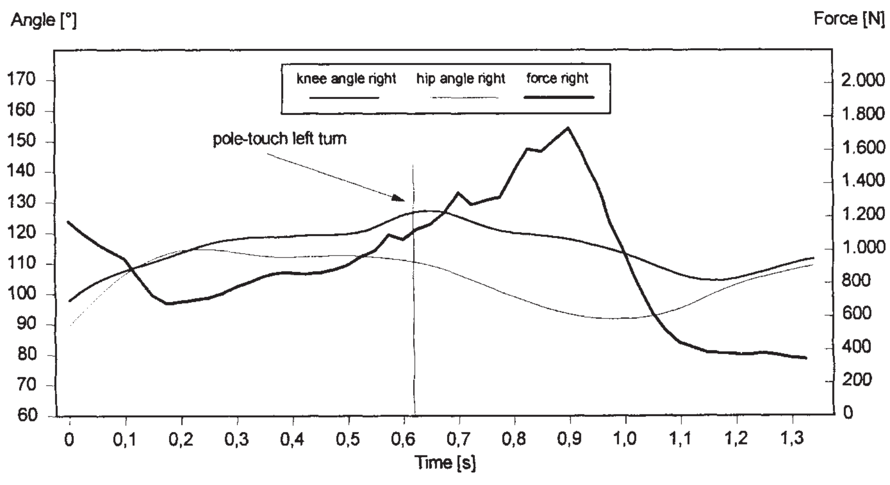

Fig. 2. Force-time curves, knee- and hip-joint-angle time curves, of the right (outside) leg in a left turn.

In contrast to that, (compare Fig. 2 and 3), the knee- and the hip-joint-angle time curve of the left side (inside leg) shows a clear bending phase, which starts when the fall-line is passed through. During that phase extensor muscles act eccentrically. This phase is followed by an extension phase, during which extensor muscles work concentrically.

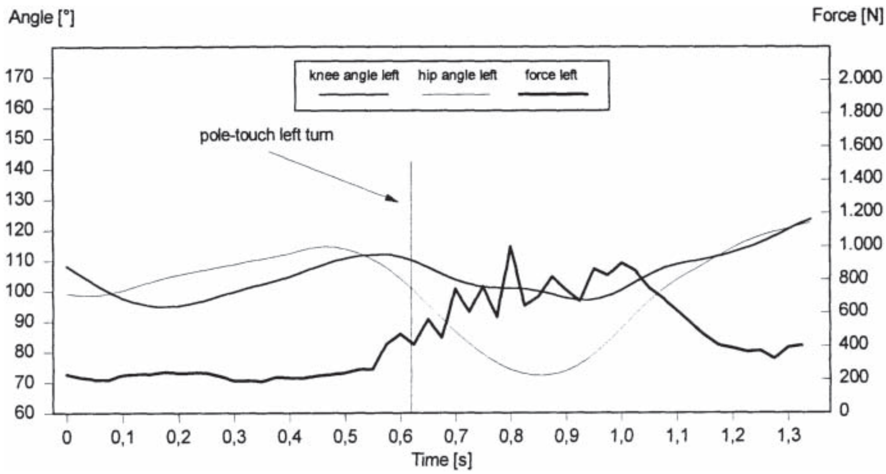

Fig. 3. Force-time curves, knee- and hip-joint-angle time curves, of the left (inside) leg in a left turn.

Simultaneously, an initial rise and subsequent decline of the force-timecurve was registrated. Except for the high-frequency oscillation, which is superimposed in this case, the characteristic of this force-time curve is of the same type as those of jumps. *Therefore one can assume that knee- and hip-extensor muscles of the inside leg use SSC during the turn!*

The force-time curves as well as the joint-angle time curves shown above are results of a single turn of one subject. Therefore the intraindividual reproducibility has to be checked first. Fig. 4 shows the force-time curves of the outside leg of one person during three runs.

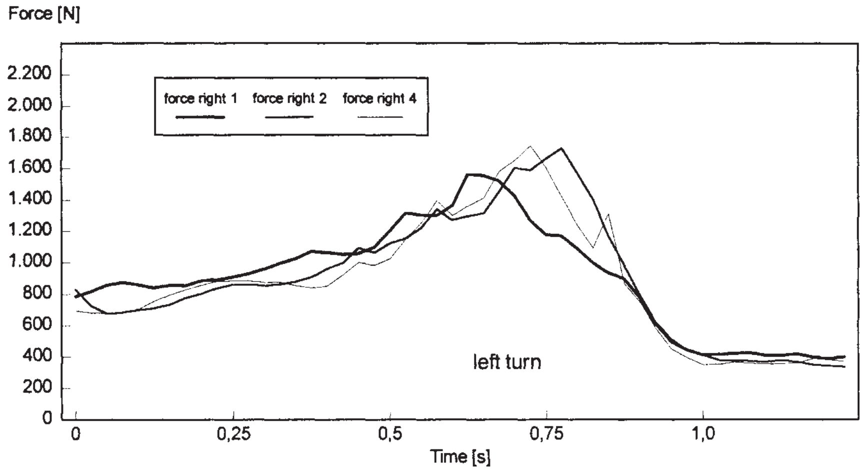

Fig. 4. Force-time curves of the right (outside) leg in left turns, during three runs of one subject.

Although slight differences between the peak-forces of the three runs are detectable, the force-time characteristics are quite similar.

The same is true for the force-time curves of the inside leg during the three runs: the absolute force-peaks differ, but the pattern is almost the same (see Fig. 5). Particularly remarkable is the high-frequency oscillation during the increasing part of the force-time-curves in all three runs.

Although the amplitudes of the knee-joint angle curves of the inside leg differ considerably between the three runs, all three curves show a typical pattern: after the pole is touched, the knee-joint angle is reduced first and increased thereafter (see Fig. 6).

As shown in Fig. 6 the angle-time curves of the hip joint of the inside leg are very similar in all three runs. After the pole is touched there is a marked bending of the hip joint with a duration of approximately 350 ms and a subsequent extension of nearly the same size in amplitude and duration.

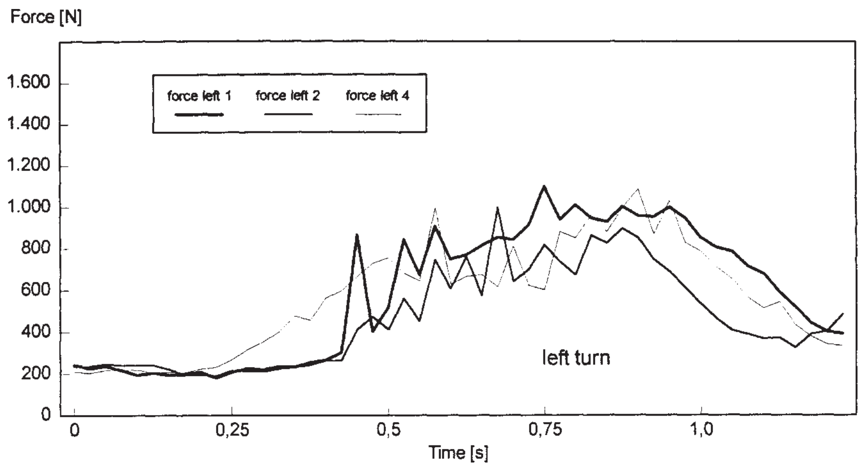

Fig. 5. Force-time curves of the left (inside) leg in left turns, during three runs of one subject.

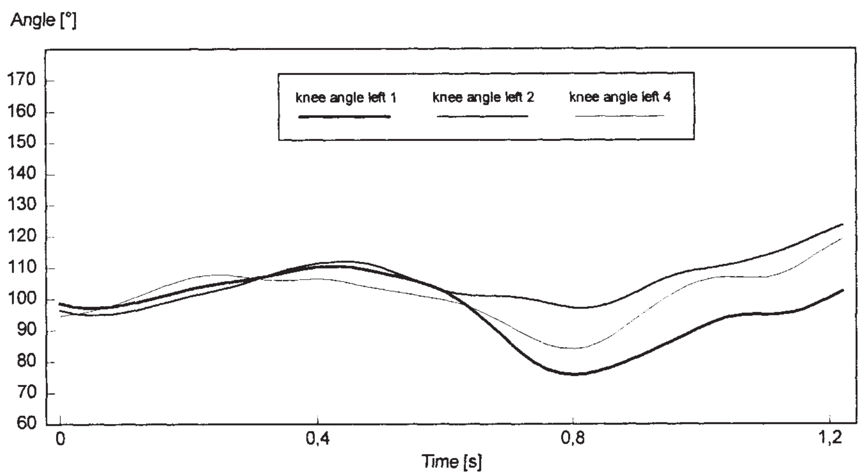

Fig. 6. Knee-joint-angle time curves of the left (inside) leg in left turns, during three runs of one subject.

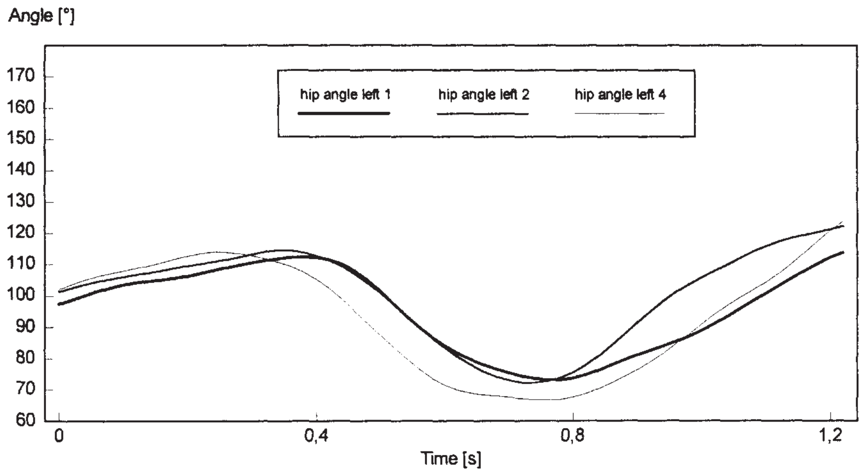

Fig. 7. Hip-joint angle-time curves of the left (inside) leg in left turns, during three runs of one subject.

In summary, one can state that the results concerning force-time curves as well as the knee- and hip-joint-angle time curves are successfully reproducible *intra*individually.

Comparing the force-time curves of the inside leg of three different subjects (compare Fig. 3, 8 und 9), beside slight differences in duration, some similarities are evident: the overall pattern is alike, the peak-forces are approximately one kN, and there are some high-frequency oscillations visible in the force-time curves of each subject.

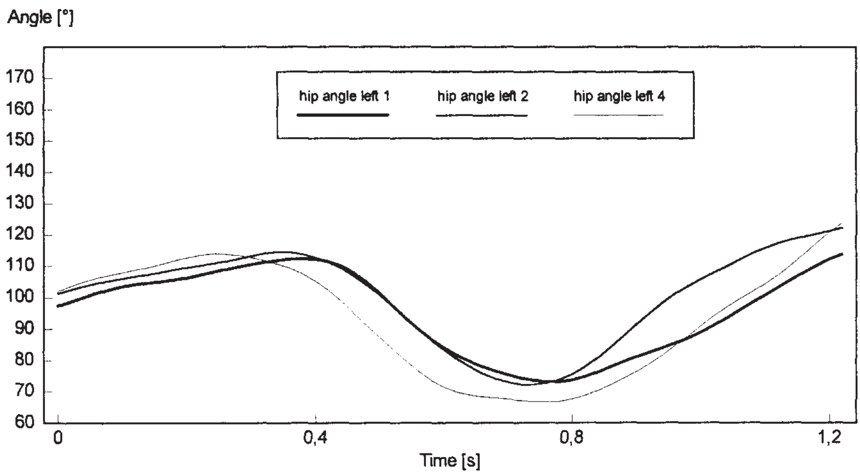

Fig. 8. Force-time curves and knee- and hip-joint-angle time curves of the left (inside) leg in a left turn of subject two.

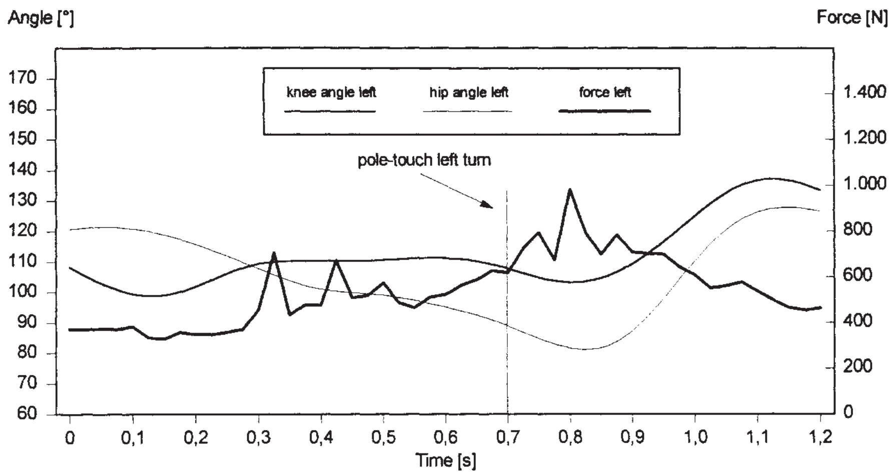

Fig. 9. Force-time curves and knee- and hip-joint-angle time curves of the left (inside) leg in a left turn of subject three.

After the pole is touched the hip- and knee-joint-angle time curves show similar patterns in all subjects presented, (see Fig. 3, 8 und 9). Corresponding results were found comparing the force- and angle-time curves of the outside leg of different subjects.

In summary, the comparison of the interindividual results leads to more or less pronounced differences. But the remarks concerning the types of MA used by the extensor muscles of the outside and the inside leg during the turn are valid for *all* analysed subjects.

4 Discussion

As indicated by the results of the study, during slalom turn knee- and hip-joints of the inside leg are bent first and are extended immediately after. During that time knee- and hip-extensor muscles are active [9]. Therefore one can assume, that these muscles use the slow type of SSC (duration of MA≈600ms) [10]. Another most interesting finding concerning the inside leg are the high-frequency oscillations visible on the force-time curves, (see Fig. 3, 5, 8 und 9). The origin of these oscillations can not be determined with certainty. Possible reasons are that the vertical forces on the inside ski are not high enough compared to the horizontal (centrifugal) forces and that the radius of the chosen track of the inside ski is too small in relation to the radius of the loaded-ski edge. Therefore the grip of the inside-ski edge is lost for short periods of time and drifts a little over the snow. Consequently, this should lead to a more or less pronounced reduction of speed. In addition, one can speculate that these oscillations could have an impact on the regulation of muscle stiffness. In each oscillation there is a phase with a high rate of force development, which could lead to a short intense stretch of the extensor muscles and, as described above, to a further stretch reflex activation [6].

In contrast to the inside leg, the extensor muscles of the outside leg are loaded predominantly eccentrically after the pole is touched.

In conclusion, one can state that the predominantly used MA of the inside and outside leg, as well as the sequential organisation of the movement, should be taken into account when training exercises are selected and when devices for the simulation of the movement of interest and for specific strength training are constructed.

Therefore in training exercises:

- the stretch-shortening cycle should last about 400 to 800ms,
- the main load should be set on the outside leg,
- the movement should involve the inside leg, however it should not be used as a swing element, but as an active support during the second phase of the turn,
- the influence of the anklejoint should be minimised and,
- the exercise should happen on a lateral slope (imitation of the edge grip).

Usually specific devices are difficult to transport. Therefore they are used primarily during the preparation period. All other training movements demanding only transportable equipment can be exercised during competition period also.

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PREDICTING SKIING PERFORMANCE IN 14–18 YEAR OLD COMPETITIVE ALPINE SKIERS

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Keywords: adolescents, anthropometry, motor performance, prediction, alpine skiing.

1 Introduction

Children and youth in a variety of sports, including alpine skiing, possess unique structural, physiological, and behavioral characteristics which contribute to successful performance. These characteristics may be similar to the profile of mature elite athletes in the same sport. However, as children grow and mature, the relative contribution of theses characteristics to high-level performance are likely to change. By studying the growth and performance profiles of young skiers, a better understanding of the substrate of successful performance can be identified. Additionally, if characteristics of successful skiing performance can be identified in children and youth, perhaps they can be used in the process of selecting young skiers for advanced training programs and perhaps elite competition.

The purpose of this study, therefore, was (1) to compare the anthropometric and motor characteristics of successful and less successful junior competitive JI and JII alpine skiers from the U.S., and (2) to predict alpine skiing performance, based on national points, from anthropometry and motor performance.

2 Review of literature

Presently available knowledge of the physical and physiological characteristics of elite alpine skiers is based largely on adult skiers [1] [2] [3], while considerably less data is available for alpine skiers≤18.0 years of age [4]. While it is not certain that there are physical differences between successful and less successful young skiers, motor-performance tests developed by Kornexl [5] and adapted by McGinnis [6] and Reid et al. [7], have been used extensively to characterize differential levels of alpine skiing. Performances in a variety of motor-performance tests specific to alpine skiing discriminated among giant-slalom performance levels of young alpine skiers [8]. However, Andersen et al. [8] did not consider the potentially confounding effect of age-associated variability in motor performance in the three different age groups which were, on average, 14.1, 15.7, and 16.4 years. Given the reliability of these sport-specific motor tests and selecting those appropriate for field testing, the vertical jump (VJ), the high box (BOX), hexagonal obstacle (HEX), the double-leg lateral vault (TLEG), and the Bass test of dynamic balance (BAL) were used for this study.

3 Methods

A sample of alpine skiers 14.0–18.9 years of age (females, n=92, 16.3± 0.8 years; males, n=94, 16.2±0.9 years) attending racing camps in Mt. Hood, Oregon, U.S., was tested in July, 1995. All skiers were volunteers and gave informed consent in accordance with the Institutional Review Board at The University of Texas at Austin.

Skiers were grouped by the age standards of the United States Skiing Association (USSA): JI skiers are 16.0–18.9 years and JII skiers are 14.0–15.9 years. Skiers were subsequently rank-ordered according to USSA national points which are calculated similarly to FIS point distributions (range 62–5 50 points).

Measurements were made according to the procedures of Lohman et al., [9] and included age; weight; stature; sitting height; sitting height/stature ratio; estimated leg length; biocromial, biocristal, biepicondylar, bicondylar breadths; arm (relaxed and flexed), calf, and estimated thigh circumferences and areas; skinfold thicknesses at the biceps, triceps, subscapular, suprailiac, supraspinale, abdominal, thigh, and medial and lateral calf sites; and five motor performance tests: VJ, BOX, HEX, TLEG, and BAL [5] [10]. Body composition was estimated from skinfolds using gender- and age-specific constants [11] and trunk/extremity ratio of subcutaneous fat distribution [12].

All measurements were made in the field at various sites adjacent to the ski hills. Testing occurred at an elevation of approximately 2100 m. Attempts were made to standardize the conditions of motor-performance testing, including surface conditions, parimeter space, and time testing occurred after training. Replicate anthropometry on 16 subjects and replicate measures of motor performance tests on 15 or 20 subjects were done. Intra-obserfer measurement variability for anthropometry was similar to the National Health Examination Survey (U.S.), and reliabilities (intraclass correlations) of motor-performance tests ranged from 0.68 to 0.93.

4 Design/Statistical Analysis

To answer question (1), successful (approximate top 15% of the point distribution) and less successful skiers for JI and JII racing categories were compared using analysis of covariance with age as the covariate. To answer question (2), independent variables best representing factors identified in gender-specific principal component analyses were used in forward stepwise multiple regression to predict national points, i.e., skiing performance. Validation of the resulting linear regression model was established using the PRESS statistic [13]. Significance levels were set at $p<0.05$ for all analyses.

5 Results

Means and standard deviations, F-ratios, and p values for variables used in the ANCOVA for female JI and JII skiers are presented in Tables 1 and 2 and for male in Tables 3 and 4.

5.1 Females

Successful JI female skiers have a larger flexed arm circumference, and smaller estimated thigh muscle circumference, estimated thigh muscle area, and medial and lateral calf skinfolds than less successful JI skiers. In contrast, successful and less successful female JI alpine skiers are similar in stature, weight, skeletal breadths and measures of subcutaneous fat. Successful and less successful skiers do not significantly differ in all measures of motor skill; however, values are consistently higher in the successful group.

Successful female JII skiers are significantly older, but are similar to less successful skiers in all body dimensions. Successful JII female skiers are better than less successful skiers on all measures of motor performance and differences in VJ, TLEG and BAL are significant.

Table 1. Analysis of covariance with age as the covariate of successful and less successful female skiers (16.0–18.9 years).

Females JI	Successful (n=8)		Less Successful (n=45)		ANCOVA		
	M	SD	M	SD	F-ratio	p	
Points	81.3	11.1	198.4	78.6	17.4	0.000	*
Age (yr)	17.5	0.8	17.3	0.8	0.2	0.690	
Weight (kg)	59.3	7.6	58.0	7.0	2.2	0.025	
Stature (cm)	165.2	9.1	164.6	6.0	0.8	0.672	
Sitting height (cm)	87.3	6.1	86.4	3.5	0.7	0.792	
SH/ST ratio (%)	52.8	2.0	52.5	1.4	1.0	0.531	
Estimated leg length (cm)	77.9	5.0	78.0	3.8	1.0	0.521	
Breadths (cm):							
Biacromial	37.5	2.0	36.8	1.7	1.1	0.431	
Bicristal	26.7	1.5	26.0	1.7	2.0	0.037	
Biepicondylar	6.2	0.2	6.2	0.3	0.9	0.602	
Bicondylar	8.4	0.5	8.6	0.5	1.1	4.168	
Estimated Muscle Areas (cm^2)							
Arm	42.1	3.8	41.3	7.0	1.1	0.377	
Calf	70.3	5.7	69.1	8.6	0.7	0.817	
Thigh	141.9	16.9	152.5	15.0	2.5	0.014	*
Skinfolds (mm):							
Sum Skinfolds (9)	107.1	20.0	105.5	28.4	0.0	0.872	
T/E ratio (mm/mm)	1.2	0.3	1.2	0.3	0.0	0.965	
Motor Tests:							
Vertical jump (cm)	43.1	6.3	36.5	3.7	0.8	0.726	
High box (jumps/90 s)	73.3	5.4	61.4	9.6	1.2	0.311	
Hexogonal (sec/3 revolutions)	15.8	0.8	17.1	1.5	1.0	0.456	
Lateral vault (sec/20 jumps)	7.5	0.3	7.7	0.3	0.7	0.810	
Balance (score out of 100)	87.3	5.1	78.8	10.6	1.0	0.488	

*Significance level set at $p < 0.05$

Table 2. Analysis of covariance with age as the covariate of successful and less succesful female skiers (14.0–15.9 years).

Females JII	Successful (n=9)		Less Successful (n=30)		ANCOVA		
	M	SD	M	SD	F-ratio	p	
Points	115.9	21.5	298.1	108.9	24.5	0.000	*
Age (yr)	15.4	0.5	14.8	0.5	9.6	0.004	*
Weight (kg)	56.0	9.3	55.0	4.5	2.2	0.488	
Stature (cm)	160.7	7.3	157.8	4.8	0.9	0.574	
Sitting height (cm)	84.9	5.9	82.5	3.2	1.2	0.341	
SH/ST ratio (%)	52.8	2.0	52.3	1.6	1.2	0.374	
Estimated leg length (cm)	75.8	3.7	85.3	3.7	0.9	0.599	
Breadths (cm):							
Biacromial	36.6	1.8	35.6	2.5	0.9	0.611	
Bicristal	25.7	2.2	26.7	4.2	0.8	0.683	
Biepicondylar	6.2	0.4	6.1	0.3	1.4	0.232	
Bicondylar	8.6	0.6	8.7	0.4	1.5	0.195	
Estimated Muscle Areas (cm^2)							
Arm	39.0	5.3	38.3	6.9	1.9	0.081	
Calf	73.5	11.5	68.5	10.6	0.8	0.648	
Thigh	158.6	11.1	144.7	15.3	0.6	0.892	
Skinfolds (mm):							
Sum Skinfolds (9)	106.4	20.1	105.4	22.2	0.0	0.901	
T/E ratio (mm/mm)	1.3	0.3	1.3	0.4	0.2	0.640	
Motor Tests:							
Vertical jump (cm)	40.6	4.8	34.3	4.5	3.9	0.006	*
High box (jumps/90 s)	63.0	6.6	56.5	11.4	3.2	0.081	
Hexogonal (sec/3 revolutions)	17.0	1.0	18.3	2.0	3.9	0.055	
Lateral vault (sec/20 jumps)	7.5	0.3	7.9	0.2	21.3	0.000	*
Balance (score out of 100)	80.0	4.6	74.3	12.2	4.7	0.036	*

*Significance level set at $p < 0.05$

5.2 Males

Successful JI male skiers have a significantly lower trunk/extremity ratio (relatively less trunk fat), less subcutaneous fat, and better BAL scores than less successful skiers. Although successful and less successful skiers do not differ significantly on other measures of motor performance, means performances are consistently better in the successful skiers.

Among male JII skiers, successful male JII skiers are older and heavier, and have larger relaxed and flexed arm circumferences and estimated arm muscle circumference. In contrast, successful JII skiers have smaller sitting heights, calf and thigh circumferences, and estimated calf muscle circumferences and areas. Successful JII skiers have consistently better scores in all motor performance tests and differences in VJ, BOX, and TLEG are significant.

Table 3. Analysis of covariance with age as the covariate of successful and less successful male skiers (16.0–18.9 years).

Males JI	Successful (n=9)		Less Successful (n=40)		ANCOVA		
	M	SD	M	SD	F-ratio	p	
Points	79.9	12.3	202.7	98.7	12.1	0.001	*
Age (yr)	17.5	0.5	17.3	0.9	0.5	0.467	
Weight (kg)	72.0	5.4	69.0	8.1	0.4	0.542	
Stature (cm)	176.0	8.4	174.7	6.8	0.7	0.405	
Sitting height (cm)	91.9	4.1	90.7	3.9	2.1	0.158	
SH/ST ratio (%)	52.2	1.3	51.9	1.3	1.1	0.301	
Estimated leg length (cm)	84.2	5.3	84.0	4.3	0.0	0.929	
Breadths (cm):							
Biacromial	41.6	1.6	40.3	1.8	1.3	0.262	
Bicristal	28.4	0.9	27.4	1.9	2.6	0.116	
Biepicondylar	7.3	0.3	7.1	0.3	0.1	0.756	
Bicondylar	9.5	0.3	9.5	0.4	2.0	0.169	
Estimated Muscle Areas (cm^2)							
Arm	60.4	6.2	55.0	8.7	0.0	0.897	
Calf	88.1	8.9	84.6	10.3	2.9	0.096	
Thigh	193.1	18.4	185.5	19.7	0.5	0.474	
Skinfolds (mm):							
Sum Skinfolds (9)	70.5	15.6	78.4	21.7	7.4	0.009	*
T/E ratio (mm/mm)	1.2	0.4	1.4	0.3	2.5	0.030	*
Motor Tests:							
Vertical jump (cm)	56.7	11.2	52.4	7.2	0.1	0.739	
High box (jumps/90 s)	84.6	13.3	74.3	10.6	0.0	0.981	
Hexogonal (sec/3 revolutions)	16.7	2.7	17.2	1.2	0.3	0.602	
Lateral vault (sec/20 jumps)	7.1	0.5	7.4	0.4	1.1	0.295	
Balance (score out of 100)	78.8	6.9	73.0	8.0	6.0	0.019	*

*Significance level set at $p < 0.05$

Table 4. Analysis of covariance with age as the covariate of successful and less successful male skiers (14.0–15.9 years).

Males JII	Successful (n=12)		Less Successful (n=33)		ANCOVA		
	M	SD	M	SD	F-ratio	p	
Points	111.2	12.0	334.9	185.6	12.3	0.001	*
Age (yr)	15.4	0.6	14.8	0.5	7.0	0.012	*
Weight (kg)	63.7	9.6	62.9	7.8	4.2	0.046	*
Stature (cm)	172.8	4.2	172.5	4.9	2.8	0.100	
Sitting height (cm)	88.8	2.1	89.4	3.8	4.3	0.044	*
SH/ST ratio (%)	51.4	1.2	51.8	1.3	1.7	0.204	
Estimated leg length (cm)	84.0	3.5	83.1	2.9	0.1	0.788	
Breadths (cm):							
Biacromial	39.1	2.1	38.4	2.3	2.1	0.160	
Bicristal	27.2	2.0	26.7	1.4	3.3	0.076	
Biepicondylar	7.2	0.3	7.0	0.4	1.0	0.325	
Bicondylar	9.5	0.4	9.6	0.4	0.0	0.987	
Estimated Muscle Areas (cm^2)							
Arm	51.6	9.1	48.3	10.1	4.0	0.052	
Calf	79.6	18.1	79.7	8.8	6.8	0.012	
Thigh	171.3	24.2	176.0	11.2	4.0	0.054	
Skinfolds (mm):							
Sum Skinfolds (9)	82.1	26.5	79.9	27.5	0.1	0.821	
T/E ratio (mm/mm)	1.3	0.4	1.3	0.3	0.0	0.981	
Motor Tests:							
Vertical jump (cm)	53.5	7.5	47.1	7.9	8.4	0.006	*
High box (jumps/90 s)	69.6	13.3	67.3	10.2	5.2	0.027	*
Hexogonal (sec/3 revolutions)	17.4	1.9	17.6	2.0	3.1	0.084	
Lateral vault (sec/20 jumps)	7.5	0.5	7.6	0.5	5.7	0.021	*
Balance (score out of 100)	76.3	5.8	74.7	7.8	0.0	0.096	

*Significance level set at $p < 0.05$

5.3 Prediction of National Points—Females

Results of the forward stepwise multiple regression of national points on anthropometry and motor-performance variables identified in a principal components analysis from all variables in female skiers, 14–18 years of age, are presented in Table 5. Forward stepwise regression of the ten independent variables results in an R=0.74. Variables that significantly predict national points are weight, VJ, and BOX:

National Points = 1139.03 - (4.20 *weight) - (8.76 *VJ) - (6.06* BOX),

with an SEE of 68.5 points. The adjusted R^2, which considers the number of predictor variables in the model, is 0.52, which indicates that 52% of the variance in national points is accounted for. The model was cross validated using the PRESS statistic and results in R^2_{press} of 0.49. Theoretically, 49% of the variance in points could be explained if this model was cross validated on an independent sample of 14–18 year old female skiers.

Subsequent regression analyses were conducted using age and anthropometry or motor-performance items in order to determine whether either could predict performance independently. The forward stepwise multiple regression using age and all anthropometric variables yields an R= 0.49 and an adjusted R^2=0.22. Biepicondylar breadth and age are the significant predictors. Forward stepwise multiple regression of points on the five motor-performance tests yields an R=0.69, and an adjusted R^2= 0.47. VJ and BOX are the significant predictors.

In summary, about one-half of the variance in national points of female alpine skiers is explained by motor-performance items rather than by anthropometry. Nevertheless, the best linear prediction model of national points in female JI and JII skiers is a combination of weight, VJ, and BOX.

Table 5. Results of forward stepwise multiple regression of national points from anthropometry and motor skill in JI and JII female skiers.

	Coefficients	Standard Coefficients	t	p
Intercept	1139.03	1139.027	7.46	0.01
Weight	-4.20	-0.23	2.25	0.04
Vertical Jump	-8.76	-0.33	2.57	0.01
High Box	-6.06	-0.48	3.67	0.01

SEE = 68.5 points

Variables NOT in Model: Stature, Estimated Arm, Calf, and Thigh Muscle Areas, Sum of Skinfolds, Lateral Vault, and Balance.

Analysis of Variance--Points versus 3 independent variables

	df	SS	MS	F	p
Regression	3	1398384.8	139838.5	6.79	<0.0001
Residual	89	1252301.5	15867.5		
Total	92	1650686.4			

significance set at $p < 0.05$

5.4 Prediction of National Points—Males

Results of the forward stepwise multiple regression of national points on anthropometry and motor-performance variables identified in a principal components analysis from all variables in males 14–18 years of age, are presented in Table 6. The R for the regression model is 0.62. After adjusting for the number of variables in the model, 36% of the variance in national points is accounted for. Variables that best predict national points in males are age, BOX, and sum of skinfolds:

National Points = 853.3 - (24.50 * age) - (3.2 * BOX) - (0.893 * sum of skinfolds),

with an SEE of 79.2 points. Validation of the regression model results in R^2_{press}=0.31. Thus, 31% of the variance in national points may be accounted for when cross validating the regression model on an independent sample of 14–18 year old male skiers.

Separate multiple regressions of national points on anthropometry or motor-performance were also done. Forward stepwise regression of points on age and all anthropometric variables yields an R=0.45, and accounts for approximately 18% of the variance in national points. The significant predictors in this model are age and estimated percentage fat. The forward stepwise regression of national points on motor-performance items yields an R=0.39, and accounts for about 13% of the variance. The only contributor to the regression equation is the BOX test.

It thus appears that the best prediction of national points in male JI and JII alpine skiers is obtained with an equation combining both anthropometry and motor-performance items. The best linear prediction model of national points in male JI and JII skiers is a combination of age, high-box test, and sum of skinfolds.

Table 6. Results of forward stepwise multiple regression of national points from anthropometry and motor skill in JI and JII male skiers.

	Coefficients	Standard Coefficients	t	p
Intercept	853.50	853.50	6.75	0.00
Weight	-24.50	-0.29	3.06	0.01
Vertical Jump	-4.20	0.32	3.30	0.01
High Box	-0.89	-0.21	2.89	0.02

SEE = 68.5 points

Variables NOT in Model: Stature, Estimated Arm and Thigh Muscle Area, Vertical Jump, Hexagonal, Lateral Jump and Balance.

Analysis of Variance--Points versus 4 independent variables

	df	SS	MS	F	p
Regression	3	1323238.6	147026.5	12.64	<0.0001
Residual	91	9777350.6	11635.1		
Total	94	11100589.2			

significance set at $p < 0.05$

6 Discussion

Obviously the best predictor of performance is actual skiing performance; however, for 7 to 8 months a year, the average alpine ski racer is off-snow. The U.S. Ski Team's Medal Test was designed to assess general fitness related to the physical demands of ski racing but not necessarily predict performance. Therefore, an objective means of predicting performance is needed. Reid et al [7], have invested a substantial amount of energy validating a test battery to categorize competitive alpine skiers for the United State Ski Team. This scale allows a coach to easily administer and compare off-snow performance to validate skiing performance. This scale is a valuable tool since it allows young skiers to judge their motor performances and muscular endurance against international, national, regional, divisional, and club skiers. However, the USST's test battery does not consider age-related variation in performance and, therefore, may give a coach or skier an erroneous profile of performance potential.

Within this reasonably homogenous and select sample, differences between successful skiers were small and it can not be stated with certainly that there are distinct morphological characteristics which distinguish one level of skiers from another. It does appear, however, that successful skiers are better in most motor-performance tests than less successful skiers.

Predicting skiing performance of young alpine skiers (14–18 years of age) based on national points can be achieved with a combination of age, anthropometry and motor-performance items better than predicting performance with either anthropometry or motor-performance items independently. The prediction equations account for 36%–52% of the variance in skiing performance, which is higher than attempts to predict swimming [14] and speed-skating [15] performance. The two motor-performance items in the regression equation for females may have accounted for the higher predictability over the male equation.

The remainder of the variance in national points not explained by the regression analyses may be related to a variety of factors. The test battery did not include any measures of skiing technique. While difficult to quantify, skiing technique and, specifically, the ability to adjust to varying terrain, snow, and speed conditions, may be highly related to success in alpine skiing.

The study did not consider the number of USSA competitions in which each skier may have participated. Alpine skiing is an expensive sport where travel and equipment costs may be prohibitive. If a potentially elite junior skier can not afford to race outside of his or her region, the national points totals will be affected. In this regard, financial considerations or socioeconomic status of the parents may exclude many potentially elite skiers from being identified with national points as the criterion.

Finally, this study did not consider any psychological factors which may be associated with alpine skiing. It was assumed that success in skiing requires a complex interaction of psychological, physiological, and physical characteristics. Indeed, elite athletes in a number of sports respond differentially to stress and arousal, and are more goal oriented, and have higher levels of self-efficacy than non-athletes [16]. Measuring the psychologial factors associated with success in alpine skiing may increas the predictability of performance.

In summary, two prediction models were generated, one for each gender, which could explain 36% and 52%, respectively, of the variance in national points. While much of the variance remains unexplained, a combination of age, anthropometry and motor performance can predict skiing performance better than each independently.

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VALIDITY OF SPORT-SPECIFIC FIELD TESTS FOR ELITE AND DEVELOPING ALPINE SKI RACERS

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1 Introduction

Assessment is an important component of any physical conditioning program. As part of the assessment process, field testing has several distinct advantages over laboratory testing, including rapid feedback and low cost [1]. However, the field testing environment presents challenges in terms of control not found in a laboratory setting. It is, therefore, very important that field tests be evaluated for reliability, objectivity, and validity prior to incorporation in an assessment battery to maximize their usefulness.

In the 1970s a battery of sport-specific field tests was developed by Kornexl to evaluate the motor skill, agility, and power of alpine ski racers [2]. Fifteen tests, including the High Box (BOX), Hexagonal Obstacle (HEX), Single Leg Lateral Vault (SLEG), and Two-Leg Latereal Vault (TLEG) tests, which demonstrated good reliability and validity were recommended for use in discriminating between skiing abilities.

In 1978, Piper, Ward, McGinnis and Milner [3] used a step-wise multiple regression to predict the on-snow performance time of 30 male subjects enrolled in a university ski class by using scores from a test battery including the BOX, HEX, and TLEG. Both performances on the HEX and TLEG were included in the multiple-regression prediction equation.

In 1980, McGinnis [4] selected ten test items from Kornexl's battery of tests and used the test-retest procedure to determine reliability and objectivity simultaneously. He concluded that the HEX, BOX, and TLEG tests were both reliable and objective, based on a correlation of.70 or greater between scores of the same subject group, measured by two different examiners at two different testing periods. The SLEG test was not evaluated for reliability or objectivity by McGinnis.

Subsequently, McGinnis [4] divided subjects into the following three groups: 1) exceptionally skilled skiers, 2) highly skilled skiers, and 3) recreational skiers of average skiing ability to evaluate the validity of the selected tests. Kruskal-Wallis One-way ANOVA indicated statistically significant differences ($p<.001$) in performance between the three groups for both males and females on the BOX, HEX, SLEG, and TLEG. It was recommended that these four tests be included in a test battery to discriminate skiing levels.

In 1981, Shea [5] tested skiers using a test battery that included the BOX, HEX, SLEG, and TLEG tests. Results from the tests were compared to ski racing performance time to establish criterion-related validity. Multiple-regression analysis revealed that inclusion of jump and reach, BOX, Berg und Tal, and HEX test scores can account for 93% of the variance in ski-racing performance.

Brown and Wilkinson [6] compared the performances of National, Divisional, and Club ski racers on the BOX test in 1983. It was found that Club skiers scored significantly ($p<.01$) lower than National and Divisional racers.

In 1989, Jasmin, Montgomery, andHoshizaki [7] examined the specificity of the HEX test to measure the anaerobic endurance of alpine skiers. Subjects were categorized into three groups: 1) varsity alpine skiers, 2) varsity athletes, and 3) physical education students. Subjects completed six trials of the HEX over two days of testing (three trials per day). Times for each trial were used to determine test-retest reliability. The resulting intraclass-correlation coefficient was.96, indicating high reliability. The HEX test did not discriminate alpine skiers from the two groups of non-skiers. As a result, the authors suggested that the HEX test primarily measured agility rather than skiing ability. If this is true, then the lack of significant differences in HEX test results between skiers and non-skiers would be expected, because both subject groups came from populations known to have good agility.

In 1990, Andersen, Montgomery, and Turcotte [8] evaluated criterion-related validity for a test battery that included the BOX and HEX tests, by correlating the results of the test battery with performance in a giant slalom time trial. The correlation coefficients for the HEX ($r=.82$) and the BOX ($r=-.80$) tests indicated good criterion-related validity. Construct validity was examined by comparing the test scores of three levels of alpine skiers. ANOVA revealed significant differences ($p<.05$) among Provincial, Divisional, and Club skiers on both the BOX and HEX tests, suggesting that these tests can discriminate between skiers of varying ability.

As changes are made in ski equipment and technique, the physical demands of the sport will also change, necessitating re-evaluation of the validity of field tests, and modification of test standards. Over the past decade, alpine ski racing on the World Cup circuit has evolved [9] significantly. Athletes are skiing smaller radii turns and more "arc to arc". They are skiing more aggressively yet more smoothly, with more lateral movement and relatively little up-and-down movement. The observed changes in technique are also associated with equipment changes [9]. Skis are wider in the tails and tips and thinner in the middle, i.e., they demonstrate more sidecut. Devices are placed between the binding and the ski which allow the skier to develop a greater edge angle between the ski and snow, allow for a more gradual development of pressure during the turn, dampen vibrations, and optimize the bending in the ski. Additionally, different constructions and materials are being used for boots that are typically higher and stiffer than boots of a decade ago. These changes have put a heavy demand upon the absolute strength of alpine athletes [9]. Heavier-set skiers with higher absolute strength, i.e., skiers who can take a more direct line down the hill by actually skiing through the gates, would seem to be favored over smaller skiers, due to these advances.

In light of the evolution in ski racing technique and equipment, as well as different physical abilities, the purpose of the present study was to re-evaluate the construct validity of the BOX, HEX, SLEG, and TLEG tests using a large subject pool. A secondary purpose was to determine how fine the discriminating abilities of these tests were in relation to competitive levels and to establish normative data by competitive level for coaches and athletes to use in evaluating test results.

2 Methods

2.1 Subjects

Four hundred and twenty subjects (249 males and 171 females) participated in this study, during one of two testing periods. During the first testing period in the Fall of 1991, the United States National A and B Ski Teams (USST) were tested in a laboratory setting. The second period of testing occurred during the summer of 1992, when skiers attending summer-racing camps were tested in Government Camp, Oregon. All subjects gave informed consent and were told of the nature and risks associated with the experimental protocol.

Subjects were categorized into six competitive groups based on previous race experience. The six groups represented International (INT), National (NAT), Regional (REG), Divisional (DIV), and Club (CLUB) racers, and Recreational skiers (REC). Classifications were based on the highest level competitive experience during the season preceding the test period.

Table 1. Group descriptives in means and (standard error of the mean).

Group	n	Age (yrs)	Height(cm)	Mass (kg)
INT				
Male	17	22.7 (0.59)	179 (1.29)	80 (1.56)
Female	23	21.4 (0.53)	167 (1.12)	65 (1.23)
NAT				
Male	38	18.4 (0.50)	176 (1.09)	74 (1.84)
Female	23	17.0 (0.24)	169 (1.22)	62 (1.39)
REG				
Male	37	17.5 (0.35)	176 (0.99)	72 (1.34)
Female	25	16.4 (0.17)	165 (1.42)	60 (1.43)
DIV				
Male	46	15.3 (0.17)	170 (1.35)	61 (1.32)
Female	32	15.0 (0.19)	164 (1.02)	57 (0.89)
CLUB				
Male	112	15.3 (0.14)	170 (1.02)	62 (1.17)
Female	66	14.6 (0.16)	160 (0.84)	54 (0.99)
REC				
Male	4	14.8 (0.74)	164 (4.34)	58 (5.71)
Female	2	15.0 (0.00)	161 (6.50)	56 (1.92)

2.2 Testing Procedures

During the first testing period, male and female USST members completed all four tests as part of a battery given to the USST each Fall. During the second testing period, skiers typically completed the testing as part of afternoon training activities, after skiing in the morning. The test procedures were explained and demonstrated, and subjects were allowed to practice before each test was administered. Subjects completed the tests in random order, except that all subjects completed the BOX last.

2.3 Test Designs

2.3.1 Hexagonal Obstacle (HEX)

The HEX test apparatus consisted of a hexagonal shaped base and six sides with hurdles of varying height (three 20 cm hurdles and one each of 25 cm, 32 cm, and 35 cm hurdles). The hurdles were not attached to the base in any way, so that a hurdle that was touched or hit would fall and thus invalidate that test trial. The subject began the test in the center of the HEX apparatus and after the commands, “Ready, set, GO!”, began jumping back and forth over each hurdle as fast as possible, using two-footed jumps, and facing the direction of travel. Each subject performed at least two trials in each of the clockwise and counterclockwise directions. One trial consisted of three laps around the HEX. If an obstacle was knocked over during a trial, the trial was repeated. Each subject was given up to three attempts, with a two to three minute rest between trials, to achieve their fastest time in each direction. The sum of the fastest clockwise and counterclockwise times was recorded as the score.

2.3.2 Single-Leg Lateral Vault (SLEG)

The test apparatus for the SLEG consisted of two mounted plywood platforms, inclined towards each other at 27 degrees. A horizontal line was drawn across each platform 20 cm above its lower edge. The area below this was red to indicate the error zone. The horizontal distance between the top of the two error zones was adjustable. Leg length (LL), defined as the vertical distance from the center of the greater trochanter of the femur to the sole of the foot when standing, was measured before the test. The apparatus was then adjusted so that the distance between the top of the error zones was equal to LL multiplied by the constants 1.67 and 1.50, for males and females, respectively. Each subject began the test standing on the platform above the red error zone. At the commands, “Ready, set, GO!”, the athlete began jumping back and forth, laterally from platform to platform, landing on the outside foot only, above the red error zone. The inside leg was brought over to touch the outside leg on each jump, but the foot of the inside leg was not allowed to touch the platform. The subject continued to jump in such a manner for 60 seconds, with the goal of attaining as many correct jumps as possible in that time. The subjects were informed when 30, 20, and 10 seconds were remaining in the test. Incorrect jumps were not counted, and were defined as touching either foot in the red error zone, or not touching the inside leg to the outside leg during a jump. The total number of correct jumps in one trial was recorded as the score.

2.3.3 Lateral Vault (TLEG)

The test apparatus for the TLEG consisted of two plywood platforms, 75 cm square, mounted on a base, inclined towards each other at 8 degrees, and separated by a 60-cm, red error-zone. A subject began the test standing on either platform, and at the commands, “Ready, set, GO!”, began jumping laterally from platform to platform using two-footed jumps, and avoiding the red center. The tester timed the subject until 20 correct jumps were completed. An incorrect jump consisted of the subject touching the red center of the apparatus with either foot, or single-footed jumping. The score recorded was the subject’s fastest time.

2.3.4 The High Box (BOX)

The BOX test apparatus was constructed of plywood, 40-cm high, 60-cm long, and 51-cm wide. Each subject began the test standing on top of the BOX. At the commands, “Ready, set, GO!”, the subject jumped off of the BOX to one side, back up onto the top, and then off the other side, using both feet. The subject jumped back and forth in this manner trying to achieve as many jumps as possible in 90 seconds. Each time the subject jumped to the top of the BOX with both feet, a jump was counted. Subjects were informed when 30, 20, and 10 seconds remained in the test. The total number of jumps counted was recorded as the subject’s score. One trial was administered to each subject.

2.4 Data Analysis

Descriptive statistics, including the mean, 25th percentile, 75th percentile, minimum and maximum, were calculated for each competitive group’s results on the tests. Separate One-way analysis of variance (ANOVA) was run to determine if group differences existed for each test for both females and males. Post-hoc Tukey HSD tests were used to determine which groups were responsible for the group effects revealed by the ANOVA.

3 Results

Due to the small number of members in the REC group, this data was not included in the analysis. For the same reason, the INT group was not used in the evaluations of the TLEG test. Means and standard errors of the mean (SEM), for age, height, and mass, for each of the groups by gender, are presented in Table 1. Normative data for group performance on each of the tests are presented in Tables 2–5.

Table 2. Group results in number of jumps on the High Box.

Group	Maximum	75%-ile	Median	25%-ile	Minimum
INT					
Male	115	101	96	92	89
Female	92	85	78	75	63
NAT					
Male	108	96	89	83	76
Female	87	79	70	55	50
REG					
Male	102	92	82	76	53
Female	76	64	58	50	41
DIV					
Male	95	76	72	63	36
Female	70	61	53	48	36
CLUB					
Male	100	70	61	52	30
Female	68	56	49	38	25

Table 3. Group Results in seconds on the Hexagonal Obstacle.

Group	Minimum	75%-ile	Median	25%-ile	Maximum
INT					
Male	26.89	27.59	29.02	30.32	33.23
Female	27.41	28.56	29.70	30.45	33.46
NAT					
Male	27.80	29.32	30.93	32.92	35.11
Female	29.64	30.82	32.53	33.50	35.73
REG					
Male	28.38	30.46	31.13	32.48	41.83
Female	30.82	32.08	32.95	34.90	40.73
DIV					
Male	29.46	32.09	34.11	35.69	44.54
Female	31.04	32.73	33.92	36.41	40.07
CLUB					
Male	30.71	34.32	37.04	39.31	58.31
Female	32.83	34.71	36.26	38.61	54.02

Table 4. Group Results in number of jumps on the Single-Leg Lateral Vault.

Group	Maximum	75%-ile	Median	25%-ile	Minimum
INT					
Male	106	103	100	90	78
Female	114	108	105	98	90
NAT					
Male	123	100	88	69	31
Female	114	96	85	76	60
REG					
Male	112	93	82	71	40
Female	101	89	81	69	51
DIV					
Male	95	78	67	52	20
Female	88	80	77	67	52
CLUB					
Male	96	69	59	46	19
Female	96	80	72	56	23

Table 5. Group Results in seconds on the Lateral Vault (TLEG).

Group	Minimum	75%-ile	Median	25%-ile	Maximum
NAT					
Male	5.64	6.37	6.88	7.37	8.21
Female	6.02	6.90	7.37	7.78	8.51
REG					
Male	6.38	6.67	6.99	7.54	8.38
Female	7.15	7.34	7.69	7.98	8.61
DIV					
Male	6.64	7.12	7.53	7.93	9.57
Female	7.02	7.59	7.87	8.07	8.74
CLUB					
Male	6.38	7.51	7.95	8.38	9.55
Female	7.00	7.73	8.08	8.63	10.35

Results of the one-way ANOVA indicated significant differences ($p<.001$) between male groups on all tests. Similarly, significant differences ($p<.001$) between groups on all four tests were revealed for females. Results of the post-hoc Tukey HSD tests are summarized in Table 6.

For males, the SLEG, HEX, and BOX tests discriminated between the elite groups (ie., the INT and NAT groups) and the developing groups. Both the BOX and the HEX discriminated among the developing groups but the SLEG did not. None of the tests were able to discriminate between the INT and NAT male groups.

For females, the SLEG, HEX, and BOX tests all showed significant differences between the INT group and all of the other groups. The SLEG and BOX tests showed significant differences between the elite and developing groups but not among the developing groups. In addition to showing significant differences between INT racers and all of the other groups, the HEX test showed significant differences between CLUB racers and all of the other groups.

Table 6. Result of the post-hoc TUKEY HSD Analysis

Test	INT	NAT	REG	DIV	CLUB
BOX					
Male	97.82	89.37	82.85[1]	70.43[1,2,3]	61.38[1,2,3,4]
	(1.78)	(1.48)	(1.81)	(1.75)	(1.33)
Female	79.44	68.17[1]	57.83[1,2]	53.08[1,2]	47.35[1,2,3]
	(1.54)	(2.99)	(2.44)	(1.65)	(1.50)
HEX					
Male	29.05	31.12	31.82[1]	34.35[1,2,3]	37.03[1,2,3,4]
	(0.40)	(0.36)	(0.44)	(0.46)	(0.42)
Female	29.68	32.53[1]	33.66[1]	34.72[1]	37.29[1,2,3,4]
	(0.30)	(0.42)	(0.53)	(0.47)	(0.56)
SLEG					
Male	96.75	82.93	80.65[1]	64.60[1,2,3]	57.93[1,2,3]
	(2.02)	(4.18)	(2.72)	(2.61)	(1.61)
Female	103.86	85.29[1]	79.13[1]	73.17[1,2]	67.65[1,2,3]
	(1.25)	(3.30)	(2.70)	(1.96)	(2.06)
TLEG					
Male		6.83	7.12	7.67[2,3]	7.96[2,3]
		(0.13)	(0.09)	(0.11)	(0.06)
Female		7.35	7.70	7.86[2]	8.25[2,3,4]
		(0.15)	(0.08)	(0.07)	(0.09)

Values are means (SEM). BOX and SLEG scores are number of jumps. HEX and TLEG scores are elapsed time in seconds.

1. Significantly different from INT, $p < .05$;
2. Significantly different from NAT, $p < .05$;
3. Significantly different from REG, $p < .05$;
4. Significantly different from DIV, $p < .05$;

When an ANCOVA was used with the athlete's age category (2 year intervals, and greater than 18 years old) as a covariate, the significance on all ability levels for the four tests generally rose from.05 to.01, or nonsignificant to the.05 level. The authors felt the use of an ANCOVA did not contribute to the implications that the previous significance level had revealed.

4 Discussion

Athlete testing is an essential component of the annual training plan. Field tests are useful to many development level and regional programs, because of their ease in administration, convenience, and relatively low cost. Field tests may be the only available assessment meth od for many programs.

Despite the technical changes in alpine skiing over the years, this research demonstrated that the battery of tests, consisting of the BOX, HEX, SLEG, and TLEG, was useful in delineating skiing performance based on levels of racing experience. However, there were notable differences in how well the tests discriminated between ability groups for males and females.

For males, the BOX, HEX, and SLEG tests were valid in discriminating between elite level racers (i.e., the INT and NAT groups) and developing racers (i.e., the REG, DIV, and CLUB groups). The BOX and HEX tests were also valid in discriminating between levels of the developing groups. Thus, the BOX and HEX were most predictive of group membership for males. The TLEG was valid only in coarse discriminations of skiing ability.

The results of the present study do not indicate that any of the four tests are valid in discriminating between INT and NAT level male racers, which is consistent with past studies [2, 4, 6, 8, 10]. In technique-dependent sports such as alpine ski racing, it is difficult to develop a test battery that can distinguish between athletes in the most elite categories [11]. For these athletes, perhaps the greatest use for these tests is to monitor the effects of training.

For females, the results indicated that the SLEG test differentiated between the elite and developing groups. The HEX test was valid for identifying INT level female racers and CLUB racers from the other three groups. The BOX, HEX, and SLEG tests discriminated between INT and NAT level female racers. As is the case for males, the TLEG test provides only coarse discriminations between levels of skiing ability for females.

Once quality normative data have been gathered, the four tests used in this study can serve a variety of purposes. However, it should be noted that in order to establish useful normative data, there must be consistency in the classification of ability groups among the researchers. In this study, a system of classifying skiers into competitive groups based on race experience was established. The normative data generated for each competitive group may be helpful for the coach and athlete in identifying the level of ski racing at which the athlete is currently physically prepared to perform.

One potential use of these assessments is for talent identification in developing athletes [5]. A battery of tests that can predict potential for success in alpine ski racing may be useful in selecting athletes for development camps, racing quotas, and special teams. Care must be taken, however, as many factors other than physiological variables influence ski-racing success. A test battery such as the one used in the current study only accounts for a small portion of the variability in skiing performance. Therefore, interpretation of the test results should be done with caution.

This battery of tests can also be used to assess the effectiveness of rehabilitation following injury. Because injuries are a frequent misfortune in ski racing, many athletes are in various stages of recovery. This raises the question of whether traditional methods of rehabilitation adequately prepare the athlete for the demands of alpine skiing and related training.

These tests are sport-specific in terms of intensity and movement pattern, and may be used to assess an athlete's readiness to return to on-snow training and competition.

Perhaps the greatest use for these tests is in monitoring compliance and progress in a physical-conditioning program. Although the only true tests of performance in ski racing are the actual races, tracking physical progress using these assessments may help to identify strengths and weaknesses. This knowledge can then be used to make appropriate adjustments in training-program emphasis, before the competitive season begins, to allow time to correct deficiencies.

More research is needed to demonstrate relationships between training methods and the development of skills measured by these tests. A detailed tracking program of training, in addition to systematic assessment at critical phases in the training process, could result in visible trends regarding effective training methods.

Finally, research should be done to determine if these tests can discriminate between specialists in the four events of alpine ski racing. If the skiing events are different in their physiological demands, then the specificity of training should reflect this, and preparation could be monitored by use of the appropriate test(s).

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RELATIONSHIP OF ANAEROBIC PERFORMANCE TESTS TO COMPETITIVE ALPINE SKIING EVENTS

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Keywords: wingate tests, anaerobic performance, USSA points, alpine skiing.

1 Introduction

The purpose of this study, therefore, was to measure and evaluate the relationship of short-term (30 s & 60 s) and long-term (90 s & 120 s) anaerobic performance of different intensity, corresponding lactate values, USSA competition points, and the relationship of various physiological variables to skiing performance in young elite male and female Alpine ski competitors. In the laboratory environment, physiological measurements of elite Alpine skiers are difficult to assess and are frequently unreliable [1]. However, anaerobic power tests appear to be better predictors of Alpine-skiing ability compared to aerobic power tests [2]. Elite competitive Alpine skiers exhibit a high level of muscle strength characterized by high aerobic and anaerobic power and anaerobic capacity [3] [5] [6] [7] [8] [9] high endurance and above-average leg power [10]. Tests to measure muscle strength and local endurance have been developed over the past years to elicit qualitative (fatigue) and quantitative (exercise performance) properties [10]. Katch et al.[12] have suggested that long-duration all-out tests may not be necessary since a high correlation exists between 40-s and 2-min tests. Van Dewalle et al. [1] reported that a 30-s Wingate test may be too short to exhaust anaerobic energy stores even though a significant drop in power occurs within 30 s. Other research [13] [14] has suggested a 90-s Wingate test for Alpine skiers due to the nature of skiing events. Stark et al. [15] used a 90-s Wingate protocol comparing elite slalom (SL) and downhill (DH) skiers and found a crossover effect. Bacharach and von Duvillard [15] conducted 30-s and 90-s Wingate tests and reported improved mean power measures for all male competitors and improvement for females in all but absolute and relative minimum power output over a period of one year. Hill and Smith [7] suggested that higher power-output values can be achieved with greater resistance setting, and reported that total work during a 30-s Wingate test underestimates gender differences in anaerobic capacity. When correlating the USSA-SL and GS points for 30-s and 90-s Wingate performance for females, minimum power and fatigue index were associated with success for both events. For males, no significant correlations were found for the 30-s test; however, a significant relationship appeared between the SL and GS points for the 90-s Wingate test [15].

2 Methods

Twenty-six nationally ranked male (N=12) and female (N=14) Alpine ski racers, who were members of a ski-racing academy in the eastern United States, served as volunteers in this study. Subjects were informed of all testing procedures and provided written, informed consent. Written, parental permission was obtained for subjects under 19 years of age. The experimental protocol was approved by the Human Subjects Committee at William Paterson College of New Jersey. Fourteen of the subjects (4 females and 10 males) had USSA points considered to be competitive at the National Team level with all other subjects being young, elite-level Alpine ski competitors. Physical characteristics of the subjects are shown in Table 1; the United States Ski Association (USSA) point list for the subjects is in Table 2.

Table 1. Physical characteristics of the subjects (N=26, females=14, males=12).

Variable	**Mean (combined)**	**±**	**SD**	**Mean (males)**	**±**	**SD**	**Mean (females)**	**±**	**SD**
Age (yrs)	17.1	±	0.9	17.6	±	0.9	16.6	±	0.6
Weight (kg)	68.3	±	10.2	76.9	±	7.9	60.9	±	4.3
Height (cm)	171.2	±	8.9	178.1	±	7.8	165.3	±	4.7
% body fat	13.1	±	6.1	7	±	1.6	18.2	±	2.7
Lean body mass	59.8	±	12.1	71.4	±	6.5	49.8	±	3.6

Table 2. Subjects USSA point list for all Alpine competition events (May 1995).

Variable	SL Mean	±	SD	GS GS	±	SD	SGS Mean	±	SD	DH Mean	±	SD
Males	71.7	±	14.7	56.5	±	11.7	77.1	±	18.1	120.5	±	45.9
Females	98.0	±	42.9	78.7	±	19.8	87.7	±	27.6	198.9	±	78.5
Combined	85.9	±	35.2	68.4	±	19.9	82.4	±	23.5	157.4	±	73.3

3 Instrumentation

A computerized Wingate system (SMI, Inc., St. Cloud, MN) was utilized to accurately quantify power output generated from all Wingate and modified Wingate tests, performed on a mechanically braked cycle ergometer (Monark 814E, Stockholm, Sweden). An infrared photoelectric cell, sensitive to reflective markers placed on the ergometer flywheel, was used to monitor and record flywheel rpm with approximately a 0.01% error. The sensor was interfaced to the serial port of an IBM compatible computer. A second-by-second power output was displayed throughout each test and then recorded. Blood-lactate analysis was conducted via finger stick utilizing lactate analyzer (YSI 1500, Yellow Springs, OH). Heart rate was monitored and recorded throughout all testing by means of Polar heart-rate monitor (Polar Electro Oy, Finland). All vertical jumps were measured using Fastex equipment (Cybex, Ronkonkama, NY). Each subject completed two 30-s Wingate tests and three modified Wingate tests of 60-, 90-, and 120-s duration. In the first 30 seconds, intermediate anaerobic performance Wingate test resistance was set at 0.090 $kg.kg^{-1}$ of individual body weight (BW). The second 30-s Wingate test was conducted at a resistance of 0.075 $kg.kg^{-1}$. BW. The 60-s Wingate test was conducted with resistance of .075 $kg.kg^{-1}$. BW. The long-term anaerobic power tests of 90- and 120-s were conducted with resistance of 0.050 $kg.kg^{-1}$. BW. During all Wingate testing the computer monitored and recorded the following performance indicators: peak power output (PPO), defined as the highest power output in a 5-s period; mean power output (MPO), defined as the average work output over the duration of the individual test; minimum power output (MinPO), defined as the lowest power output during **any** given test; and fatigue index, defined as the difference between the PPO and MinPO, divided by PPO and expressed as percent. The 30-s and 60-s tests were all-out supramaximal tests. In the 90- and 120-s tests, subjects were asked to pedal as fast as possible for the first 20 seconds to determine maximal effort, and asked to maintain the highest possible effort for the remaining time of each test. All power measures were expressed in Watts as either absolute values (W) or calculated relative to body weight (BW) and reported as $W.kg^{-1}$. Blood samples from finger stick (25μ) were collected at rest, immediately after peak exercise and after 3, 6, and 9 minutes during all Wingate and box-jump tests, and analyzed for lactic acid. All subjects completed a high box jump consisting of a 40 cm high, 60 cm long and 50 cm wide box. Successful jumps were those where the subject touched the top of the box with both feet simultaneously. The number of successful jumps made within 90 seconds determined the score. Vertical jumps were conducted on Fastex equipment (Cybex, Ronkonkama, NY); **the** height of the jump was calculated based on the "airtime". Five maximal vertical jumps, single-best jump and an average of the five jumps were measured and recorded for each subject.

4 Statistical analysis

Pearson product-moment correlation coefficients were calculated to determine the relationship between USSA national SL, GS, SGS and DH points, absolute and relative power measures from the two 30-s, 60-s, 90-s and 120-s Wingate power tests. In addition, we calculated correlation coefficients for BW, %BF, LBM, BJ, SBJ, and AJ in relation to USSA national points and power measures obtained from Wingate tests. Analysis of variance (ANOVA) was used to determine statistically significant differences for all performance measures between the combined and gender groups. Alpha of $p \leq 0.05$ was accepted as significant. Wingate test variables of interest included PPO, MPO, MinPO, FI expressed in absolute (W) and in relative terms $W.kg^{-1}.BW$.

5 Results

Pearson product-moment correlation coefficients *(r)* were calculated to determine the relationship between the USSA national points for slalom (SL), giant slalom (GS), super-giant slalom (SGS) down-hill (DH), BW, %BF, LBM, and any of the absolute and relative muscle power measures resulting from the Wingate tests for the combined group (N=26) are presented in Table 3. The correlation coefficients depicting the relationship between the 90-s 40-cm BJ, SBJ, AJ, USSA national points for all competitive Alpine skiing events and BW, %BF, LBM for combined group (N=26) are presented in Table 4. Analysis of variance (ANOVA) was conducted to determine significant differences between the performance variables for combined and gender group. Table 5 depicts combined and gender specific performance data generated for all Wingate tests, 90-s 40-cm BJ, SBJ and AJ. Wingate test data is expressed in absolute (W) and relative measures ($W.kg^{-1}$. BW).

Table 3. Correlation coefficients for all Wingate test power scores for combined group (N=26). Values are mean ±SD,* significant at p=0.05.

Variable	SL	GS	SGS	DH	BW	%BF	LBM
30-s Wingate Test at 0.090 kg. kg^{-1} . BW							
PPO (W)	-0.44*	0.70*	-0.35	-0.18	0.64*	-0.68*	0.70*
MPO (W)	-0.51*	-0.66*	-0.18	-0.26	0.54*	-0.63*	0.62*
MinPO (W)	-0.57*	-0.70*	-0.32	-0.31	0.51*	-0.07*	0.62*
FI (%)	-0.17	-0.48*	-0.31	0.00	0.53*	-0.44*	0.54*
PPO. kg^{-1} (W)	-0.37	-0.65*	-0.31	-0.05	0.13	-0.40	0.23
MPO. kg^{-1} (W)	-0.31	-0.39	0.01	-0.04	-0.35	-0.05	-0.24
MinPO. kg^{-1} (W)	0.05	-0.20	-0.07	0.08	-0.52	0.03	-0.40
30-s Wingate Test at 0.075 kg. kg^{-1} . BW							
PPO (W)	-0.41*	-0.59*	-0.27	0.09	0.39	-0.49*	0.46*
MPO (W)	-0.41*	-0.58*	-0.29	0.16	0.34	-0.46*	0.41*
MinPO (W)	-0.37	-0.53*	-0.31	0.24	0.29	-0.42*	0.35
FI (%)	-0.07	-0.12	0.09	-0.29	0.27	-0.20	0.27
PPO. kg^{-1} (W)	-0.3	-0.32	-0.23	-0.69*	0.50*	-0.70*	0.60*
MPO. kg^{-1} (W)	-0.14	-0.48*	-0.21	-0.69*	0.48*	-0.78*	0.61*
MinPO. kg^{-1} (W)	-0.22	-0.50*	-0.18	-0.57*	0.25	-0.67*	0.40*

Variable	SL	GS	SGS	DH	BW	%BF	LBM
60-s Wingate Test at 0.075 kg. kg^{-1} . BW							
PPO (W)	-0.27	-0.43*	-0.31	-0.52*	0.88*	-0.78*	0.93*
MPO (W)	-0.39	-0.53*	-0.30	-0.43	0.92*	-0.81*	0.97*
MinPO (W)	-0.37	-0.52*	-0.28	-0.27	0.90*	-0.76*	0.94*
FI (%)	0.35	0.40	0.14	-0.24	-0.44*	0.36	-0.45*
PPO. kg^{-1} (W)	-0.8	-0.33	-0.33	-0.63*	0.37	-0.68*	0.51*
MPO. kg^{-1} (W)	-0.39	-0.59*	-0.39	-0.56*	0.63*	-0.89*	0.78*
MinPO. kg^{-1} (W)	-0.35	-0.57*	-0.36	-0.21	0.63	-0.80*	0.75*
90-s Wingate Test at 0.050 kg. kg^{-1} . BW							
PPO (W)	-0.31	-0.44*	-0.18	-0.49*	0.95*	-0.81*	0.98*
MPO (W)	-0.34	-0.47*	-0.21	-0.48*	0.95*	-0.82*	0.98*
MinPO (W)	-0.41*	-0.53*	-0.30	-0.45	0.93*	-0.83*	0.96*
FI (%)	0.42*	0.41*	0.40*	0.00	-0.21	0.32	-0.26
PPO. kg^{-1} (W)	-0.30	-0.53*	-0.27	-0.67*	0.74*	-0.91*	0.85*
MPO. kg^{-1} (W)	-0.35	-0.55*	-0.31	-0.60*	0.71*	-0.89*	0.83*
MinPO. kg^{-1} (W)	-0.45*	-0.61	-0.44*	-0.47	0.61*	-0.81*	0.73*
120-s Wingate Test at 0.050 kg. kg^{-1} . BW							
PPO (W)	-0.13	-0.34	-0.25	-0.55*	0.92*	-0.86*	0.96*
MPO (W)	-0.18	-0.35	-0.29	-0.51	0.94*	-0.85*	0.97*
MinPO (W)	-0.27	-0.39	-0.30	-0.47	0.86*	-0.85*	0.91*
FI (%)	0.33	0.12	0.24	0.04	-0.40	0.20	-0.35
PPO. kg^{-1} (W)	-0.23	-0.52*	-0.32	-0.68*	0.69*	-0.92*	0.82*
MPO. kg^{-1} (W)	-0.27	-0.44	-0.36	-0.52	0.73*	-0.84	0.82*
MinPO. kg^{-1} (W)	-0.35	-0.43	-0.42	-0.39	0.63*	-0.75	0.71*

Table 4. The correlation coefficients between all jumps, and selected physiological characteristics in relationship to USSA national points for combined group (N=26). Significant correlations are indicated as * ($p<0.05$).

Variable	SL	GS	SGS	DH	BW	%BF	LBM
BJ	-0.38	-0.67*	-0.34	-0.60*	0.55*	-0.86*	0.71*
SBJ	-0.46*	-0.60*	-0.43*	-0.53*	0.62*	-0.86*	0.74*
AJ	-0.44*	-0.63*	-0.39	-0.58*	0.61*	-0.92*	0.76*
BW	-0.29	-0.35	-0.15	-0.30			
%BF	0.39*	0.68*	0.31	0.58*			
LBM	-0.34	-0.49*	-0.21	-0.42			

Table 5. Performance data for Wingate tests, and all jumps for combined (N=26) and gender-based groups (male N=12; female N=14). Values are mean±SD. Statistically significant scores are denoted as * $p\leq0.05$.

Variable	Combined	±	SD	Males (N=12)	±	SD	Females (N=14)	±	SD
30-s Wingate test at 0.090 kg . kg^{-1} . BW.									
PPO (W)	1022.6*	±	270.3	1215.6*	±	269.2	844.5*	±	90.0
MPO (W)	600.2	±	106.3	667.1*	±	102.1	538.4*	±	66.6
MinPO (W)	441.6*	±	67.1	487.7*	±	65.9	399.0*	±	30.7
FI (%)	55.6	±	6.6	59.0*	±	5.7	52.4*	±	4.6
PPO. kg^{-1} (W)	14.9	±	3.0	16.0	±	3.6	14.0	±	2.0
MPO . kg^{-1} (W)	8.8	±	1.4	8.7	±	1.3	8.9	±	1.6
MinPO . kg^{-1} (W)	6.6	±	0.9	6.4	±	1.1	6.8	±	0.9

Variable	Combined	±	SD	Males (N=12)	±	SD	Females (N=14)	±	SD
30-s Wingate test at 0.075 kg . kg^{-1} . BW.									
PPO (W)	694.5*	±	152.2	761.5*	±	168.7	632.7*	±	107.7
MPO (W)	573.7*	±	131.0	627.5*	±	150.7	524.0*	±	89.1
MinPO (W)	458.4	±	101.7	496.1*	±	120.0	423.7*	±	30.7
FI (%)	33.7	±	5.7	34.9	±	5.7	32.7	±	5.6
PPO. kg^{-1} (W)	10.1	±	0.9	10.7	±	0.7	9.5	±	0.8
MPO . kg^{-1} (W)	8.3	±	0.9	8.9	±	0.5	7.7	±	0.6
MinPO . kg^{-1} (W)	6.7	±	0.7	7.1	±	0.6	6.3	±	0.6
60-s Wingate test at 0.075 kg . kg^{-1} . BW.									
PPO (W)	721.8*	±	140.6	831.7*	±	64.1	587.4*	±	69.9
MPO (W)	488.6*	±	109.1	576.5*	±	50.8	381.1*	±	38.1
MinPO (W)	346.7*	±	90.8	415.1*	±	59.7	263.1*	±	28.8
FI (%)	52.2	±	6.5	50.0	±	6.2	54.8	±	6.0
PPO. kg^{-1} (W)	10.2*	±	0.9	10.8*	±	0.6	9.5	±	0.8
MPO . kg^{-1} (W)	6.9*	±	0.8	7.5*	±	0.3	6.2*	±	0.3
MinPO . kg^{-1} (W)	4.9*	±	0.7	5.4*	±	0.5	4.3*	±	0.3
90-s Wingate test at 0.050 kg . kg^{-1} . BW.									
PPO (W)	538.1*	±	122.8	654.4*	±	70.2	438.4*	±	40.4
MPO (W)	336.5*	±	79.4	413.7*	±	39.3	270.4*	±	24.4
MinPO (W)	262.8*	±	66.4	327.1*	±	32.2	207.6*	±	22.4
FI (%)	51.3	±	4.1	49.8	±	4.3	52.6	±	3.7
PPO. kg^{-1} (W)	7.8*	±	0.7	8.5*	±	0.2	7.2*	±	0.4
MPO . kg^{-1} (W)	4.9*	±	0.5	5.4*	±	0.2	4.4*	±	0.2
MinPO . kg^{-1} (W)	3.8*	±	0.5	4.2*	±	0.4	3.4*	±	0.3

Variable	Combined	±	SD	Males (N=12)	±	SD	Females (N=14)	±	SD
120-s Wingate test at 0.075 kg . kg^{-1} . BW.									
PPO (W)	556.3*	±	115.7	643.5*	±	51.3	436.5*	±	48.5
MPO (W)	328.8*	±	71.1	383.5*	±	25.8	253.8*	±	30.1
MinPO (W)	270.5*	±	68.7	321.1*	±	35.6	200.9*	±	27.7
FI (%)	51.9	±	5.6	50.5	±	6.2	54.0	±	4.2
PPO. kg^{-1} (W)	7.9*	±	0.8	8.5*	±	3	7.1*	±	0.5
MPO . kg^{-1} (W)	4.7*	±	0.5	5.1*	±	0.3	4.1*	±	0.3
MinPO . kg^{-1} (W)	3.8*	±	0.6	4.1*	±	0.4	3.3	±	0.3
Box jump (BJ), single-best jump (SBJ) and average of five vertical jumps (AJ).									
BJ (90-s)	89.0*	±	14.7	101.8*	±	7.5	77.3*	±	8.5
SBJ (cm)	40.3*	±	6.5	45.7*	±	2.3	35.8*	±	5.0
AJ (cm)	36.9*	±	6.4	42.7*	±	2.4	32.2*	±	4.3

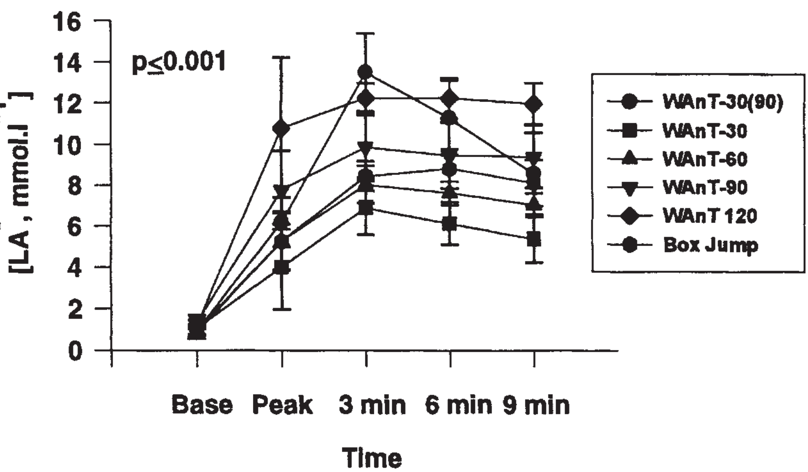

Fig. 1. Changes in lactic acid levels measured before, immediately after peak and after 3, 6, and 9 min of recovery following all Wingate tests and box-jump performance. Values are mean±SD for combined group (N=26).

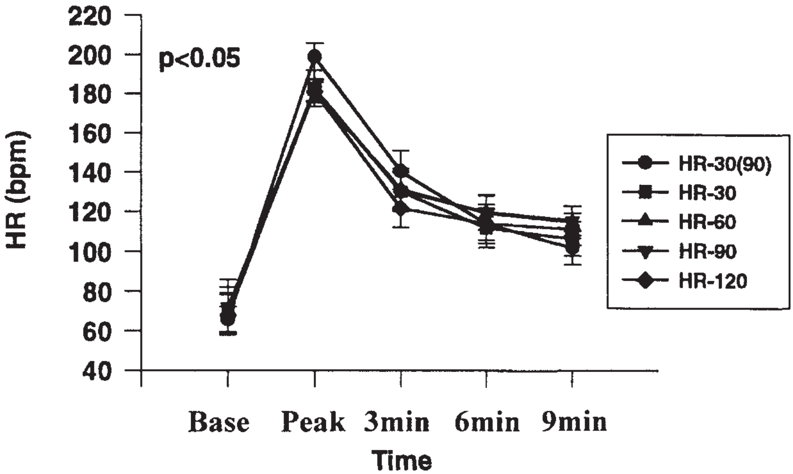

Fig. 2. Changes in heart rate before and following all Wingate test measuredimmediately after peak exercise and after 3, 6, and 9 min of recovery. Values are mean ±SD for combined group (N= 26).

6 Discussion

In the present study, the 30-s Wingate test with 0.090 kp/kg resistance yielded significantly higher absolute and relative PPO values for gender groups compared to the standard 30-s 0.075 kp/kg test. Subsequently the MPO and MinPO was also lower for the 30-s 0.090 kp/kg compared to the standard 30-s test at 0.075 kp/kg. It is noteworthy to mention that the fatigue index for all Wingate tests was not significantly different with the exception of the 30-s test at 0.075 kp/kg which was significantly lower compared to the other four Wingate tests. This increase in resistance gives credence to the fact that we do not maximally task the Alpine skiers in a laboratory environment unless we increase the resistance load. Currently, there is no published data available on increased resistance of 30-s all-out maximal tests in Alpine skiers, nor is there any data available on 60-s and 120-s Wingate tests in competitive Alpine skiers [Table 5]. Male Alpine skiers performed better in all test categories most likely due to significantly larger lean body mass—43% more as compared to female skiers. Lactate values resulting from the Wingate tests and the box jump were statistically not significant for the gender group ($p>0.05$) despite greater lean body mass for male competitors. Lean body mass, percent body fat and total body weight for both genders contributed greatly to performance of all Wingate tests as indicated by high correlations and significance. Lean body mass and percent body fat yielded higher correlations associated with longer (90-and 120-s) tests compared to the 30-s tests alone. Male skiers performed on an average between 20–30% better and in some cases exceed the 30% in all anaerobic test categories. Hill and Smith [7] reported that relative to body mass, women's mean peak power is about 77% of men's. However, in our study there were no significant differences between gender groups for the fatigue index. The 30-s 0.090 pk/kg Wingate test produced higher correlations in our subjects than the standard 30-s 0.075 kp/kg test. Percent body fat correlated very well with the single-best jump and average vertical jumps for both gender groups, whereby there was no correlation between the jumps and body weight or lean body mass for the gender-specific group. Although there were numerous high negative correlations between various power-output indices and individual Alpine skiing events, there is little association if any between the performance in anaerobic tests and actual skiing performance as measured by the USSA points. More importantly is perhaps the range of individual power measures, rather than an absolute or relative specific value or score of a test. The ski-racer's performance cannot be determined or predicted from various anaerobic batteries tested in this investigation. However, Wingate anaerobic tests of different duration and intensity produce better correlations compared to the box jump and/or the vertical jump in our subjects based on gender groups. Thus, power-output variables of different duration (30 to 120 s) and different intensity may yield important measures to assess success in competitive Alpine skiing.

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27

ASPECTS OF TECHNIQUE-SPECIFIC STRENGTH TRAINING IN SKI-JUMPING

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Keywords: ski-jumping, strength training, in-run position, take-off durance, take-off velocity, power capacity.

1 Introduction

The increasing numbers of artificial jumping hills and the supply of existing jumping hills with chairlifts induced a greater intensity of jump training on jumping hills. However, technique-specific strength training still has a relevant importance. Technique-specific strength training is mainly practiced by so-called simulation jumps. These are take-offs from a specific in-run position with the purpose of simulating the take-off motion on jumping hills as exactly as possible (Fig. 1). Simulation jumps are a favourite means within the technique training of ski-jumpers, and there are many scientific studies dealing with this subject [9] [4] [10] [5] [6] [7] [11]. If possible, simulation jumps should largely correspond in their dynamic-temporal and kinetic-temporal structure to hill jumps. Admittedly the prerequisites and conditions for hill jumps are essentially different in comparison to simulations jumps. On one hand, hill jumps result in great wind resistence against the direction of motion, and on the other, the jumper can use the take-off force—with slight deviations—through the smaller amount of friction present. In oppostion to this, wind resistence has no effect in simulated jumps, the friction between the boot and ground is so great that a take-off with a distinctly forward directional component is made possible. Such a direction of the jump is selected in order to recreate a similar feeling as hill jumps. In simulation, the ski jumpers are caught or stopped after take-off (Fig. 1).

For the reasons mentioned, distinct differences with respect to dynamic and kinematic structure of both forms of take-off result. Tveit/Pedersen [9], Sasaki/Tsunoda [5] und Sasaki/Yagi/Tsunoda [6] have provided research towards the goal of examining and interpreting these differences. In the literature of training research, take-off simulations have been assessed varyingly with respect to their technical-training quality.

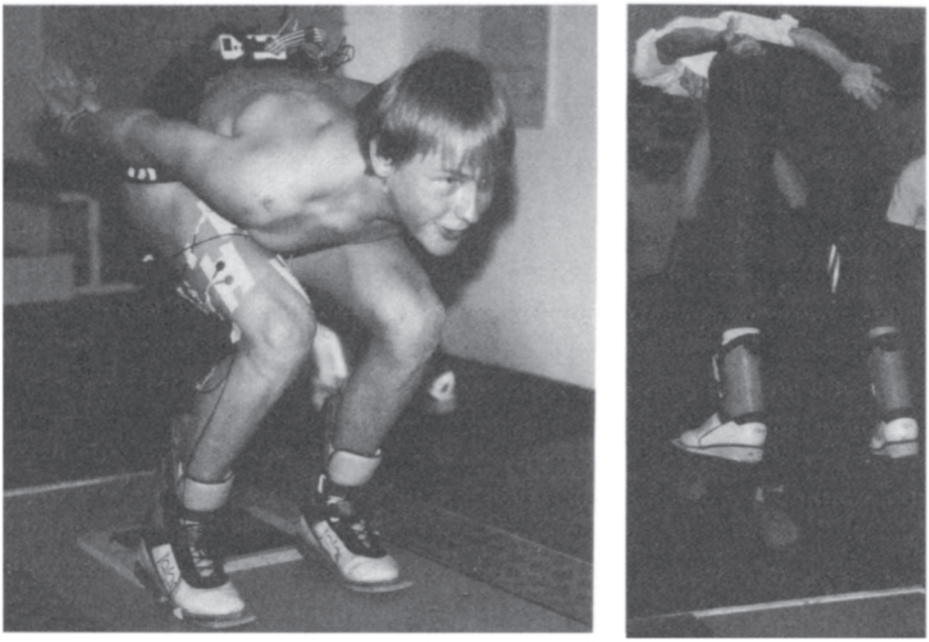

Fig. 1. Starting and final position of a simulation jump.

Dillman/Campbell/Gormley [2] consider take-off simulations on force-measuring plates to be very important, but note that the jump pattern differs from that of the hill jump and, therefore, the comparability appears to them limited. Tveit/Pedersen [9] conclude, based on their comparison of dynamic measurements, that the conditions of hill jumps and simulations are so significantly different that simulation jumps are not suitable for technique training, and even suspect a negative influence on jump technique. In this connection, the paper on the improvement of special jump forces of ski jumpers by Müller/Wachter [3], oriented towards training methodology, is integral.

The purposes of this study are to clarify following questions:

- Ski-jumpers may show a high degree of stability with respect to important take-off parameters. This aspect is of significance in that strictly automated movements can be changed only at great expense. Here, intra- and interindividual differences regarding selected dynamic and kinematic characteristics should be shown (Aspect 1).
- Simulation jumps are often taken with training shoes. More technique-specific

are, no doubt, jumps taken while wearing jumping boots. Whether and how significantly simulation jumps differ regarding dynamic structure, depending on the type of footwear used, should be recorded (Aspect 2).

- A question often discussed amongst trainers and jumpers is that of the approach position most suitable to the individual. Whether and to what extent dynamic and kinematic characteristics during simulations change depending on the starting position is a topic of investigation in this paper (Aspect 3).

The goal is to determine the foundation for individualizing and improving the strength training or for improving the take-off technique respectively.

2 Methods

2.1 Te st persons, jump variations

Nine ski jumpers of the Austrian National Team took part in this investigation, which was carried out in May 1993. They had to perform simulation jumps on a force plate from a starting position similar to the inrun position in hill jumps. The heels were heightened by a wooden wedge of a thickness between 2 cm and 3 cm, according to each individual. The test persons had to perform the jumps four times each under the following conditions: (A) middle starting position with training shoes (Aspect 2), (B) middle starting position with jumping boots (Aspect 1, 2, 3), (C) high starting position with jumping boots (Aspect 3) and (D) low position with jumping boots (Aspect 3).

2.2 Measuring methods

For determining the dynamic parameters, a Kistler force plate (100 Hz) was used. In order to determine the differences with respect to the starting position, video recordings (50 Hz) were evaluated two-dimensionally (PEAK Video Analysis System). For the determination of the duration and strength of the m. gastrocnemius while wearing different types of footwear, electromyographical methods were used (Biostore, 1000 Hz).

2.3 Selected parameters

Two components of the forces (vertical and horizontal anterior-posterior) were measured to determine the parameters jumping durance (t), resultant take-off velocity (v) and power capacity defined as the maximum of the grade (Fex). The starting positions were determined by calculating the hip-(α) knee- (ß) und ankle-angles (γ) by means of a 3-segment-model consisting of upper body, thigh and shank. As criterion to assess the height of the starting position, the knee-angle was used.

2.4 Statistical methods

The statistical differential testing was conducted using ANOVA methods. Correlation testing was examined with product-momentum correlation. Statistical safeguards are designated as follows:

$0.10>p\geq 0.05$	(*)	tendency
$0.05>p\geq 0.01$	*	significance
$0.01>p$	**	high significance

3 Results

3.1 Intra- und interindividual comparison of dynamic parameters

For this aspect, data was selected from exemplary jumps with jumping boots in the middle position. In the other jump types, similar results were found. Coefficients of variability CV=SD/AM (SD=standard deviation, AM=mean) serve as measure for the intra- and inter-individual deviation with respect to the selected characteristics. To differentiate, the coefficients of variability for the entire group CVG as indicator for the inter-individual deviations and the average individual coefficient of variability CVI as measure for the inter-individual deviation is included in each characteristic.

Table 1. Inter- und intrainidividual deviations of the selected parameters.

Parameter	t	v	Fex
CVG [%]	6.4	5.4	37.6
CVI [%] (min - max)	2.8 (1.6 - 3.9)	1.4 (0.4 - 2.3)	11.9 (0.8 - 15.5)
CVG/CVI [%]	229	386	316

Table 1 presents the results of the first aspect in summary. Especially the take-off time (t) and the take-off velocity (v) show with intraindividual variations of 2.8% and 1.4% a very high intrainidvidual stability.

In relation to this, the average variability for power capacity turns out significantly higher (almost 12%)—nevertheless, it can be considered to be relatively slight. This is made more clear, when one compares the group-specific variability for this parameter (37.6%). In summation, it can be said, that the inter-individual variabilities CVG are approximately 2 to 4 times higher than the average intra-individual deviations CVI (Table 1). These results indicate a very high level of automation of the investigated movement. In spite of the high homogenity of the investigated group, the parameters have a very high reliability. The correlations (two by two) between the trails show the following coefficients of reliability (Table 2).

Table 2. Paired correlation coefficients (r) in the investigated characteristics.

Parameter	r
t	0.71 - 0.92
v	0.90 - 0.97
Fex	0.89 - 0.98

3.2 Comparison between jumps using jumping boots and training shoes
As characteristic distinctions, the mean of the four attempts in the middle position (A and B) is here used. The results are shown in Table 3.

Table 3. Kinematic und dynamic take-off parameters-Comparison of jumps with jumping boots and training shoes (AM±SD).

Parameter	jumping boots	training shoes	%	p
α [°]	22.7 ± 4.7	23.9 ± 4.9		
β [°]	78.4 ± 3.3	79.9 ± 3.6		
γ [°]	53.3 ± 2.6	52.9 ± 2.9		
t [s]	0.333 ± 0.020	0.349 ± 0.028	+ 4.8	**
v [m/s]	3.05 ± 0.17	3.18 ± 0.15	+ 4.3	**
Fex [kN/s]	5.9 ± 2.2	5.6 ± 2.0	- 5.4	

With respect to the starting position, represented by the angle at the hip-(a), knee- (ß) and ankle-joint (γ), no significant difference appears between the two series of attempts, meeting the prerequisites for a comparison. With the exception of the hip angle, which is somewhat greater during the hill jump, these values largely correspond to the hill-jump position [10] [11]. While wearing training shoes, the take-off duration is 0.016 s longer (+4.8%) and the take-off velocity 0.13 m/s greater (+4.3%) in comparison to the jump with jumping boots. The differences are significant. Regarding power capacity, the differences are coincidental (-5.4%). Since the power capacity is mainly caused by the hip- and knee-extensors, it is largely unaffected by the type of footwear used, which seems quite plausible.

Through the limited plantar flexion in the ankle joint in the use of jumping boots, the significant differences with respect to take-off duration and takeoff velocity can be explained. In order to test this supposition, the m. gastrocnemius was deduced electromyographically under the conditions described. Fig. 2 shows synchronized electromyograms and values of the IEMGs under both conditions. The averaged value of the five attempts are shown for each (t=0 refers to the time of take-off).

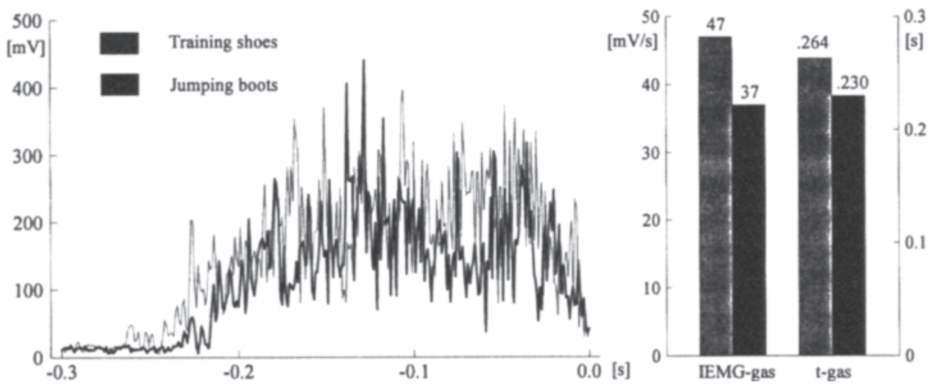

Fig. 2. Synchronized electromyograms, strength and duration of the m. gastrocnemius—Comparison between jumps with training shoes and jumping boots.

It should be recognized that the duration (t-gas) as well as the strength of the utilization of the m. gastrocnemius (IEMG-gas) while wearing training shoes turns out significantly greater (Fig. 2). The technical sequence of the take-off motion is accordingly dependent on the footwear worn.

3.3 Comparison between jumps with jumping boots in varying starting positions

Here, in each case (B and C) the means of the four attempts are drawn on as characteristics.

3.3.1 Comparison between middle and high starting position

In comparison to the middle position, the three body angles are significantly greater in the high starting position (Table 4). A knee angle increase accordingly results in a change in the same direction with respect to both other body angles.

Table 4. Kinematic and dynamic take-off parameters—Comparison of jumps in the middle and high starting position (AM±SD).

Parameter	middle	high	%	p
α [°]	22.7 ± 4.7	28.4 ± 5.4		**
β [°]	78.4 ± 3.3	90.6 ± 4.4		**
γ [°]	53.3 ± 2.6	57.3 ± 3.1		**
t [s]	0.333 ± 0.020	0.306 ± 0.026	- 8.1	**
v [m/s]	3.05 ± 0.17	3.03 ± 0.16	- 0.7	
Fex [kN/s]	5.9 ± 2.2	6.9 ± 2.1	+ 16.9	*

While the jump duration is, by 27 ms, significantly shortened in the higher starting position (-8.1%), the take-off velocity remains almost unchanged (-0.7%). Closely connected with this is the significant increase in power capacity (+16.9%). At an equally effective level, a higher starting position results in a shorter and more explosive take-off motion.

3.3.2 Comparison between middle and low starting position

A decrease in the knee angle of approx. 8 degrees results in a significant decrease in the ankle angle, while the hip angle remains nearly unchanged. Apparently, the minimum bending of the hips has already been reached in the middle position.

Table 5: Kinematic and dynamic take-off parameters depend on the starting position (AM±SD).

Parameter	middle	high	%	p
α [°]	22.7 ± 4.7	22.3 ± 5.9		
β [°]	78.4 ± 3.3	70.2 ± 3.3		**
γ [°]	53.3 ± 2.6	51.1 ± 4.0		*
t [s]	0.333 ± 0.020	0.356 ± 0.031	+ 6.9	**
v [m/s]	3.05 ± 0.17	3.03 ± 0.15	- 0.7	
Fex [kN/s]	5.9 ± 2.2	5.4 ± 1.6	- 8.5	(*)

At a lower starting position, the take-off duration increases by 23 ms (+6.9%) on average, as a result of the reduced power capacity (-8.5%), which admittedly shows only a tendential and not a statistically ascertained difference. The take-off velocity remains almost unchanged in comparison to the middle position (-0.7%).

4 Conclusions

Technique-specific strength training in ski-jumping must be seen under the aspect of the highest possible congruence to the hill jump from the kinematic and dynamic viewpoint. Simulations can fulfill this demand only conditionally, as a result of the absent wind resistance, the high friction between boot and ground, and the take-off angle, which has been significantly altered through the conditions above.

Aspect 1:

Simulation jumps of high-level ski jumpers show very high intraindividual consistency and stability concerning the dynamic structure. Intended changes of these stabilized motor patterns require the use of specific training methods to improve power and speed capacity.

Aspect 2:

The jumping technique depends on the footwear used regarding important characteristics. The use of jumping boots is an essential requirement for technique-specific training in ski-jumping.

Aspect 3:

The advantages of a higher starting position in comparison to a middle position lie in a shorter jumping duration and in the fact that the in-run position can be kept longer. On the other hand, the jumper has to take a higher position during the entire in-run. A further advantage of the higher starting position is the higher power capacity. With respect to these aspects, a three-part in-run and jumping technique could be used, delineated as follows: (1) in-run phase in the aerodynamically best position, (2) in-run phase in a heightened in-run position assumed before the jump and which makes possible an optimal approach to jump duration and take-off power (that is, in the sense of the shortest possible jump duration without loss of take-off velocity) and (3) the actual take-off phase.

The lower take-off position is characterized by an aerodynamically favourable posture until the beginning of the take-off motion, albeit including a longer take-off duration and weaker power capacity. The disadvantages could be minimized by a specific speed-capacity training for the purpose of shortening the ‘acyclic time-pattern’ [1].

A reference to the fact that the approach and take-off technique is forced by jumpers as the approach position is lowered, is found in Vaverka/Zhanel [12]. This effect can be explained by improved training methods, which make it possible for ski-jumpers to take-off powerfully even from a low and technically disadvantageous position.

To clarify these questions and to safeguard the suggested in-run and takeoff techniques, the results of the dynamic experiments must be complemented by aerodynamic measurements. The individual diagnosis of kinematic, dynamic and aerodynamic parameters appear important as well.

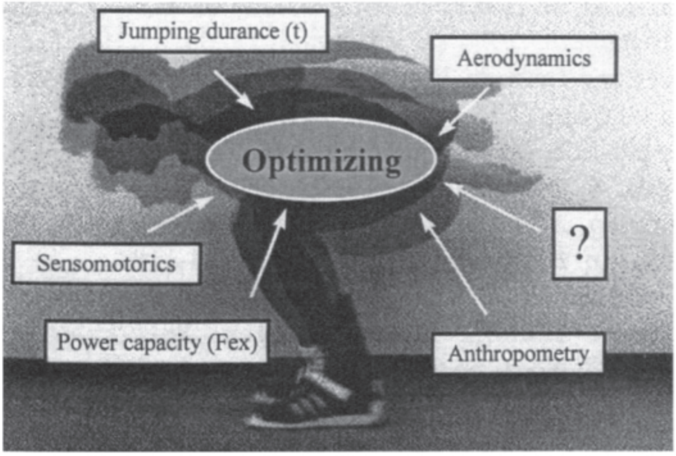

Fig. 3. Optional pattern for individual optimizing of the in-run position.

As we have seen, the starting position from which the simulation is carried out influences the parameters of jump duration and power capacity in a significant way. It is surprising that the resultant take-off velocity is largely unchanged in varying starting positions. It follows that other criteria (e.g. take-off duration, power capacity, aerodynamics, anthropometry, sensomotorics, etc.) must be considered in assessing the quality and effectiveness of take-off motion depending on the starting position (Fig. 3).

To clarify these questions and ascertain suggested approach and take-off techniques, the results of the dynamic investigation must be complemented by aerodynamic measurements. Also important appears the individual diagnosis of kinematic, dynamic and aerodynamic parameters.

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28

PROGRAMME FOR THE OBJECTIVIZATION OF SPORT-SPECIFIC PERFORMANCE PRECONDITIONS, IN THE LONG-TERM DEVELOPMENT OF PERFORMANCE OF CROSS-COUNTRY SKIERS

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Keywords: cross-country skiing, sport-specific tests, longitudinal study.

1 Introduction

In the course of the long-term development of performance (LLA) in cross-country skiing, approximately between the ages of 10 and 20, the development of the sport-specific performance capacity is characterised by a very high dynamic. Temporarily significant changes in the level of performance (phases of increased development) can be reached in a few months or weeks. Simultaneously, you can see partially, essential differe nces in the level of performance between athletes of the same age and with similar training background. These differences are not only found between the two genders but also between retarded and accelerated athletes.

Standardised test programmes for performance diagnostics of homogenous populations (e.g. adult elite athletes) can be applied in longitudinal studies of LLA only to a limited degree.

Therefore, a standard test-programme for the assessment of the level of sport-specific relevant performance presuppositions in cross-country skiing has been developed in close co-operation between the Institute for Applied Training Science in Leipzig, the Regional Skiing Association of Saxony and the Skiing Club Klingenthal-Mühlleiten. The programme has been especially developed for longitudinal studies, and has been tested over a longer period with gifted female and male skiers (cadre athletes).

2 The test programme

A rollerski step-test on a treadmill with an external drive forcing the skiers to ski in classic style until break-off because of maximum load constituted the core of the test programme (Fig. 1). Loading was determined on each level by distance (constant for any level with 1000 m), inclination of the treadmill, and treadmill velocity, simultaneously taking the rolling friction of the rollerski into account. The rest-periods between the loading levels lasted one minute. In the test, enhancement of performance from one level to another was not linear (as it is usually), with an unchanged step distance, but exponential, the beginning small, but then with steadily increasing steps. On each loading level heart rate, oxygen uptake and blood-lactate concentration, as well as step distance and step frequency were monitored. At the point of break-off, distance and time were monitored.

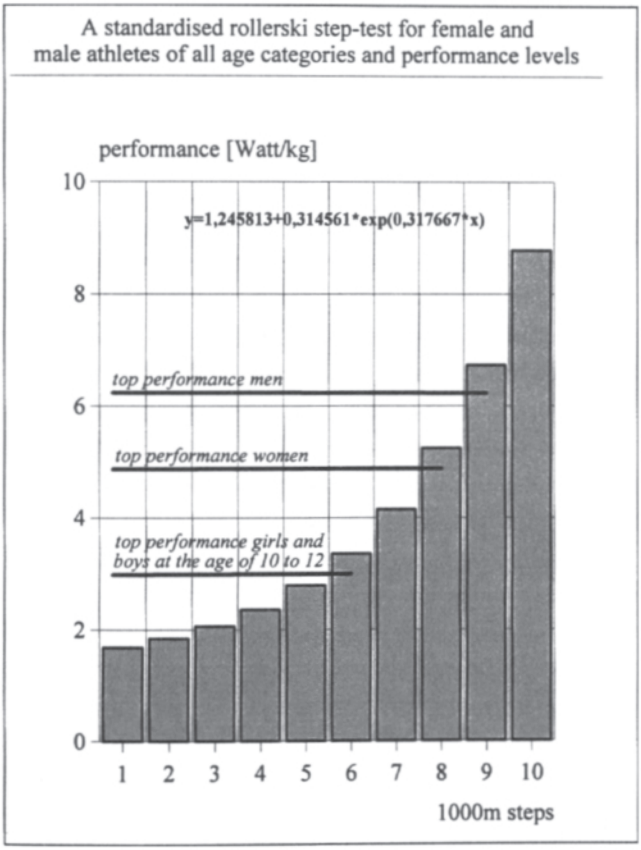

Fig. 1. Course of loading in the rollerski step-test.

Besides the rollerski step-test, a speed-strength, maximum-strength, and strength-endurance test were performed, using a special arm-pull apparatus (AKZ).

Based on all test data, the following parameters were determined as criteria to assess the level of sport-specific performance presuppositions:

- Using the rollerski step-test the final performance (FINALLEIST, Watt/ kg), the total distance (m), the maximum blood-lactate concentration (LAKMAX, mmol/l), the maximum oxygen uptake (VO2MAX, ml/kg/ min), the maximum heart rate (HFMAX, bpm), the rollerski performance at a blood-lactate concentration of 3 mmol/l (LEIBLAK3, Watt/kg), the rollerski performance at a heart rate of 170 bpm (LEIBHF170, Watt/kg), as well as the oxygen uptake at a blood-lactate concentration of 3 mmol/ 1 (HFBLAK3, bpm) res. (VO2LAK3, ml/kg/min);
- Using the arm-pull apparatus (with a sport specific movement pattern), the speed strength (RSK, kpm), the maximum strength (RMK, kpm), the strength endurance of the arms with a reciprocal rope pulling (RKADIA, Watt/kg), and with parallel rope pulling (RKADOP, Watt/kg).

The programme has been tested in the course of two years with a population of 22 young skiers, 11 male and 11 female, who performed the tests one to five times (Table 1). These data were used to prove the validity of the test. The determination of biochemical and gas metabolism parameters was done by the Dept. of Sportsmedicine at the Institute for Applied Training Science headed by Prof. Dr. G.Neumann.

Table 1. Mean value, standard deviation, minimum and maximum of the performance parameters of the population of skiers.

parameter	n	mean value	standard deviation	minimum	maximum
AGE [month]	47	195,91	16,09	166,00	252,00
FINALLEIST	47	3,60	0,51	2,37	4,45
LEIBLAK3	47	2,81	0,36	1,76	3,45
LEIBHF170	47	2,37	0,45	1,49	3,42
LAKMAX	47	8,04	2,12	3,70	11,40
HFMAX	47	198,96	8,10	185,00	215,00
VO2MAX	47	53,19	7,12	38,75	66,50
HFBLAK3	47	182,02	9,89	159,00	204,00
VO2BLAK 3	47	41,46	4,83	27,67	52,10
RSK	47	0,272	0,071	0,140	0,423
RMK	47	0,990	0,230	0,599	1,428
RKADIA	47	1,367	0,413	0,760	2,191
RKADOP	47	1,925	0,522	1,054	2,990

3 The applicability of the test programme for longitudinal studies with male and female skiers between the ages of 14 and 20

3.1 Loading during the rollerski step-test

Because of the exponential increase of loading during the treadmill test, both young, relatively weak athletes and strong, experienced athletes of both genders can successfully do the programme. The relatively low load increase at the beginning of the programme causes a relatively slow onset of blood-lactate accumulation. This is advantageous for an exact determination of the aerobic-anaerobic transition range. After exceeding the anaerobic threshold, the load increase becomes increasingly bigger, quickly leading to an exhaustive load, enabling/promoting an intensive use of an anaerobic lactic energy supply. Consequently, individual top performances are reached or promoted.

The total loading time varies depending on age and the level of performance of the athlete between 35 and 55 minutes. This approximately complies with the medium loading time in skiing competitions in the individual age groups.

3.2 The reliability of the test values

Using multivariant statistical procedures, the inter-relations of the data monitored in the step-test and with the AKZ, as well as their relation to the final performance were checked.

According to this procedure, there were, for almost all parameters monitored in the rollerski step-test and with the AKZ, significant mean value differences between the data of the male and the female subjects, though the two gender groups only slightly differ with respect to their mean age. Male skiers had, in the majority of cases, a higher sport-specific level of performance, and show accordingly better performance presuppositions when compared with female athletes of the same age (Table 2).

But if the respective ages of the male and female skiers is not taken into account, and only the relations between the level of final performance in the rollerski step-test and the level of the other parameters monitored are considered, no real differences between the two gender groups are found. The total correlation coefficients which were considered independently in both groups did not show significant differences. Similar to this finding, the regression function between the final performance in rollerski step-test and the other parameters only slightly differed between the female and the male population (Table 3).

When finally considering the tested female and male skiers as a homogeneous group, we found (see Table 4) highly significant linear dependencies between the final performance in the rollerski step-test and the other parameters (with the exception of the parameters HFMAX and HFBLAK3).

Thus, comparing athletes of a higher level of performance with those with a lower level of performance, the former are, regardless of their age and gender, characterised by a better skiing performance at blood lactate 3 and at heart rate 170. On one hand, they have a better skiing performance with a lower heart rate, and on the other, they have a higher oxygen uptake. They also have a higher maximum oxygen uptake and better arm-pull abilities, and they can mobilise themselves (measuring the value of maximum blood-lactate concentration) better.

But the influence of the individual parameters on the level of final performance in the rollerski step-test is quite different. Table 4 shows some reasons for the differences between the total and the partial correlation coefficients.

The multiple regression equation also proves the good reliability of the rollerski step test with respect to the actual sportspecific performance capacity of an athlete. When introducing the correct individual data into the equation, the result reflects the real final performance with an extraordinary exactness (Fig. 2). At the least, the multiple coefficient of determination illustrates that the parameter acquired from the rollerski step-test with the AKZ explains 98.8 percent of the final performance. The remaining variance of 1.2 % proves that the parameters monitored with the test programme represent sport-specific relevant performance presuppositions.

Table 2. Mean values of data monitored in the study for male and female subjects and calculated mean value differences between both gender groups (a=0.05).

Criterion: significance level <0.05=significant differences of the data in the study.

[shaded box] significant mean value differences (t-test) and medium differences (U-test)

parameter	gender	n	mean value	t-test		U-test	
				t	sig.-level	Z	sig.-level
ALTER	m	25	197.3	0.652	0.517	0.064	0.949
	f	22	194.4				
FINALLEIST	m	25	3.95	7.169	4.047E-9	-5.351	8.749E-8
	f	22	3.20				
LEIBLAK3	m	25	2.96	3.521	9.547E-4	-3.353	7.985E-4
	f	22	2.93				
LEIBHF170	m	25	2.59	4.268	9.245E-5	-4.037	5.416E-5
	f	22	2.13				
LAKMAX	m	25	8.89	3.140	2.890E-3	-2.913	3.584E-3
	f	22	7.08				
HFMAX	m	25	198	-1.027	0.309	1.008	0.314
	f	22	200				
VO2MAX	m	25	58.32	1.930	0.060	-4.720	2.361E-6
	f	22	47.36				
HFBLAK3	m	25	179	-2.686	0.010	2.338	1.938E-2
	f	22	185				
VO2BLAK3	m	25	43.74	0.665	0.509	-2.912	3.589E-3
	f	22	38.86				
RSK	m	25	0.573	5.486	2.154E-6	-4.424	9.689E-6
	f	22	0.476				
RMK	m	25	1.087	7.652	1.112E-9	-5.149	2.620E-7
	f	22	0.794				
RKADIA	m	25	1.645	9.134	8.199E-12	-5.639	1.710E-8
	f	22	1.150				
RKADOP	m	25	2.300	8.106	2.417E-10	-5.192	2.087E-7
	f	22	1.650				

4 Interpretation of test results

To assess and evaluate the test results individually, all data monitored was compared with age and gender specific target values, so called orientation values.

The developmental trend of elite female and male skiing performance in the long-term development of performance resulting from the known race speeds of the winning skiers in National Youth Competitions, Junior World Championships, World Championships and Olympic Winter Games was used to form the basis for calculating orientation values (Fig. 3).

Table 3. Comparison of the linear correlation and regression coefficients between the final treadmill performance and the individual performance parameters between male and female subjects (according to Weber 1961); a=0.01.

- Criterion for the comparison of regression coefficients: If |*t—calculated* |<*t—chart* .α; *f*, then assumption of H_0
- Criterion for the comparison of the correlation coefficients: If $|d| < t_{\alpha;f} * s_d$, then assumption of H_0

		correlation coeffizient			regression coeffizient		
parameter	f	difference of the z-values (d)	test value ($t*s_d$)	hypo-thesis	t calculated	t chart	hypo-thesis
LEIBLAK3	43	0,47	0,85	H_0	2.16	2.69	H_0
LEIBHF170	43	0,35	0,85	H_0	2.61	2.69	H_0
LAKMAX	43	0,25	0,85	H_0	0.74	2.69	H_0
HFMAX	43	0,03	0,85	H_0	0.40	2.69	H_0
VO2MAX	43	0,14	0,85	H_0	0.28	2.69	H_0
HFBLAK3	43	0,16	0,85	H_0	1.04	2.69	H_0
VO2BLAK3	43	0,38	0,85	H_0	1.58	2.69	H_0
RSK	43	0,55	0,85	H_0	0.98	2.69	H_0
RMK	43	0,22	0,85	H_0	0.61	2.69	H_0
RKADIA	43	0,03	0,85	H_0	0.09	2.69	H_0
RKADOP	43	0,03	0,85	H_0	0.13	2.69	H_0

Literature analyses and former studies led to the assumption that the mean age to reach real top performances, independent of gender, was 28 +/-3 years, both in rollerski and cross-country-skiing, and that a maximum oxygen uptake of about 75 ml/kg (women) and 82 ml/kg (men), respectively, was an absolute necessity to reach such a performance. These findings, and our former investigations, made it possible to apply mathematic procedures to conclude from the developmental trend in elite skiing performances concerning an "adequate developmental trend of the final performance in the rollerski step-test" (Fig. 4) and made conclusions concerning all other orientation values possible.

In the case that skiers perform these orientation values, which should be considered as target values, in the rollerski step-test and with the AKZ, one can expect them to reach top results in cross-country skiing on national level (athletes between the age of 14 and 20), or on international level (athletes older than 20).

The test results, as well as the age and gender-specific orientation values, were calculated using a computer software which has been developed for this purpose only. With the software, the results can be forwarded to partners in sport practice within a very short period of time (Fig. 5).

Multiple R	.994049
Multiple R squared	.988134
Adjusted R squared	.984404
Std. Error of Est.	.06412477
Constant	2.325454

Analysis of Variance	DF	Sum of Squares	Mean Squere	F Ratio	Prob. Level
Regression	11	11.984472	1.089497	264.9565	.0000
Residual	35	.1439195	.004111986		
Adj. Total	46	12.128391			

STEP	Num vars now in	Mult R	Mult R Sq.	Change in Rsq	Variable entered (* shows deleted)	B, raw coeffi-cient	Stand error of B	BETA Stand. coeffi-cient	Final F to delete	F when entered of deleted	Simple cor. with dep.	Partial cor.in final step
1	1	.7105	.5049	.5049	LEIBLAK3	1.566758	.1158089	1.097150	183.029	45.886	.7105	.9162
2	2	.7548	.5698	.0649	LEIBHF170	-.3890729	.1190165	-.3410420	10.687	6.636	.6346	-.4836
3	3	.8834	.7804	.2106	LAKMAX	.01132609	.01005837	.04684267	1.268	41.227	.6068	.1870
4	4	.8891	.7905	.0101	HFMAX	.007731267	.004001980	.1219154	3.732	2.027	-.0002	.3104
5	5	.9223	.8506	.0602	VO2MAX	.05320219	.004469494	.7375702	141.691	16.521	.8157	.8955
6	6	.9692	.9393	.0886	HFBLAK3	-.02189954	.006662210	-.4216905	10.805	58.359	-.2701	-.4857
7	7	.9932	.9864	.0472	VO2BLAK3	-.06311489	.005970730	-.5933834	111.740	135.576	.4966	-.8726
8	8	.9932	.9864	.0000	RSK	.4612675	.2913059	.06398485	2.507	.005	.6381	.2586
9	9	.9938	.9876	.0011	RMK	-.1016659	.1010943	-.04544122	1.011	3.327	.6587	-.1676
10	10	.9940	.9881	.0006	RKADIA	-.07542177	.06694085	-.06066728	1.269	1.697	.7234	-.1871
11	11	.9940	.9881	.0000	RKADOP	.01167909	.04702211	.01186953	.062	.062	.7356	.0419

Regression Equation:

FINALLEIST (pred) = 1.56676 LEIBLAK3 + -.389073 LEIBHF170 + .0113261 LAKMAX + .00773127 HFMAX + .0532022 VO2MAX + -.0218995 HFBLAK3 -.0631149 VO2BLAK3 + .461268 RSK + -.101666 RMK + -.0754218 RKADIA + .0116791 RKADOP + 2.32545

Table 4. Final summary of regression on dependent variable FINALLEIST.

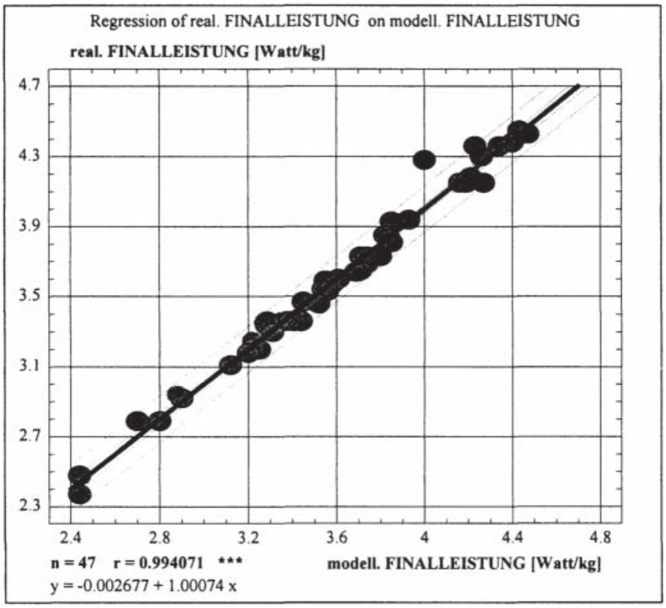

Fig. 2. Linear regression and correlation between performed final performance and modelled final performance on the basis of multiple regression.

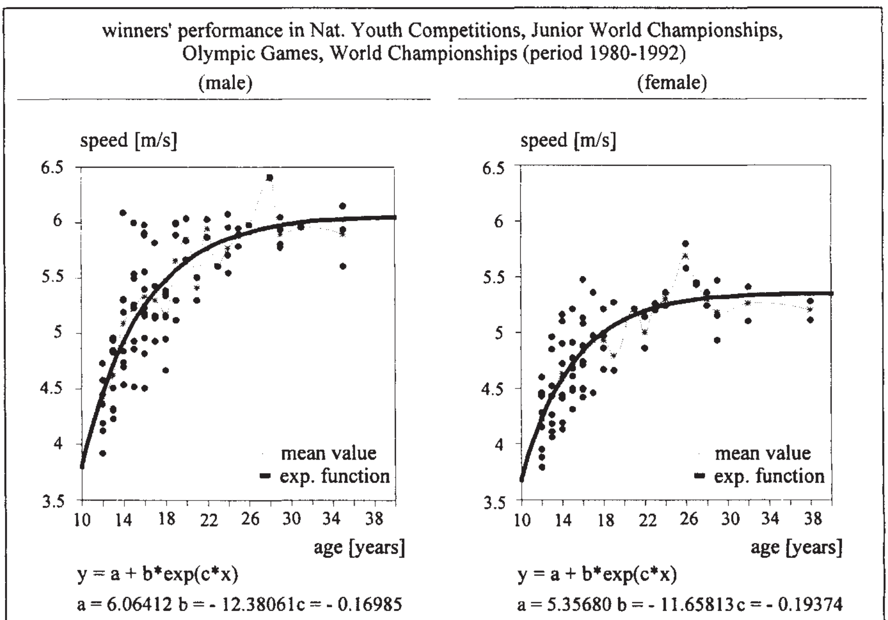

Fig. 3. Developmental curves of race speed for winners in cross-country events of different age-groups.

The actual data of one skier presented in the data sheet can be compared with data of athletes of the same age and gender. In case there are several test data sheets for one athlete, her/his athletic development in the sport specific performance capacity and in his/her performance presuppositions, caused by training/exercise and advance in years, can be assessed.

The differences (in percent) between the actual and the orientation values can be used to evaluate the actual state of the sport-specific performance of a skier, and the actual level of performance presuppositions in relation to age and gender. Strong and weak parameters in sport-specific performance presuppositions can be determined.

A comparison of hitherto monitored test results with the competition results of the same skiers proved the applicability of the test protocol to evaluate specific performance presuppositions in cross-country skiing. For a statistically reliable statement on this topic, the number of competitions performed by the athletes within the test period is still too low.

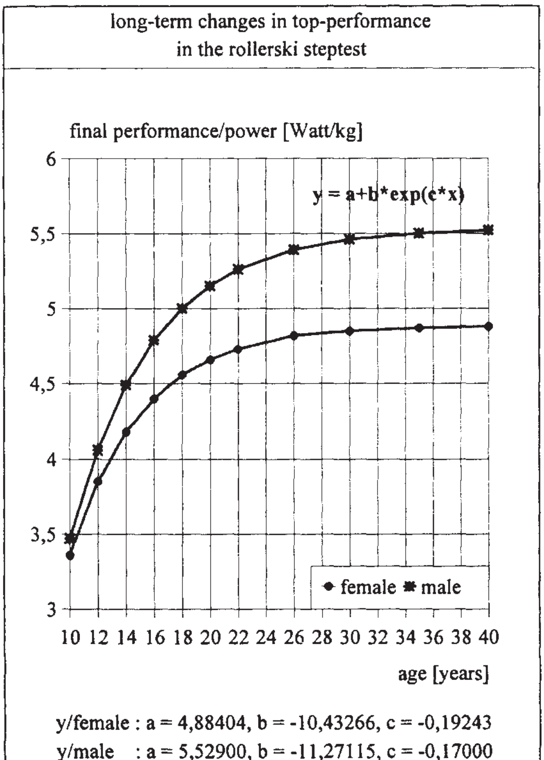

Fig. 4. Orientation values for the age and gender specific development of the final performance in the treadmill test in long-term development of performance.

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name: B. F. sportsclub: SV KLINGENTHAL date of the test: 12.06.95
date of birth : 09.05.79 age: 16/1 Jahre/Monate
bodyheight: 177.2 cm start of elite age: 2004
bodyweight: 69.0 kg difference to ideal bodyweight: -0.48 kg

programmed parameters in treadmill step-test

level	1	2	3	4	5	6	7	8	9	10
angle (°)	4	4	4	4	4	4	4	5	7	10
v (m/s)	1.61	1.77	1.98	2.27	2.68	3.23	3.99	4.33	4.34	4.27
s (m)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
t (min)	10:21	9:25	8:25	7:21	6:13	5:10	4:11	3:51	3:50	3:54
P (Watt/kg)	1.68	1.84	2.06	2.36	2.79	3.36	4.15	5.24	6.73	8.78

monitored values under load

SL (m)		2.89	3.17	3.39	4.07	4.72	5.17	5.29		
SF (Sch/min)		36.7	37.4	40.2	39.4	41.0	46.2	49.1		
lactate (mmol/l)			0.74	1.15	1.46	3.30	8.06	10.34		
heartrate (Sch/min)		133	141	152	164	178	187	194		
VO2 (ml/min/kg)					42.34	51.27	60.93			
break-off distance (m)								303		
break-off time (min)								1:10		

calculated values

		real value		orientation
TREADMILL	FINALLEIST (Watt/kg)	4.45	-7%	4.80
	TOTAL DISTANCE (m)	7303		7646
	VO2MAX (ml/min/kg)	66.5	0%	66.7
	HFMAX (Sch/min)	194		
	LAKMAX (mmol/l)	10.3	-6%	11.0
	LEIBLAK3 (Watt/kg)	3.31	-3%	3.40
	VO2BLAK3 (ml/min/kg)	49.5	5%	47.0
	HFBLAK3 (Sch/min)	171		
AKZ	RSK (kpm/kg)	0.302	-20%	0.378
	RMK (kpm/kg)	1.009	-25%	1.342
	KADIA (Watt/kg)	1.771	-14%	2.064
	KADOP (Watt/Kg)	2.723	-3%	2.820

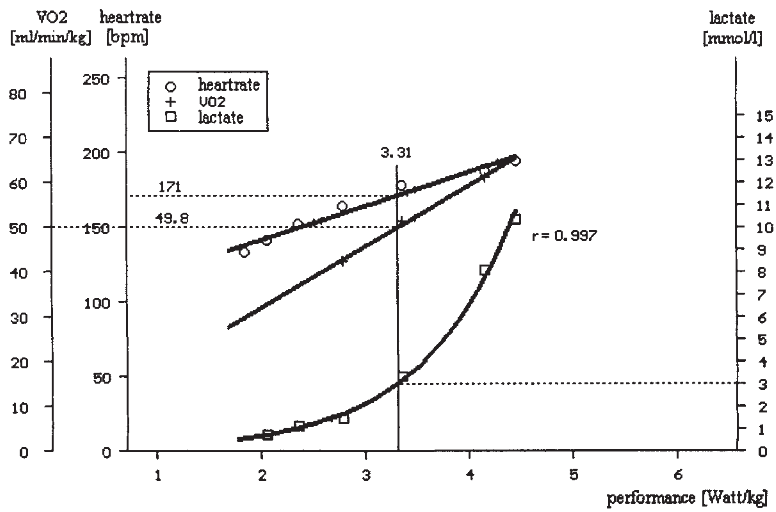

Fig. 5. Test data sheet performance diagnostics in skiing.

Part Three

Movement Control and Psychology in Skiing

29
MOVEMENT REGULATION IN ALPINE SKIING

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Keywords: alpine skiing, movement regulation, motor control, equilibrium, electromyography, EEG, vibration load, biomechanics.

1 Introduction

Since the beginning of alpine skiing in Norway in the 12th century, the guidelines for alpine technique have, of course, changed. Due to the development of the skiing equipment especially in the last few decades, outstanding changes in the alpine-skiing technique are to be registered. The development of the alpine technique used in leisure-time skiing in the last 50 years was influenced by strong international controversies. The main sources for these conflicts were commercial and national interests and the fact that no really objective reasons were available for the correctness of technique. It should be mentioned, that the elements of techniques were mainly derived from the description of postures rather than of movements. This can be explained by the non-existence of methods and technical devices for measuring kinetic and kinematic variables in these years. The first major scientific approaches with a biomechanical and preventive background occurred in the Fifties [1].

Currently a great variety of goals in leisure-time skiing linked with the modern alpine equipment leads to various skiing-situations. These range from experiencing nature outside the standard slopes to high risk skiing with competition-like velocities. On the other hand, alpine technique in competitive skiing was always led by the most important goal, i.e. simply to reach the finish line as soon as possible. For many years, however, the development of technique in competitive skiing suffered from a lack of scientific results as well.

This lack of scientific activities even during the last few decades in leisure-time as well as in competitive skiing can be mainly associated with the difficult situation for measurements of any kind on the slope. Other sports, e.g. track and field or gymnastics, which take place in rather standardized situations, have remarkably fewer problems of this kind.

It is not until recently that the number of scientific investigations in alpine skiing has risen considerably [2] [3] [4]. With modern miniaturization of measurement devices and computer technology it has become possible to focus more on the details of the skiing technique. Nevertheless, the great variety of situations on the slope and of different techniques used by the skier, even nowadays, does not allow a modelling of alpine techniques based on mechanical/biomechanical parameters as frequently used in gymnastics or other sports.

One major reason for this lack of holistic theoretical concepts in alpine skiing can be seen in the fact that certain movements, e.g. bending or stretching the various joints, usually cannot be directly associated with a specific physical effect, like certain movements of the alpine ski. This, of course, increases the problems for the experimental analyses considerably, because just "standing" on the ski is the outward appearance of this basic problem.

Standing upright—in the context of equilibrium control—has been investigated in physiology many times [5] [6], suggesting that even standing with gravity as the only external force must be regarded as a regulation process with highly complicated motor control implications on the sensory "input" level as well as referring to the motor "output". Modern approaches in this context, of course, do not clearly separate between "input" and "output".

The main approach in this paper will be based on current concepts of human movement regulation on the central level as well as on the peripheral level of motor control. Results from our own research in alpine skiing will be presented in this frame.

2 The Framework of Movement Regulation

Many results from scientific work in the area of motor control suggest that the hierarchy of movement regulation on the central and the peripheral level is influenced to an considerable extent by the goal of the movement. Models with such a broad application also for motor control characteristics of limb movements have been offered in recent years within the context of psychological approaches [7], on a general level, and on a mathematical basis, with a background from bioengineering [8] [9] (see Fig. 1).

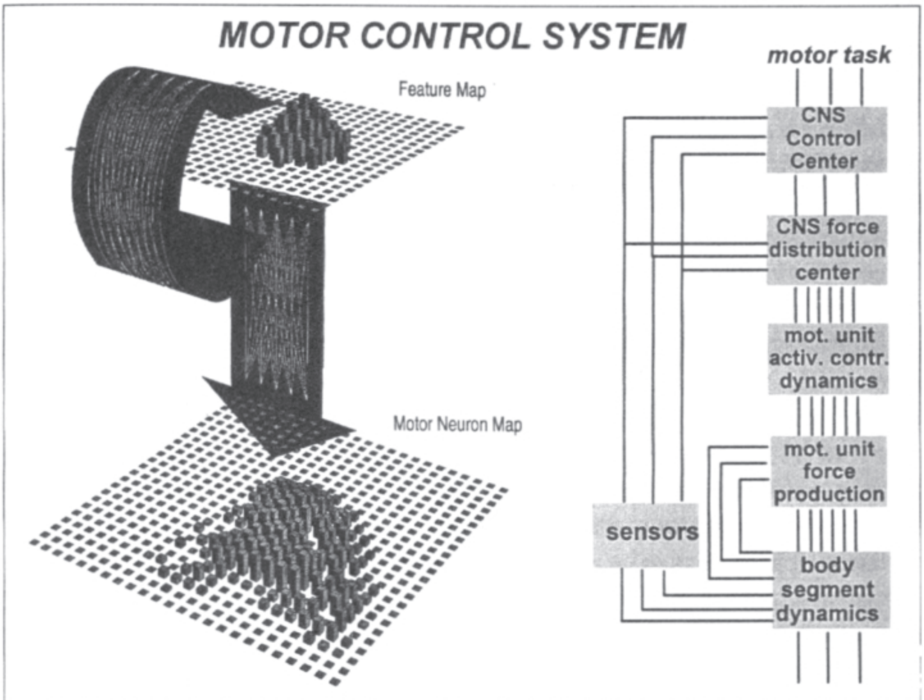

Fig. 1. Motor Control System [8].

The basic idea in the current approach of motor control by KUO [8] is that the coordination of billions of cortical neurons, motor neurons on the spine level, and more than 600 muscles with 240 degrees of freedom can only be controlled by a highly sophisticated network. This cooperation between central instances (e.g. motor cortex) and peripheral accountability (e.g. motor units) has largely been ignored by the natural science disciplines in sport sciences during the last few years. This “neglect” of the brain seems to be unjustified, although many events in sport, of course, do not or must not require “conscious” control mechanisms. The brain, however, is somehow involved in every motor event.

One of the most important ideas of KUO [8] is the existence of “Mapping-Systems” at the level of the brain as well as at the spinal level of motor neurons. This idea is important, because it explains to a certain degree the fact that every movement, even movements of small body segments such as as hands or fingers in standardized situations, have a remarkable amount of variability and that they are “regulated” in order to achieve a defined goal. The model of a “Feature Map” and a “Motor Neuron Map” (see Fig. 1) assures that there is a high capacity for flexible responses. The “zones” of activation in the brain map are not clearly defined. Thus, slight differences in starting conditions of the movement, e.g. limb positions, can be compensated or regulated. As the local excitation area varies with the input and the requirements of the movements, the existence of a flexible topographic organization of the brain can also be sustained on the basis of this approach. The area of the excitation indicates the direction of the muscular action, whereas the excitation size and the firing rate encode the force. A similar existence of a map of neurons with similar properties is assumed at the level of the motor neurons.

As it is very unlikely, that—even for a given and defined movement or motor task—the starting conditions are absolutely identical, it is not useful to activate the same area of cortical neurons as well as motor neurons. The required homogeneity of activation is provided by the fact that excitatory connections are located in the neighbourhood of the neurons, whereas inhibitory connections are established with neurons located at a greater distance. This seems to be a very good solution because it provides flexibility for motor actions with similar tasks or similar starting conditions. Considering the complexity of motor tasks and the highly developed capacity of the motor system to solve these tasks, this motor control system can no longer be regarded simply as a network but as a network of networks. Other approaches presented in the literature support this with emphasis [9].

At an abstract level, this model can be described by five steps (see Fig. 1). The CNS-Control Center is faced with the motor task and gives an input into the CNS-Force Distribution Centre, where an initial signal differentiation takes place. Afterwards the signals are transformed into Ft-characteristics and embedded in the dynamic environment of the motor units. Then the force production of the motor units is calculated inducing the Body Segment Dynamics, which can be measured e.g. in kinematic terms. The described model can be applied to single joint movements as well as to whole-body movements.

What happens in the area of neurophysiological regulation during the eccentric phase of the carved turn in alpine skiing is, that via central motor commands from the brain a certain muscle and joint stiffness is set. The combination of both settings is very important. The intensity of cocontraction, e.g. between the leg extensors and flexors, defines the resisting forces during the changes of hip, knee and foot angles. If the co-contraction and thus the joint stiffness is set too high, absorption efficiency will be lowered. The second important factor for an adequate absorption is the muscle stiffness, defined as the change of tension for a given change of fibre length ("spring constant"). Rather little is known in vivo about the control of stiffness under whole-body vibration load [10].

The requirements for complex movement regulation in alpine skiing can of course be explained only very basically by the in vitro findings. Major problems for quantitative analyses in skiing for situations in vivo are due to the fact that the stiffness regulation is not limited to a certain group of muscles or a single joint. As the whole body under high external forces is involved, different settings of both muscle and joint stiffness adjusted to the various masses of the segments are necessary.

Even if only the regulation processes on the spinal level are considered, the complexity and thus the variability becomes evident by focussing on the various influences on the alpha-motoneurons (see Fig. 2)

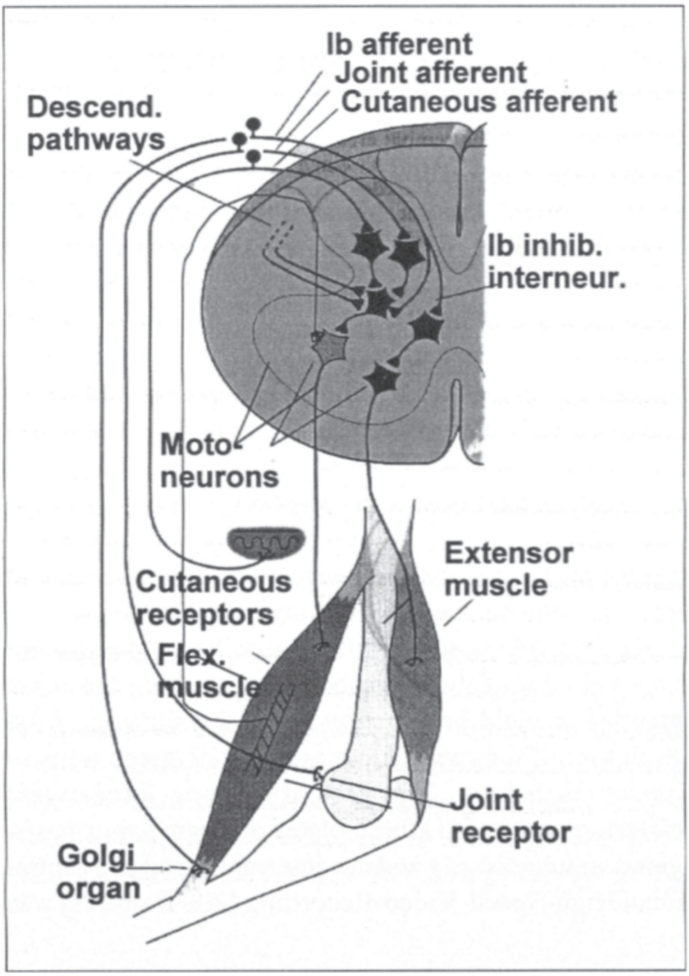

Fig. 2. Receptor's pathways to the alphamotorneurons [11].

The figure shows that sensory information from various receptors (Golgiorgans, muscle spindle, joint receptors, cutaneous receptors, etc.) is given to a “spinal level processing”. This “spinal level processing” can be described as very efficient and fast for those motor tasks, which are well-known and frequently practised.

Central commands can modify this complexity of regulation events by filtering and selecting a certain area of input, e.g. from the cutaneous receptors. By this central control those motor tasks can be supported, to which the individual is so far unfamiliar. If the central input is used in the wrong context, the “automatic” regulation process at the spinal level can be influenced negativly.

3 Experimental Results for Movement Regulation in Alpine Skiing

3.1 Subjects and Methods

In the course of the last ten years a lot of different investigations were carried out by the Cologne working group. The main goal of these activities was to understand better the specific requirements for movement regulation in alpine skiing.

The subjects involved in these experiments were

- members of the German National Alpine Skiing Team,
- members of the Demonstration Team of the German Ski Teachers’ Federation, and
- leisure-time skiers of various ages and levels of performance.

The main experimental outdoor situations were gliding straight-ahead and different turns in slalom-like courses on the slope (see Fig. 3).

For kinematic analyses four video cameras were used: Two of them were installed to measure the velocity of the subjects during the run, the other two cameras were intended to yield information about the shifting of the body segments. At each turn of the run, there was a pair of speed traps to register the time between each turn. The ground-reaction forces were measured by means of various pairs of 1D force-plates on strain gauge basis. All devices were triggered simultaneously and the data transferred to a central control, where additional High-Speed-Video-Recording (200 frames/s) was carried out.

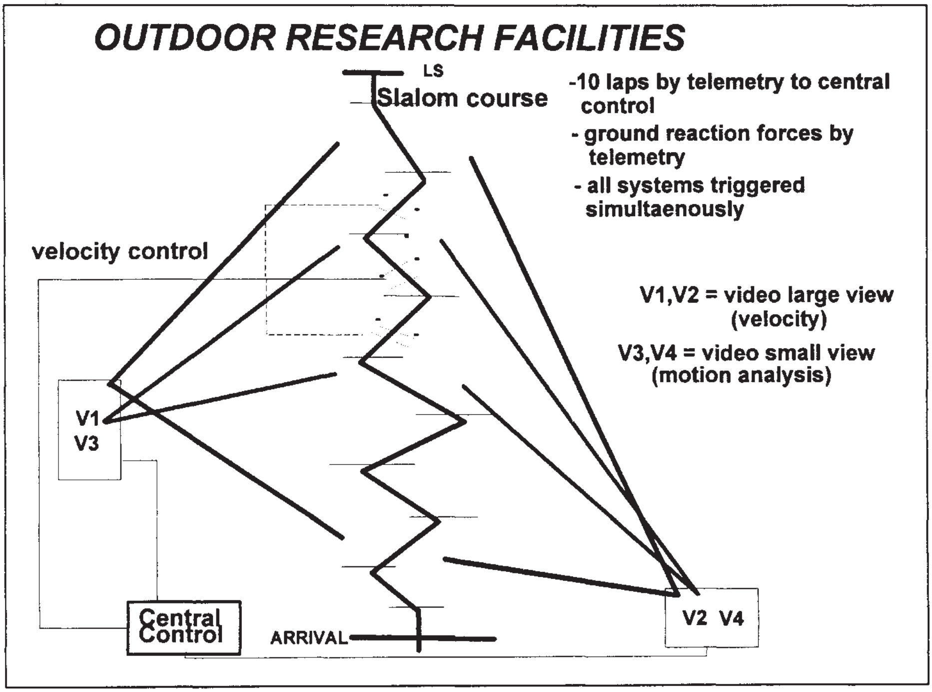

Fig. 3. Outdoor research facilities.

In the laboratory, experiments were performed in the context of equilibrium regulation and biological reactions to vibration load. Here a Hydro-Pulse-Apparatus (Fa. MARKER) was used, where the ground-reaction forces, kinematic data, EMG, and EEG were recorded.

3.2 Results

As the external forces provide information about the internal regulation events, also in the framework of movement regulation, the amplitude and frequency of the ground-reaction forces are of interest. In the Cologne working group, these forces in alpine skiing on the slope have been analysed for 15 years with different force plates and in different experimental situations. The following figure shows an example of an Ft-curve of an elite racer and the results of frequency analyses in the lower part.

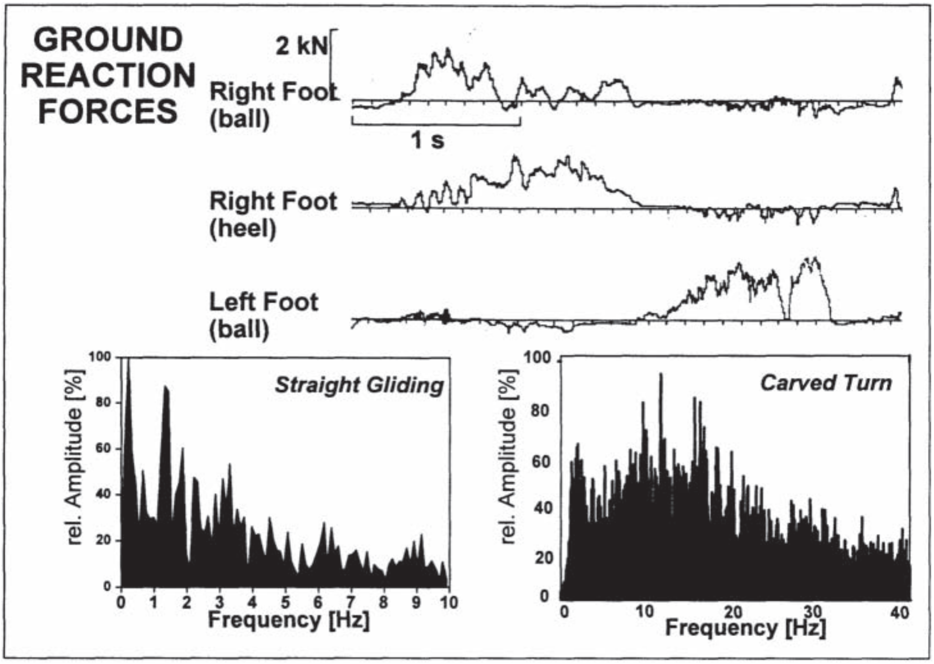

Fig. 4. Ft-curves and frequency analyses of ground-reaction forces.

In the upper part of the figure, the vertical ground-reaction forces at the ball of the foot, at the heel of the inside leg, and at the ball of the foot of the outside leg in the course of a giant slalom turn are shown. First the typical shift of the load from the front part of the foot to the heel in competitive skiing can be seen. This is associated with initiating the turn (load at the ball of the foot) and continuing the turn or acceleration in the given new trajectory (load at the heel) respectively. Attention should be given to the various peaks of the ground-reaction forces in the course of the turn. Basically, these peaks can be caused by rills in the slope as well as by an actual muscular overload with a special form of a stretch-shortening cycle [12].

Obviously the purpose of the carved turn is to reduce the velocity as little as possible. The lowering of the centre of gravity, which can be seen in the course of the turn, and which involves the enlarging of the knee and hip angle by stretching the leg extensors, is not used in order to maximize the ground-reaction forces for maximizing vertical velocity, as it is for example in track and field (high jump). There is much reason to believe that the goal in alpine skiing is to modulate the ground-reaction forces, so that a carved turn can be carried out. Therefore, in a certain sense it is more a "stretch-lengthening cycle" than it is a shortening of the muscle.

Caused by the high velocities in the turns of modern ski races with the modern equipment, the frequencies of ground-reaction forces can reach levels of around 100 Hz. These high frequencies probably are associated with vibrations of the ski itself.

The most important parts of the spectrum of the FFT for movement regulation in alpine skiing probably are located between 1–3 Hz and between 15–20 Hz. The peak around 1–3 Hz is due to the well-known “body sway” of equilibrium regulation [13]. Here most of the body segments are involved and the whole body mass is shifted in the frontal and sagittal plane. This type of movement can be explained by genetically fixed motor programs for maintaining the equilibrium.

The peak around 15–20 Hz obviously may have different reasons. To one part, it may be due to vibrations of the ski itself. These vibrations normally are somewhat higher. So there is reason to associate the peak around 15–20 Hz with biological properties, as is for instance, suggested by results from work physiology [14]. In these frequencies, for example the level of resonance frequency for the extended legs is reached [15]. The closer the frequency of vibrations gets to this area, the more the ability of the neuromuscular system to regulate and thus to compensate and to modulate the ground-reaction forces is overcharged.

The high eccentric contraction status of the involved muscles, esp. the knee extensors, can be compared to short-time ischemia-like situations. Some results show that a local lactate accumulation of up to 30 mmol/kg muscle can be reached. Thus, high local energy demands are to be expected. There are some results which indicate that specific alpine training improves the sources of creatinephosphate [16].

In order to simulate the vibration load occurring in skiing on the slope, in the laboratory a Hydro-Pulse Apparatus was used, which allowed the frequency and amplitude of vertical vibration to be set similar to skiing on the slope. On this apparatus the ground-reaction forces, kinematic parameters, the heart rate, lactic acid, EEG mapping, and EMG were recorded. The following figure shows some results of a beginner and a well-trained ski-racer.

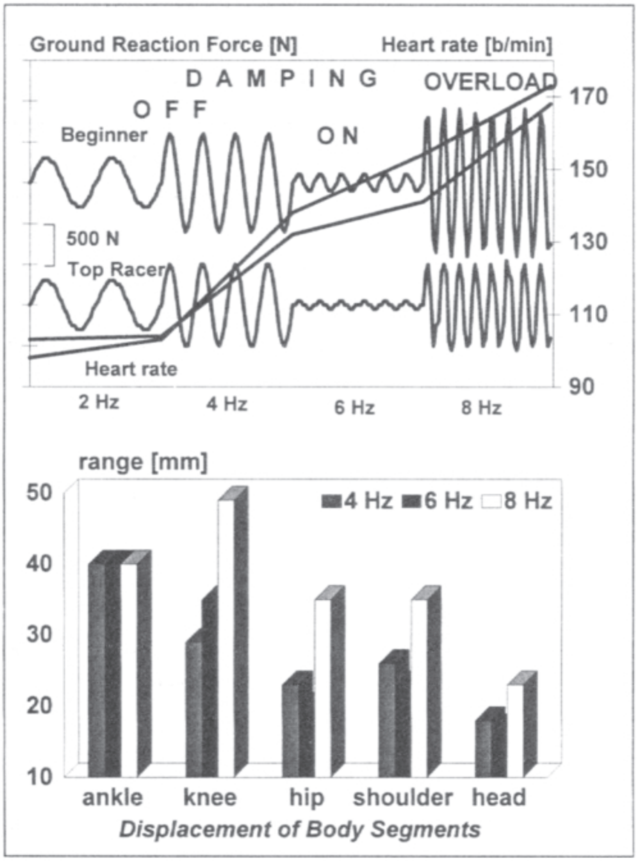

Fig. 5. Simulation on a hydro-pulse apparatus: Ground-reaction forces, heart rate and kinematic results.

In the upper part of the figure, the round reaction forces in various frequencies of vibration can be seen, with an amplitude set at 50 mm. At the lower frequencies (2–4 Hz), obviously there was no need for the subjects to compensate for, or dampen the exerted vibrations.

The subjects swung up and down in synchronization with the signal of the Hydro-Pulse Apparatus. This is indicated by the periodicity of the sinewave oscillation and the amplitude of the ground-reaction forces. When the vibration was set at 6 Hz, it became necessary to start the dampening and the subjects started to carry out compensating eccentric contractions during the upward movement of the hydro-pulser followed by a "passive" concentric action together with the downward swing of the apparatus. Thus, only small ground-reaction forces could be measured.

This changed considerably at 8 Hz, where obviously the vibration reached an overload level. The EMG signal no longer showed the rhythmic synchronization with the exerted vibration but a permanently high intensity of co-contraction of knee extensors and flexors, leading to a higher joint stiffness. The kinematic analyses show that the range of resultant segment shifting also grew remarkably. The neuro-muscular system produced an overall stiffness, which normally can be observed in threatening or dangerous situations, where an adequate muscular response is no longer possible.

The EEG recordings show activation zones in the area of the motor cortex as well as in the so-called ,,integrative area“ at the parietal lobe. This corresponds with the neuro-anatomical findings; this cortical region is responsible for the integration of the afferent information from various sensory systems. The continuous recordings of the EEG during the lower levels of vibration, e.g. 4 Hz, indicated a remarkable shift or variability of the excitation zones, although there was no greater change of position at the hydro-pulser.

These findings support KUO’s [8] concept that the region of cortical neurons as well as of motor units at the spine level for a given motor task is not clearly defined. The biological system provides a potential for a flexible motor control. This process of regulation can be called one of the most important features of the motor system. On the one hand, it makes sure that a given motor task can be fulfilled even if there are different starting conditions or varying conditions during the movement itself. On the other hand, this flexible potential for motor control contributes to general variability of movement regulation.

3.2 Variability of Performance in Alpine Skiing

In alpine racing very often time differences of only a few hundredths of a second decide the placement of the first five or more racers. Very little is known about the reasons for these differences as the total run time or even the laps do not yield information about the time that is used for each turn. Even the total running time for top racers over a slalom shows a remarkable variability. The following figure contains the data of three ski-racers, who carried out four runs: two male elite racers and a juvenile female racer.

The figure (upper part) indicates that even the total running time covers a great intraindividual variability. Racer “A” shows a range of 0.8 s, racer “B” of 0.4 s, and racer “C” of 0,9 s. When looking for the reasons for this variability, the mean duration of the turn comes into consideration (lower part). This is defined as the time between changes of the edges in the course of two turns, which can be identified when the ground-reaction force passes “zero” between load on the inside and the outside edge. This period from rising above "zero" and then going down to "zero" is called "time of turn" as it indicates the phase of the turn. Even in leisure-time skiing, when a racing-like carved turn seldom appears, this phase can easily be identified. In figure 6 it can be demonstrated that this "time of turn" reveals a similar variability as the total time of run.

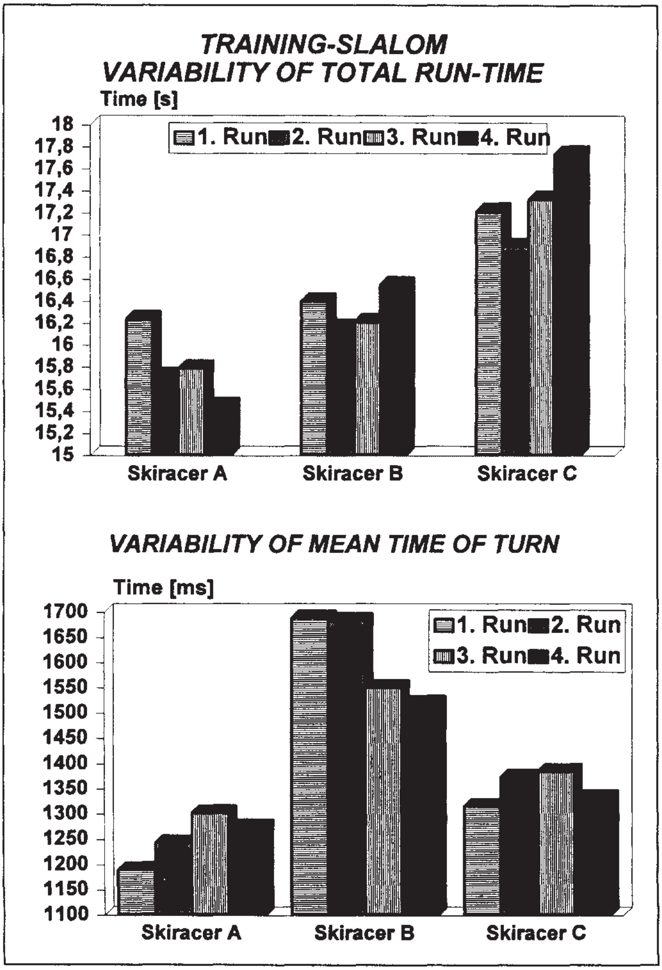

Fig. 6. Variability of total runtime and mean duration of single turns.

These results, of course, only offer very general reasons for the rather great variability of run time. As it is not very easy to measure the distance the skier covers, it is as difficult to measure the velocity. With the kinematic devices shown in Fig. 3, the velocity can be analysed. The velocity profiles of the various skiers in the slalom were so different that group statistics, e.g. in the sense of mean velocities, did not make very much sense. In order to offer an impression of the change of velocity in the course of a slalom run, the following figure shows the velocity of two runs of the same elite racer.

In the analyses of the ground-reaction forces, the expected relation to skiing velocity could be proved. Thus there was an inverse relation of velocity and ground-reaction forces at the various gates of the run. The main part of the ground-reaction forces is, of course, due to friction between the skis and the snow. As the friction reduces the velocity, the latter is low at those phases of the run with high reaction forces.

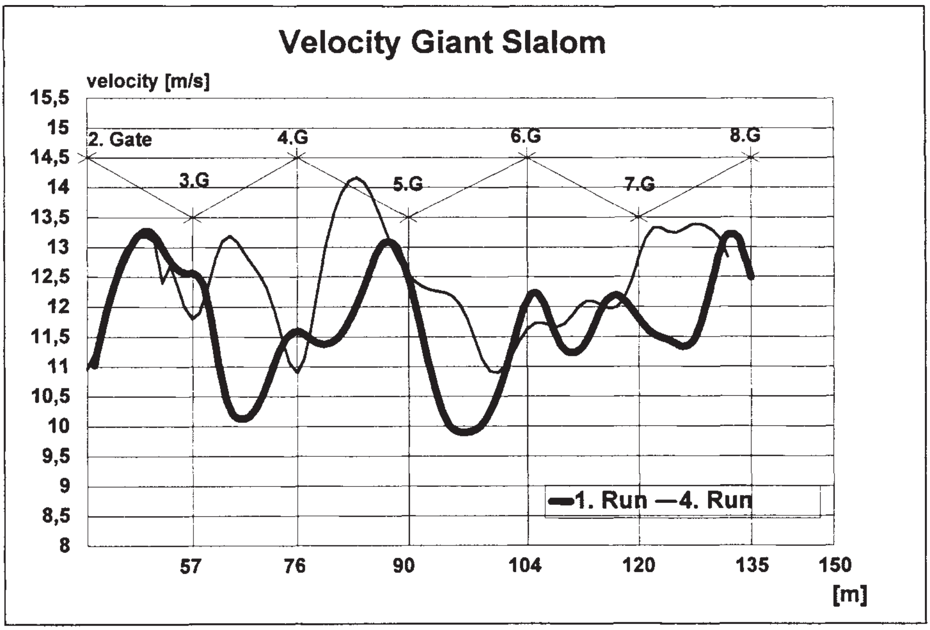

Fig. 7. Intraindividal variability of velocity in slalom (subject: top-class racer).

In Fig. 7 the velocity of two runs of the same racer is shown. At the beginning of the run the velocities are rather similar. The first greater difference occurs between the third and the fourth gate. In the first run there is a remarkable loss of velocity, whereas in the fourth run an acceleration between these gates can be seen. These differences of velocity in the two runs also occur e.g. between the fourth and fifth gate, whereas directly at the turns the velocity is quite similar, suggesting that there is a “critical” velocity for each turn. This variability can be explained by the great complexity of the situation of alpine slalom and the nature of movement regulation itself. So it is hardly possible to reproduce totally

- the edge angle,
- the force distribution between right and left foot,
- the pressure distribution between toe ball and heel,
- the turning forces with corresponding friction, and
- the trajectory during the various turns.

5 Summary

The most important objective in alpine technique is the regulation of dynamic equilibrium. All other parameters are subordinated to this objective. This, for example, refers to the control of the alpine ski, which mainly is provided by frontal and lateral shift of body mass. The shifts of body segments cannot be regarded as changes of postures but as regulation events with various frequencies and amplitudes according to the dependent mass. By means of spectral analyses differences between skiers on upper and lower performance levels can be identified.

The central representation of all these peripheral motor processes must be regarded as holistic, but simultaneously discrete sensory information, for example, from the pressoreceptors at the bottom of the foot, can be very important. Therefore, a complex pattern of movement regulation is necessary, which cannot be explained by simple input-output feedback models. Current approaches, therefore, use “meta-network models” which include networks of networks. This refers to the cortical level, as could be shown by EEG mapping results, as well as to the spinal level and explains for instance the basic variability of motor performance. Thus all kinetic and kinematic variables and even measurements of run time in a slalom show a considerable inter- and intraindividual variability.

For these empirical investigations of movement regulation on the slope as well as on a Hydro-Pulse Apparatus in the laboratory, force platforms are used, which have been developed at German Sport University. Data transmission with PCM devices is provided, data analysis is carried out on-line. Traditional video equipment with SD-analysis is used for kinematic purposes. For the description of segment shifts with higher frequencies High-Speed Video is integrated.

The muscular activity corresponding to the ground-reaction forces can be understood as a special phenomenon of the stretch-shortening cycle, which is however absolutely different from normal running and jumping events. Here the stretch-shortening cycle in most cases has the objective of producing a maximum take-off velocity, whereas in alpine skiing it is directed at a modulation of external forces in order to keep a carved turn or dynamic equilibrium. For this purpose a stiffness of muscles and joints themselves is necessary, which is oriented towards the various segments of the body with different mass and competency for coordination.

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30
THE TECHNIQUE OF GLIDING IN ALPINE SKI RACING—SAFETY AND PERFORMANCE

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Keywords: alpine skiing, equipment, feedback, gliding technique, performance diagnostic, side-camber.

1 Introduction

In the course of the last few years, development in both equipment and technique of Alpine ski racing has advanced considerably. Along with this development, the maximum speed of down-hill races have clearly increased.

Meanwhile, maximum speeds in glide passages of downhill races of 110–120 km/h in women's contests and 130–140 km/h in men's are not unusual. Even in turns it is nowadays possible to ski with higher speeds than only a few years ago due to the increased side camber of the modern ski design.

Because of these developments, the risk of falling for the skiers has grown considerably. The increase in dangerous situations not preceded by an obvious skiing mistake is remarkable. In the first place these are situations that may occur by "catching an edge".

Naturally, the intention of training in ski racing is to increase the performance of the athletes, i.e. to enable them to achieve higher speeds. Apart from the optimization of performance, a maximisation of safety must be guaranteed (at the same time). Thus, for example, the racers must be enabled to avoid the dangerous situations caused by "catching an edge". To achieve this it is above all necessary to improve the sensation of the peripherial fine motor regulation. Only if the racer is in a position to avoid or to recognize events of incorrect regulation early, will he/she be able to reduce the number of precarious situations and falls.

2 Equipment and kinematic aspects

2.1 Equipment aspects

The development of equipment in the last few years becomes obvious when one focuses on the geometry of the ski is focussed. As an example, Table 1 shows this development by a single model from 1990 to 1996.

Table 1. Changes of one downhill ski model from 1990 to 1996.

	downhill ski 1990	downhill ski 1996
shoulder width	8,7 cm	8,9 cm
heel width	7,5 cm	7,9 cm
waist width	6,7 cm	6,5 cm
side camber	0,70 cm	0,95 cm

By increasing the heel and shoulder width and narrowing the waist width, the side camber has increased. This side camber (sc) plus the length of the ski is one of the most important geometric parameters of the ski as it is mainly responsible for the radius of a carved turn. It is calculated out of the widths of shoulder (S), waist (W) and heel (H) by the formula [3]:

$$sc = \frac{S + H - 2W}{4}$$

sc=side camber, S=shoulder width, H=heel width, W=waist width

To create a geometry like this, new materials, constructions, and fabrication procedures have been necessary to stabilize the ski. The aim of this development has been to ski carved turns with even smaller radii. This makes it possible to turn with higher velocity.

2.2 Kinematic aspects

In estimating an ideal slope (total flat and solid), the theoretical turn radius of the ski can be calculated by the formula [3]:

$$r = \frac{L^2 \times \cos\Theta}{8sc}$$

r=turn radius, L=ski length, =edge angle, sc=side camber

With the same length (L) and the same edge angle (T), the radii differ from 330m for the model 1990 to 243m for the model 1996.

Estimating further, in a gliding passage where one ski is edged with a minimal angle of 1° on the outside edge and the other ski is placed flat on the slope, the running velocity should be 33,3 m/s and the observed running time 120 ms (i.e. a distance of 4m). The differences of the older and the newer ski model in some various deviation parameters can be calculated:

Table 2. Deviation of an edged (1°) ski at an velocity of 120 km/h over 4m distance.

	downhill ski 1990	downhill ski 1996
lateral deviation	0,02 m	0,03 m
velocity of deviation	0,20 m/s	0,27 m/s
angle of deviation	0,35°	0,47°
angular velocity of deviation	2,89 °/s	3,92 °/s

It can be seen that the differences even at this very small edge angle of 1 ° are remarkable. Considering a greater edge angle or/and a higher velocity or/ and a longer distance, the deviation itself and the differences between old and new model become greater. This deviation causes in every way a disturbance of the maintenance of balance that will furthermore lead to an unsafe position and to a dramatic increase in the risk of falling. Falling in gliding passages, where the speed is normally very high, often causes severe injuries. There is a need to avoid such falls by catching an edge through improving the sensation of movement regulation. Therefore, a special feedback method is necessary to make even small changes in position obvious, because the coach is not able to see these slight movements.

3 Method of performance diagnostics

In order to analyze the movement regulation in gliding, a special plate is used, mounted between binding and ski to measure the ground reaction forces in z-direction. With this system, the athletes run a gliding slope over 20–30 s, reaching top speed at about 120 km/h. The data are transmitted via telemetry to the measuring station where they are evaluated immediately. By determinating the center of force, the position of the racer is shown in sagittal and frontal plane in the form of cross wires. Moreover, the percentage of the weight distribution between the left and the right ski is given (s. Fig. 1.).

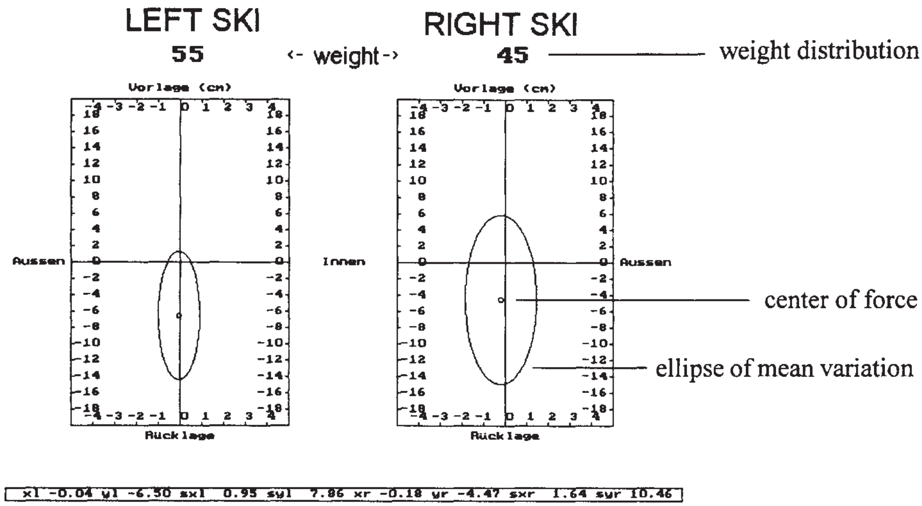

Fig. 1. Example of the evaluation of gliding-performance diagnostics.

As the evaluation is done immediately after the run, the racer (or the trainer) receives immediate feedback. This is a great advantage of the system, because the racer is able to compare his/her recent perception with the evaluation offered by the system.

4 Neurophysiological aspects

For movement regulation in gliding passages of Alpine skiing there are three main receptor types responsible: the mechanoreceptors of the skin, and the joint and muscle receptors.

The most important mechanoreceptors are the ones located in the sole of the foot and the lower leg. By measuring pressure, they deliver information about the weightening inside the ski boot and the pressure that is exerted on the boot shaft. In Alpine skiing, the ankle joint is of great importance, because even small displacements in this joint cause remarkable changes of the posture and lead to an increasing movement regulation. Therefore, among the receptors, this joint is very significant. Indicating the gliding position, the ankle joint is mainly responsible for regulation in sagittal direction.

The muscle receptors can be divided in to the two most important parts: muscle spindle and golgi tendon organ. The muscle spindle measures changes in length and has an important function in regulating the muscle tone. The golgi tendon organs inform the nervous system of the tension exerted by the muscle. Length and tension feedback function in concert in regulating muscle stiffness [4]. This muscle stiffness is a supposition for being able to react adequately to changing situations.

This information has to be processed by the motor control system (see Fig. 2) [5]. Because of the high velocity, movement adaptation has to be rather quick on the one hand, but there is a need for acting very precisely on the other hand. It is to be supposed, that reflex motor performance is mainly used in this case, whereas the central nervous system influences reflex motor performance, as well as voluntary movement [1,2,6]. Furthermore, the central nervous system can also directly control the sensitivity of the receptors.

It can thus be stressed that it is possible to have positive influence on these processes in the central nervous system by external feedback.

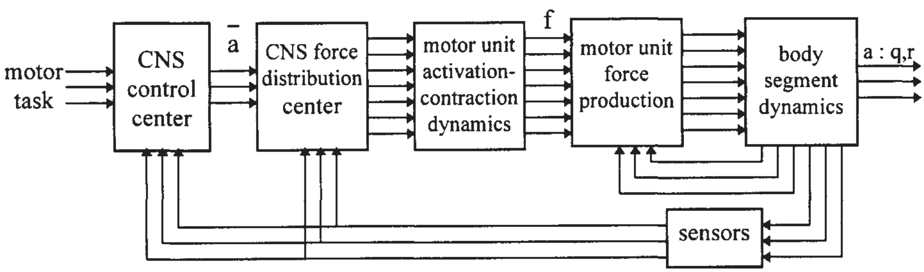

Fig. 2. Model for the motor control system (mod. Kuo) [5].

5 Results

Fig. 3 shows exemplarily the results of one racer during gliding optimization during the third and eighth run.

Results of the third run are as follows:

- The center of force is farely far to the back and on both sides on the inside edge of the two skis. That means that, on the one hand, the weight of the skier was not equally distributed on the whole ski which may be harmful for theliding conditions of the equipment, and, on the other, hand he might be in danger of "catching an edge".
- The ellipse of mean variation is rather large (esp. lateral). That means that the

racer was not able to keep a flat position of the ski; therefore variability occurred.

The instructions of the coach might have been:

- Try to move the weight more to the middle of the ski to achieve a better weight-distribution on the whole ski!
- Try to place the ski more flat on the ground (e.g. by keeping the skis closer together) to reduce lateral movement!

The evaluation of the eighth run shows a much better result:

- The center of force is more to the middle and there is a nearly optimal flat placing of the skis.
- The ellipse of mean variation in lateral the direction is also reduced remarkably.

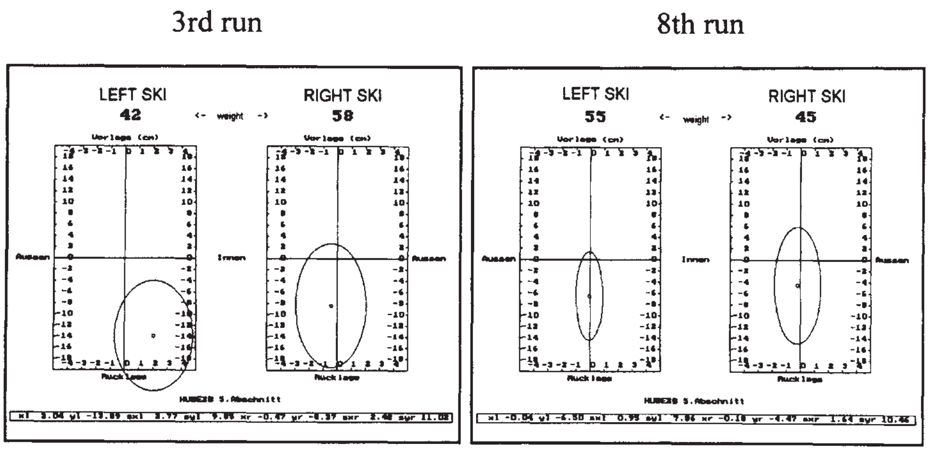

Fig. 3. Results of one racer during gliding diagnostics.

6 Summary

With the development of equipment (e.g. greater side camber of the ski) and the greater velocity in ski-races, placing the ski flat in gliding has become more and more important. Kinematic calculations show that the greater side camber of the newer ski models leads to a shorter turn radius. Due to this, the lateral deviation of an edged ski might cause a dramatic disturbance of the maintenance of balance. The flat placing of the ski is achieved by a rather complex coordination of the whole motor control system. For this precise movement regulation of the various body segments, a special feedback method is necessary, even for world-class athletes, because the perception of the athletes and the observation of the coach need support from external feedback. This external feedback can remarkably improve the sensation for movement regulation on every level of performance. Through improvment of sensation, the racer is, on the one hand, able to achieve a better, flatter placment of the ski in gliding passages, and, on the other, this improved sensation might also be faithful to precise movement regulation in turns by adapting the edge angle to the various demands. Thus, the optimization of gliding technique improves performance and safety.

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31
A PROFILE OF SENSORIMOTOR BALANCE OF ALPINE SKIERS

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Keywords: alpine skiing, balance profile, dynamic balance, lateral allocation stability, static balance.

1 Introduction

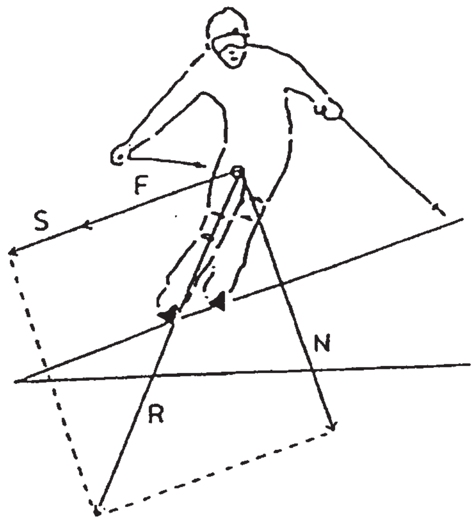
The question of the importance and the consequences for the methods of measurement and training effects of sensorimotor balance in alpine skiing has been raised by many practicians and theoreticians. Some of them are Mülly [1], Großmann [2], Albl [3], Komexl [4], Schaller [5], Schönbächler [6], and Fetz [7, 8, 9]. Various papers treating this topic were written at the Department of Sport Science at the University of Innsbruck (see Fetz [8]). Those sensors which are important for balance performances (muscle spindels, tendon organs, joint sensors, skin sensors, optical, acoustic, and vestibule sensors) and the corresponding programmes are explained in sport-specific way by Scharfenberg [10].

2 Static and dynamic balance in alpine skiing

The sensorimotor-balance demands on alpine skiers are characterized by their active efforts (internal forces) to have the direction of the resulting force of all external forces which influence the system skier-ski (especially gravity, centrifugal force, air-resistance force and resistive force of the snow) run through their plane of support. Valid balance tests for alpine skiers have to contain decisive demands on the equilibrium occuring in alpine skiing.

The illustration of dynamic equilibrium of an alpine skier (see Fig. 1) only contains gravity and centrifugal force in order to simplify the external forces. The resultant runs through the plane of support.

Regarding this system, there are two demands: first, the demand on the skier's quasi-static balance behaviour; and second, the demand on the skier's constant-distribution equilibrium, the latter being closely connected to the dynamic balance behaviour of the system skier-ski undergoing an acceleration on a slope.



F ... centrifugal force
S ... side component of downhill gravity
N ... normal component of gravity
R ... resultant

Fig. 1. Simplified, schematic representation of dynamic equilibrium.

The constant-distribution equilibrium component is most effective whenever the (racing) skier moves on a straight track at constant speed. The weight distribution onto the two skis plays an important role for such gliding movements. It can be shown by suitable tests (e.g. Stability Platform) in addition to the demand on dynamic equilibrium.

According to preliminary tests and former experiences there are ten demands which seem to be useful for a ski-specific test which measures dynamic equilibrium. First, the skier has to be in motion during the test. Static balance tests have proved to be rather useless for alpine skiing (Kornexl [4]). The only exception is the Stability Platform Test, which measures—among other factors—the weight distribution onto the two feet. Second, the test has to include acceleration and deceleration in the direction of motion. The testing device should be easily movable in different directions on an appropriate surface. Third, the test should include acceleration normal to the direction of motion (left or right deviations). The skier's sensorimotor equilibrium is jeopardized more by these accelerations than by the ones forward or backward. Fourth, there should be rotatory changes of direction (around the longitudinal axis) included in the test. Fifth, the subject should have a ski-specific decline (10–30°). Sixth, during the test there should be a simulation of the ski-specific hills and bumps on the slope. Seventh, the test itself should be a rapidity exercise and, therefore, should be practicable in as short a time as possible. Eighth, the duration of a single test should be approximately the same as the one of a short slalom run. Ninth, the changes in direction of the whole system should be influenced by a shifting of weight similar to skiing. As a tenth point, the restriction of freedom of action by using ski boots seems to be important.

3 Task

The task is to prove different forms of sensorimotor equilibrium in alpine skiing by recording them with authentic tests. In order to prove the usefulness of a test for the sensorimotor balance profile in alpine skiing, one has to prove either a corresponding correlation between test results and ski-specific qualifications or significant differences between extreme groups.

4 Methodology

In order to prove different forms of sensorimotor equilibrium in alpine skiing, authentic tests for dynamic and static equilibrium have to be established. The "Gleitrollbrett" is a device which demands dynamic equilibrium and offers a possibility of accelerating both parallel and normal to the line of vision. A board is fixed onto four steerable castors and offers a great variety of applications. The subject on the board can move forward, backward, sideways or in a circle by using his or her hands. Both squatting and sitting positions are possible. In addition, the subject can use poles in a standing position (on one or two feet) to push him- or herself forward. Furthermore, he or she can move forward similar to a scooter. For motion, an assistant can pull the subject with a rope for example, through a slalom. The surface board can also be replaced in such a way that exercises with different declines (e.g. 15% and 30%) are possible. By means of this "Gleitrollbrett" with declined surface one can simulate both schuss and skiing across the slope. Another way to create a declined surface is to use wheels of different sizes. This, however, makes simulations of straight movements across the slope more difficult.

The "Gleitrollbrett" with vertical shaking simulates hills and bumps by using either eccentric wheels (eccentric axis) or wheels diverging from a circle form. It makes perfect sense to use only one single rear wheel with such a divergence. Thus, the board is placed on two small front wheels and on one big rear wheel. The flattening of the rear wheel looks like an arc and expands over a sector of 120° containing a maximum flattening of 1.6 cm. The surface board is declined by 20%.

For a correct execution of the test, the driving force for the motion of the "Gleitrollbrett" has to be established. Apart from an inclined plane—which would allow only short distances in a gymnasium—and a motor drive, there are only two possibilities left: first, an external force allocated to the system by a partner; and second, an internal force by pushes with poles. One advantage of the latter possibility is the fact that pole pushes are important motor activities in alpine skiing. First of all the test was carried out as a "two-leg slalom on the 'Gleitrollbrett'". The device was a "Gleitrollbrett" on three wheels. The third (rear) wheel causes a decline of the surface board and—due to its flattening—shaking in vertical direction (hills and bumps). The subject pushes him- or herself forward by means of two poles while standing on the declined surface board (see Fig. 2). The length of the poles can be adapted to the subject's demands. The quests for shifting both forward—backward and left—right and for turns around the longitudinal axis are both satisfied in slalom. The slalom consists of six poles (demarcation poles), which are arranged on a straight line with a distance of 3 m in between them. The starting and finishing line is arranged 3 m from the first slalom pole. The slalom has to be completed back and forth. The subject covers a distance of more than 36 m altogether. Because of the 180° turn the required space for the slalom should exceed 21 m.

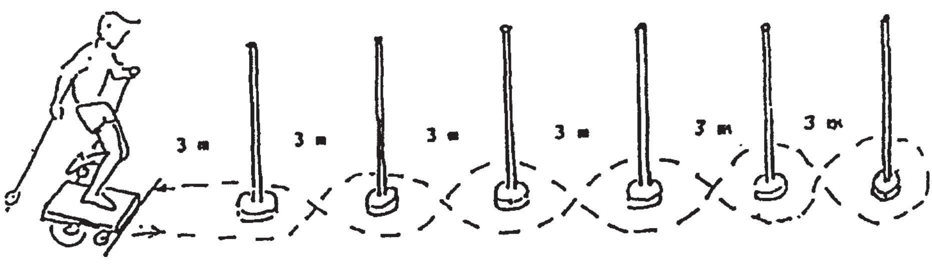


Fig. 5. Subject on the "Gleitrollbrett" doing the one-leg slalom.

4.1 One-leg slalom on the "Gleitrollbrett"

After a few preliminary tests, the one-leg slalom on the "Gleitrollbrett" has proved to have better selectivity and to be more significant. The "one-leg slalom" makes considerably greater demands. Differences which might arise in skiers' performances (left, right) are very interesting for the coach.

The best device for the one-leg slalom has several peculiarities. The bigger rear wheel (12 cm in diameter) is flattened on a sector of 120° to a maximum of 0.8 cm in an arc-like way. Consequently the now moderate vertical shaking can be managed in a one-leg slalom. A rubber layer on the surface of the "Gleitrollbrett" reduces the danger of slipping.

Instructions for the Test "One-leg Slalom on the 'Gleitrollbrett'"

After the supervisor's starting signal the subject pushes him- or herself back and forth through the slalom by using two poles (see Fig. 2). The time between the starting signal and crossing the finishing line with the front wheels is counted as a result. After a practising time of one minute the subject is offered two valid runs. The better one is taken as a result. In case a slalom pole is knocked over, the subject has to put it up again. If one leg touches the ground, the subject is penalized with two seconds every time this happens. In order to achieve exact measurements, one has to standardize not only the test devices ("Gleitrollbrett", poles) but also the characteristics of the ground (grip, softness, elasticity, and so on) and the slalom poles (demarcation poles).

The ninth demand (changes of direction should be influenced considerably by shifting of weight) can neither be fulfilled by the two-leg slalom nor by the "one-leg slalom on the 'Gleitrollbrett'". The changes of direction in these tests are caused by one-sided efforts of the pole pushes. The use of ski boots without a firm connection to the "Gleitrollbrett" has not proved to be useful with this test.

Reliability of the Test "One-leg slalom on the 'Gleitrollbrett'"

This criterion of the test "one-leg slalom on the 'Gleitrollbrett'" was ascertained with 20-year-old sport students (n=13) by means of the retest method. The reliability coefficient (after Spearman) resulted in r_s=0.86. This value is satisfying for both group and individual measurements.

Validity of the Test "One-leg slalom on the 'Gleitrollbrett'"

The validity of the test "one-leg slalom on the 'Gleitrollbrett'" is covered by a high correlation with the test "slalom on the 'Gleitrollbrett' with swinging axis". The importance of the test for alpine skiing was established operationally, as more than coincidental differences of the test results between a very highly qualified and a highly qualified group of athletes. During the "one-leg slalom on the 'Gleitrollbrett'", the Austrian national squad members achieved better test results than students from a high school for skiers at a highly significant level (see Fig. 5). The selectivity index of the one-leg slalom on the "Rollbrett" (SI'=7.6) is acceptable for the tested subjects.

4.2 Slalom on the "Gleitrollbrett" with swinging axis

The "slalom on the 'Gleitrollbrett' with swinging axis" (Drifti) runs like the "two-leg slalom on the 'Gleitrollbrett'". The only difference is the use of a "Gleitrollbrett" with swinging axis instead of the "Gleitrollbrett" (60×40 cm). The "Gleitrollbrett" Drifti is a rolling board, similar to a skateboard. It has a manoeuvrable swinging axis and thus can be steered out of the forward direction by a shifting of weight (see Fig. 3). The "Gleitrollbrett" Drifti has the advantage of being available on the market (the name Drifti corresponds to the catalogue of the company that produces it).

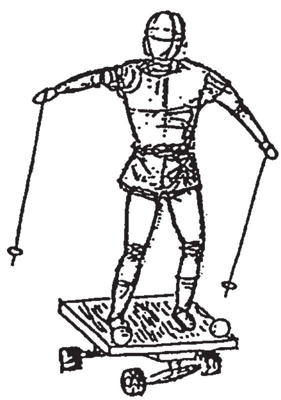


Fig. 3. "Gleitrollbrett" Drift with manoeuvrable swinging axis and a surface declined by 20%.

In order to adapt the device to the characteristics of skiing, the surface was declined by 20% by putting a woodden block of 11-cm thickness under the rear axis. The other test conditions of the "slalom on the 'Gleitrollbrett'" (distance between the slalom poles, pole pushes) remain unchanged. There is also a one-minute practising time before the first test. The rotating ability of the front axis for changes of direction (left/right) can be adjusted on the bottom side of the Drifti. In case of a change, it has to be adjusted again. The use of ski boots for the slalom on the Drifti leads to unreasonable danger due to edging.

Reliability of the Test "Slalom on the 'Gleitrollbrett' with Swinging Axis"

The reliability of the test "slalom on the 'Gleitrollbrett' with swinging axis" (Drifti) was examined with 3rd and 4th forms from a junior high school and from a junior high school for sport (n=50) using the retest method. The value of r_s=0.81 can be considered useful for group measurements. The selectivity index SI' was 4, which can be considered very good. The reliability coefficient of this test for sport students (n=20) resulted in r_s=0.86. This value can be accepted for individual measurements.

Validity of the Test "Slalom on the 'Gleitrollbrett' with Swinging Axis"

The validity of this test is based on its high concordance with other dynamic-motor equilibrium tests. In addition, it is based on the assessment by coaches, teachers and instructors, who say that the test procedure is characterized by equilibrium. Students from high schools for skiers outdo sport students at the test "slalom on the 'Gleitrollbrett' with swinging axis" at a highly significant level. The results of the Austrian national squad (downhill racers) are better than those of students from high schools for skiers at a significant level (see Fig. 9).

4.3 Stability Platform test

The Stability Platform is a device which measures equilibrium in various demands. Within a basic frame there is a platform of 64×106×2 cm. The platform distance from the axis of rotation is adjustable. The axis of rotation is 29 (25/21/17) cm above the platform. On the platform there are two thin rubber mats. This guarantees a firm standing position without slipping. The test device is connected to a computer (see Fig. 4) which measures the number of movements of the basic platform beyond a certain angle of inclination (adjustable from 0° to 15°) and the time which the platform moves beyond this angle. All data are saved and assigned automatically.

Test instructions: the subject is asked to stand on the Stability Platform with the task of keeping the basic platform as horizontal as possible (see Fig. 4). The feet have to be placed onto the grey rubber markings in a side straddle position. In order to build up a balanced position the subject grabs the bar, which is fixed onto the device, with both hands. As soon as the subject finds him- or herself in a fairly calm and balanced position, he or she lets go off the bar and tells the supervisor that he or she is ready to begin the test. The supervisor indicates the actual beginning of the test by the signal "Go!". The subject is then supposed to keep his or her balanced position as exactly as possible over a time of 30 seconds. The movements of the basic platform from the horizontal position beyond the tolerance limit to the left and to the right side are calculated by the computer in terms of their duration.

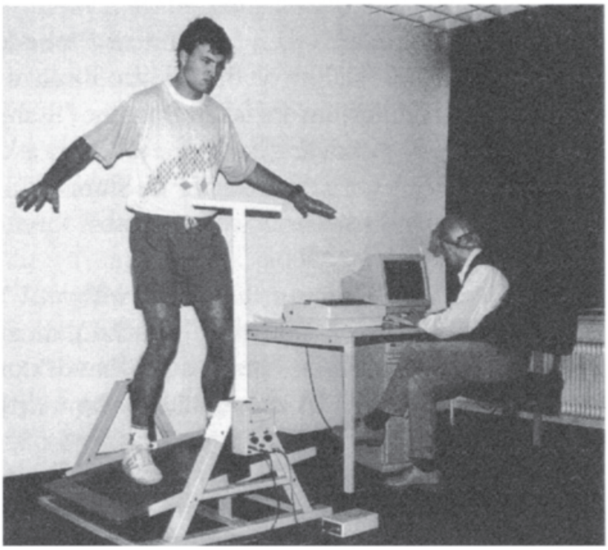


Fig. 4. Subject in a side straddle position on the Stability Platform plus computer

The mean of the two better performances of three tests is counted as a result. The difference to 30 seconds finds the subject in a deviation either to the left or to the right (left and right is related to the subject). A preliminary test is necessary before the first test. The desired test protocol is printed by the computer. The protocol shows the duration of positions within, left of, and right of the tolerance limits, which are 7.5°, 5°, 2.5°, and 1.5°.

Authenticity:

•Reliability age: 25 sex: m/f number: 24 coefficient: r=0.88
•Objectivity guaranteed by the elctronic measuring method
•Selectivity very good SI'=p=3.9%

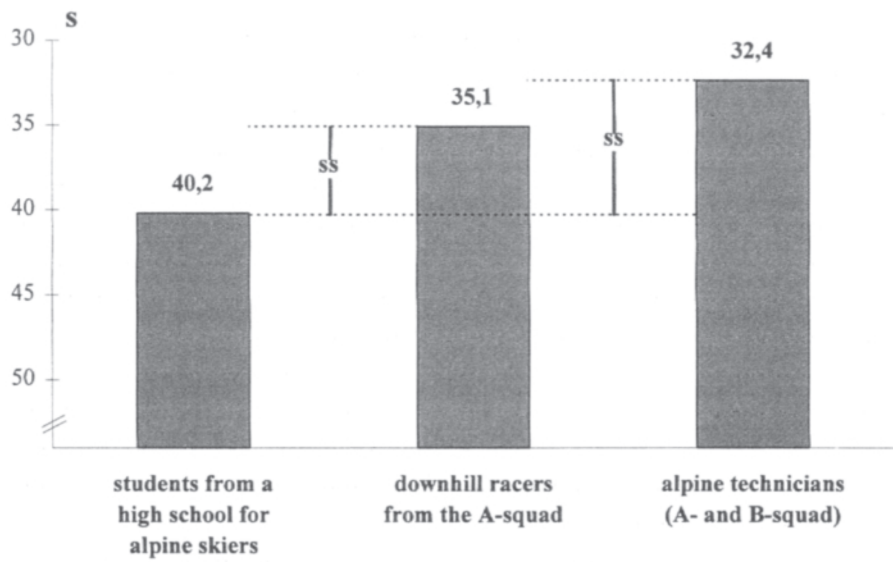
In order to make the Stability Platform Test more difficult and in order to achieve a considerably higher selectivity, one can reduce the tolerance area for the subject's equilibrium for example from 7.5° to 5°, 2.5° or 1.5°. The device can be adjusted to any angle between 0° and 15°.

5 Results

Results for dynamic equilibrium are taken from the test “one-leg slalom on the ‘Gleitrollbrett’” and from the “slalom on the ‘Gleitrollbrett’ with swinging axis”. Results for the static equilibrium are taken from the “Stability Platform Test”. Male students from a grammar school for skiers, male and female students from the high school for alpine skiers in Stams, skiers from the Austrian national squad, and sport students were available for measurements.

5.1 Results at the “One-leg Slalom on the ‘Gleitrollbrett’”

Comparing the groups “male students from the high school for alpine skiers”, “alpine technicians from the Austrian A- and B-squad” and “downhill racers (A-squad)”, the means of 40.2 s, 35.1 s and 32.4 s show differences at a highly significant level (see Fig. 5).



n	34	14	11
$\bar{x}$	40,2 s	35,1 s	32,4 s
s_x	6,1	4,4	3,8

Fig. 5. Means at the “one-leg slalom on the ‘Gleitrollbrett’” of students from the high school for alpine skiers, alpine technicians (A- and B-squad), and downhill racers (A-squad).

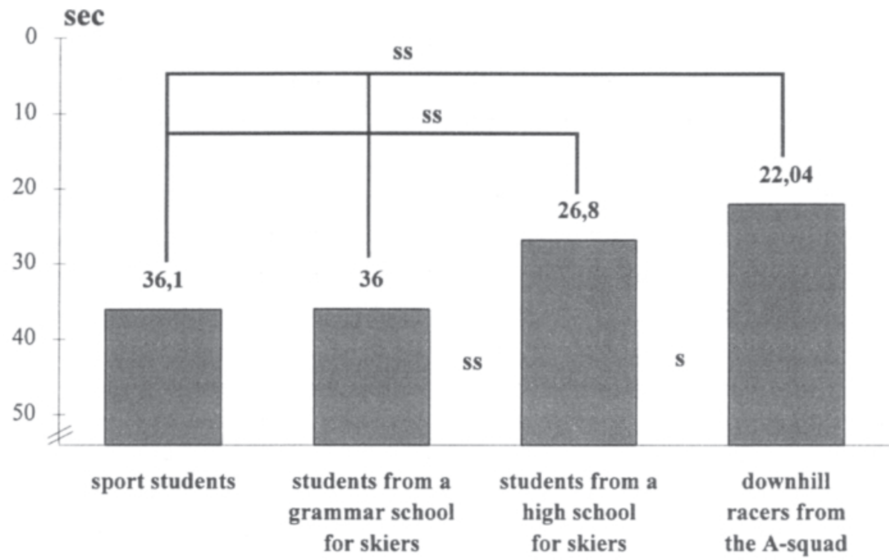
Comparing the performances of the first two groups at skiing and at the "one-leg slalom on the 'Gleitrollbrett'", their rank correlation leads to a coefficient of 0.43. On the whole, the test "one-leg slalom on the 'Gleitrollbrett'" can be recommended as a useful test procedure for dynamic equilibrium in alpine skiing.

5.2 Results at the "Slalom on the 'Gleitrollbrett' with swinging axis"

The "slalom on the 'Gleitrollbrett' with swinging axis" (Drifti) was carried out with students from a grammar school for skiers, students from a high school for skiers (junior- and C-squad), sport students and students from the Austrian A-squad (downhill racers). The students from the grammar school for skiers (3rd and 4th form) achieved a mean of $\bar{x}$=36.0 s, which equals the sport students' level ($\bar{x}$=36.1 s). The students from the high school for skiers achieved a mean of $\bar{x}$=26.8 s, which exceeds the sport students' ($\bar{x}$=36.1 s) and the grammar school for skiers students 'achievement at a highly significant level (see Fig. 6). The best results were achieved by the skiers of the Austrian national A-squad (downhill racers), who came up with a mean of $\bar{x}$= 22.0 s. With that result, their performance was better than that of the students from the high school for skiers.

Analysing the correlation between the results which were achieved by the Austrian national A-squad downhill racers at the "equilibrium test on the 'Gleitrollbrett' with swinging axis" (Drifti) and their FIS points, one comes up with a correlation coefficient of r=0.85. Thus, the slalom on the Drifti can be recommended as a high-quality test for dynamic equilibrium in alpine skiing. It can be used for regulating training, controlling fitness, establishing a squad and selecting a team.

The way the subjects have to change their direction at the ski-specific "test on the 'Gleitrollbrett' with swinging axis" (slalom on the Drifti) offers a big advantage. While at the "slalom on the 'Gleitrollbrett'" (one-leg and two-leg) the subjects change their direction by one-sided pole pushes, the rotation of the swinging axis and thus the change of direction at the slalom on the Drifti is caused by shifting of weight.



n	13	16	9	6
$\bar{x}$	36,1	36,0	26,8	22,04
s_x	8,0	12,2	3,9	5,3

Fig. 6. Comparison of performances on the Drifti (sport students, students from a grammar school for skiers, students from a high school for skiers, and Austrian national A-squad).

Although the motion does not correspond to the swinging in alpine skiing-shifting of weight onto the left (right) leg causes a left (right) turn (see Fig. 3)-there is greater technical similarity to alpine skiing. Vertical shaking (simulation of hills and bumps) could not be taken over due to the great delicateness of the adapted “Gleitrollbrett” Drifti. A profile of sensorimotor balance of alpine skiers has to contain the translatory equilibrium on a body-bound device (ski) and the rotatory equilibrium affected by rotation around the longitudinal, the transversal and the sagittal axis.

These forms of dynamic equilibrium are shown in Fig. 7. The extent of the rotation around the three axis may be low but it can be detected during each swing. Rotatory and translatory demands on equilibrium overlap.

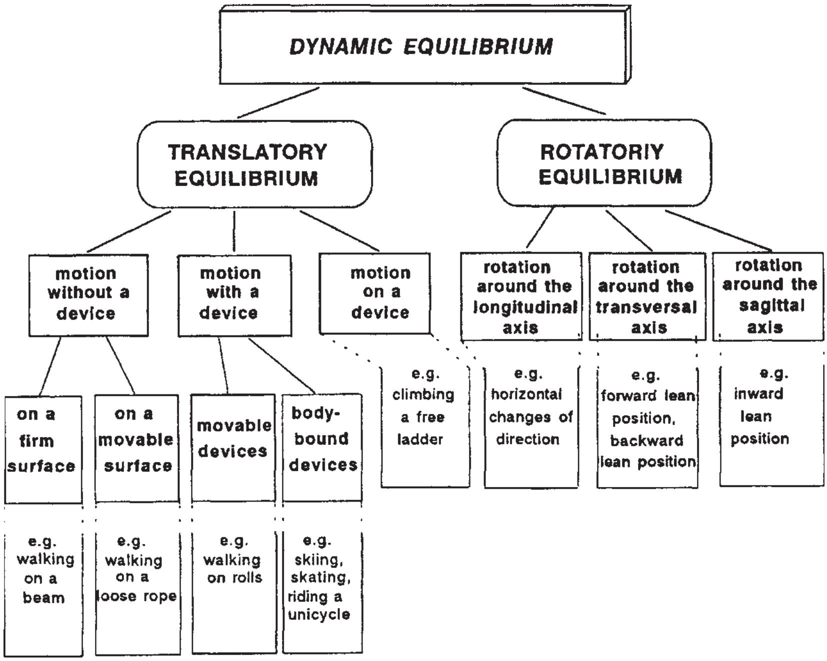
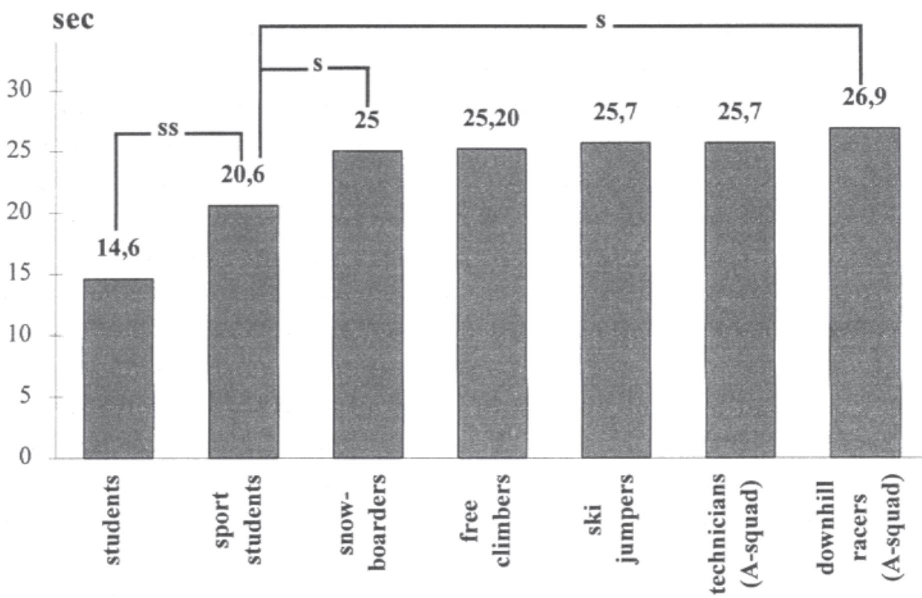


Fig. 14. Schematic sub-division of dynamic motor equilibrium.

5.3 Results at the Stability Platform Test

The group of alpine ski racers consisted of 5 technicians and 7 downhill racers from the Austrian national A-squad. Their average achievements on the Stability Platform at a tolerance limit of 7.5° were 25.7 s and 26.9 s (see Fig. 8). The results achieved by the skiers of the Austrian national squad are better than the ones achieved by sport students at a highly significant level. Regarding the sensorimotor balance ability of experts in snowboarding, climbing, ski jumping, and ski racers of the Austrian Skiing Association, they all show the same level. The performance differences between technicians and downhill racers seem to be coincidental.



n	25	30	11	23	18	5	7
$\bar{x}$	14,6	20,6	25	25,2	25,7	25,7	26,9
s_x	4,6	5,9	4	4,3	3,9	3,4	3,1

Fig. 8. Stability Platform Test at a tolerance limit of 7.5°; male subject groups (1st test).

By analysing correlations and by comparing extreme groups one can clearly point out the high demand of both dynamic and static equilibrium on alpine skiers. These two forms of equilibrium are linked very closely.

Static equilibrium deals with the relation skier-ski. Both keeping the jeopardized balance and distributing the balance usefully are important. In order to ski in an optimal aerodynamic position on gliding sections, the body weight has to be distributed equally on both skis. This special kind of static equilibrium—called "lateral distribution stability" (Fig. 9)—can be measured by the Stability Platform.

"Distribution stability" means—from a physics' point of view—a stable equilibrium, whose primary demands are on equal distribution of weight in a side-straddle position (left leg—right leg: lateral distribution stability) and in a cross-straddle position (front leg—back leg: frontal distribution stability).

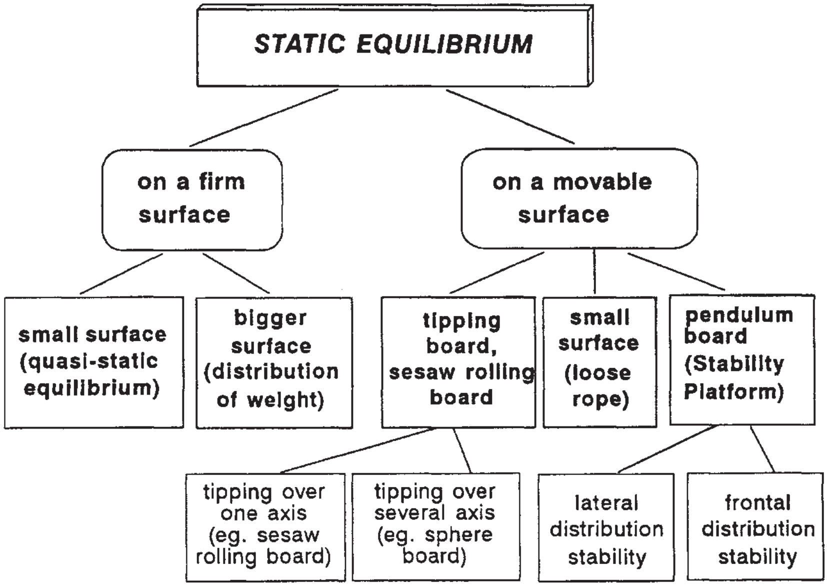


Fig. 9. Schematic representation of static motor equilibrium.

In the area of dynamic equilibrium the test "slalom on the 'Gleitrollbrett' with swinging axis" is most similar to the ski-specific demands on equilibrium (see Fig. 10). The profile of equilibristic demands on alpine ski racers is characterized by acceleration and deceleration into forward and normal to forward direction and by rotations.

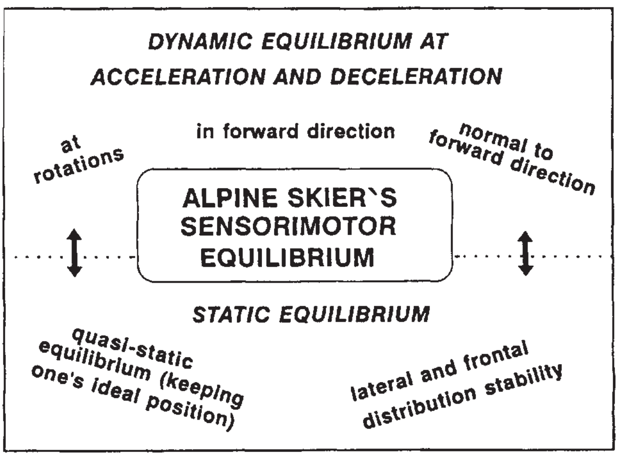


Fig. 10. Schematic representation of demands on equilibrium in alpine skiing.

5 Summary

There have been attempts to find methods for testing ski-specific demands on equilibrium in cooperation with the Austrian Skiing Association over several years, which have lead to the proof of a dynamic equilibrium profile. The "one-leg slalom on the 'Gleitrollbrett'" and the "slalom on the 'Gleitrollbrett' with swinging axis" were developed and tested. The high correlation between the two dimensions test results—FIS-points is expressed by a correlation coefficient of r=0.85 for the second test.

The proof of static equilibrium by means of correlation analysis and by comparing extreme groups caused some surprise. The Stability Platform Test as a test procedure proved very worthwile. The special static balance ability measured by this test refers to the profile component distribution of body weight onto both skis, which is the "lateral and frontal distribution stability". The correlation coefficient (result at the Stability Platform Test—FIS-points) being r=0.54 turns out to be considerably lower than for the dynamic equilibrium. The dynamic components of the sensorimotor equilibrium profile of alpine skiers mainly cover the equilibrium demands on the system skier-ski during accelerations on the slope. They are eclipsed by rotatory equilibrium demands during rotations around the three body axis. The more specialized static components refer to the equilibrium behaviour of the sub-system skier on his or her skis, which mainly makes demands on lateral (on gliding sections) and frontal (motion across the slope) distribution stability at steady speed in a steady body position.

The measured results can also be used for training checks and the setting of training goals.

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PSYCHOLOGICAL TRAINING IN ALPINE SKIING—RACING

Theoretical Considerations and Competitive Alpine Skiers' Opinions on Psychological Training

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Keywords: psychological training, interviews, ski racers, alpine skiing.

1 Introduction

This contribution reviews the opinions of male alpine skiers as to the importance of psychological training. In general psychological training with competitive athletes is aimed at the improvement of their psychological skills to optimize performance [1]. The term "psychological training" seems to be accepted as a technical term. Although not (yet) clearly defined, it is already contested [2]. The current expression [3] offers a conceptual and theoretical framework for the structuring of psychological interventions: psychoregulation and motivation training, psychomotoric (imagery) and training of cognitive strategies. Psychological training should be conducted in five phases: (1) information, (2) diagnosis (1+2 needs assessment), (3) practice, (4) integration in competition, and (5) evaluation of the effects.

This contribution tries to relate theoretical considerations to psychological training in general and to the psychological demands on skiers (deriving from a skiing action model from Amesberger [4]) to the results of a qualitative pilot study on Europe and World Cup skiers. It is therefore possible to describe the relation between (theoretically based) practical psychological interventions and the real experiences of skiers and to make the resulting opinions a subject of discussion.

Starting point:

It seems to be generally accepted that psychological training has become more and more important to competitive sports. Especially the importance of "mental strength" is rated highly by trainers, media and the athletes themselves. In the interviews of the presented survey we also find statements that "60–80% of competitions are decided in the head". It is therefore important to be sure a bout the different targets and motivation which lead to the use of psychological training in sports, that is to say, to the demand for psychological care. The expectations from psychological training are often based on the hope of “icing on the cake” or “catching the last straw” in the physical training. Usually trainers think that their athletes are physically optimally prepared, only the transfer to competition is not yet sufficient. Here the sport psychologist is asked for help. This offer flatters the possibilities of psychological interventions and the psychologist is assigned to an important place in the training process. On the other hand, psychological training remains quite separate from the general training process (the consequences of this point of view will be discussed below).

I will try to show in the following how this problematic attitude to the efficiency of psychological training develops.

2 Method

This article combines, corresponding to the question, theoretical and heuristic drafts with qualitative facts of interviews. Three male head coaches and 36 male alpine skiers (21 World Cup, 8 Europe Cup and 7 junior athletes) were asked according to an interview (ten open questions). The questions in the interviews are similar to the open questions to psychological training of Gabler [5], but enlarged with some specific questions of my own. The interviews were tape recorded and transcribed; the data collection and a first summary of the results were made within the scope of a project by Kaller [6]. The methods of content analysis and context analysis have been used on the basis of this preliminary work. The explicit content analysis which was used is a “context analysis in a narrow sense” [7], which means that only the texts of the interviews were used for interpretation.

The following description is based on a distant point of view—I did not survey the facts myself. To date I had not conducted psychological training with skiers, but worked with top athletes in different kinds of sports. On the other hand, skiing is to me the most familiar of all sports where I have both worked theoretically and practically. From this basis, I want to make clear that this work has been done with a maximum of “field distance”. My motivation to make this contribution is based on two different perspectives: on one hand, an extensive project on skiing is discussed time and again, on the other hand, I see in as a distant perspective a chance for an objective consideration. The danger lies here in the lack of ecological validity.

The interviews contain 308 to 2858 words, on average about 1000 words.

The length of the interviews is connected with the individually different dimension of dealing with the sport-psychological questions and, on the other hand, with the different eloquence and the drive to express oneself on this subject. The interviewer did not control the length of the verbal expressions, she relied primarily on the questionnaire and rarely posed follow-up questions.

3 Results

3.1 Requests of trainers to the psychological training

In the first section I pointed to the basic requirements of head coaches of sport-psychological training. The three coaches who were interviewed in this study were asked for their wishes regarding psychological training:

- Psychological care should be a long-term effort, not an intervention which does not start until problems arise. This demand stands in contrast to the opinion of many athletes who want to start to work with psychological training only when they have to deal with problems.
- Top athletes need very individual care and should search for and pay their psychological training themselves.
- Sport psychologists should offer many possibilities of psychological training and enable (guide) the athletes to an initial contact with mental training.
- Psychological training should contribute to the development of the personality of the athletes.
- Research to evaluate the success of the training should be done.
- There are not enough psychological trainers to meet the demand of the athletes and trainers.
- In some cases mental training courses raise individual problems which are not followed up after the course.

3.2 Techniques of the athletes

The interviews show that psychological training is already familiar to alpine skiers.

Almost all of the athletes asked had experience with sport-psychological treatments. Only one of the athletes who had come recently to the Junior pool said that he had no experience at all with psychological training.

These experiences are very different, both in extent of the training, the applied methods and the effects on the athletes. The most common techniques are:

Relaxation techniques:

About 80 % of those interviewed know progressive muscle relaxation, breathing techniques or autogenic training. It is noticeable that EC- and junior skiers partly did not use these techniques during the competitive season. Only one skier said that he worked intensively with relaxation techniques during the competitive period.

The athletes stated that

- it was not possible for them to use the techniques alone.
- they were not disciplined enough in doing it.
- they didn't have enough time.
- they could not see the efficiency of the methods.

About 30 % of the users described slightly positive effects like being less nervous and being generally in a better mood.

Others admitted that they did not see the purpose of the method.

The WC skiers have concrete images of the use of relaxation techniques. Some consider them totally inefficient: *"Relaxation technique did not help me at all."* Another Skier: *"If I have good equipment and I have a good race, everything is all right for me, I do not need anything else. I don't need psychological care either, you know yourself where the problems are."* Others use relaxation techniques for specific situations in competition.

Only one WC skier says that he considers experimenting with new techniques: *"I'm trying something new right now."* Some say, that they should do something.

Psyching-Up Strategies in precompetitive situations:

All the athletes have strategies for the preparation for the start. Most of them use concentration exercises (e.g. counter-rotating figure-eight circles with the arms and contralateral legs, concentration on one point, "switch off thoughts) and try to visualize the race (learning the race by heart, thinking about difficult passages, imagining technical elements).

The athletes described these techniques very differently, mostly generally. Some of them dealt systematically and detailed with this problem. In two cases individual programs for specific prestart problems were mentioned.

Hardly mentioned techniques:

- Motivation techniques: Whenever motivation techniques were mentioned, they were "naive techniques", not systematically used. Only two persons mentioned systematic goal-setting training. Systematical motivation techniques were sporadically mentioned.

- Tactics- and cognitive-skill training were also hardly ever mentioned, although different, mostly naive techniques of positive thinking are used more often.
- Perception training: only one skier mentioned the confrontation with different qualities of perception during the race.
- Psychomotoric training (mental training, imagery) in a narrower sense is hardly described.
- The athletes use classes to get to know these techniques, 4 skiers worked with specialized literature and one of them visited a mental-training course independently.

3.3 Attitudes to risk taking and coping with injury

Beside questions as to how skiers use short- and long-term psychological interventions a certain point of view was found by the question about risk taking and how to deal with injuries and come back. Here’s what we found out:

- Athletes interested in psychological training generally seem to think more about safety and risks *(“Yes, the safety measures on the course, that is something that is very important to me”).*
- Athletes who avoid psychological training also seem to avoid confrontation with thoughts about safety.
- The thoughts on risks are often contradictionary and inconsistent. A skier with the background of an injury reports: *“I am sure, you get much more sensitive in considering risks”* shortly later he says: *“If I take a serious fall, I have to switch off my feelings and to get back on the slopes as soon as possible…That is the best method, I ‘m sure…because otherwise you start thinking…”*. Another skier tells us: *“Sometimes it is better, not to have a look at safety, because in some situations you wouldn’t ski as you do, that’s the point where we have to be consciously careless.”* The same skier some sentences later: *“You have to check all possibilities (of dangers and risk), there is nothing you may disregard.”* This statements shows that it is obviously difficult for skiers to handle risk cognitions. As can be ascertained from other statements, skiers are more or less aware that they play some tricks on their thoughts; they seem to know about their strategies for reducing cognitive dissonance. Sometimes you get the impression that they feel completely at the mercy of the risks of races. They think, if you don’t take the risk, there is no chance to win, if you think about the risk, you can’t race as fast as necessary.
- Certain experiences change the way skiers think about risks: *“…You just start realizing the problem* (of risks) *at the moment you have had a critical crash and injury,…before this you don’t think about this”,* another skier: *“…This*

season there were two races I would rather not have skied, because of anxiety, but then one skies anyway…”.

Used strategies to handle dashes and injuries:

- Slow approaches to the accident and its consequences *(“Well, I had a dash two years ago, an operation,…it’s been a problem quite a long time to feel my way towards this experience,…I’m sure there is something subconsciously,…time is the great healer…”).*
- Active and systematic confrontation with the situation of the accident (imagining runnig through the race without incident).
- Method of confrontation: Looking for an explanation for the dash and running through the course immediately after the accident (if this is possible).

I think a lot could be done to help athletes by using some suggestions of Heil’s Book “Psychology of Sport Injury” [8], for example.

3.4 Phases of psychological training

The interviews demonstrate that the skiers, above all the Europe Cup and junior skiers, were not aware of the different phases of information, diagnosis and evaluation of the psychological training. The findings do not allow the author to judge the dimensions of intention and consequence of how the different phases have been pursued in the psychological intervention. Information on what psychological training is good for and the ability of self-diagnosis seems to be quite vague to most of the skiers.

The transference of psychological interventions to competition cannot be clarified with the findings of the interviews. Still, this is the sphere of psychological training which is the most important to the skiers.

3.5 Scoring the success

We can see that the confrontation and experiences with psychological training are developed differently. Also the assessment of the importance of the training varies a great deal and is associated with big uncertainty about psychological interventions.

Many statements are based on speculations: *“I do think that it is worth doing…I’m not sure whether it’s worth doing…it’s not certain what you can really change with psychological training, whether you can really ‘take off”.*

The facts proove a strong interaction between the experienced success of psychological training and the assessment of the importance to the skiers, which is connected likewise to the self-motivation towards training, (cp. 3.9)

3.6 Differences between Europe Cup, Junior and World Cup skiers

In general Europe Cup and Junior skiers seem to be more interested, but also more uncertain about psychological training.

World Cup skiers have made their decisions. Either they have already experienced the effects of psychological interventions or they refuse it absolutely. *("I don't need something like that.... Well, for someone with no self-confidence who wants to ski in the Cup it [the psychological training] is the most important thing he has, the poor dog.")*

3.7 Integration of the psychological training into the complete training process

The interviews show that psychological training was partly used during the normal training on the slope. It still seems to be very difficult for the racers to accept psychological training as a part of the normal physical training. For them psychological interventions seem strange, multi-layered and mysterious and not an integrated part of the training process. This causes even more troubles as the psychological training is based on an holistic appreciation of cognitive motor control, where the mental state is an integral part of the motor regulation [9]. I published such a description of cognitive motor control in 1990 and will use it as a starting point for the following considerations:

An extensive assessment of capacity to act starts from a "person-environment transaction" where the capacity to act is based on different levels. Acting is always based on fundamental values of the person. One of the alpine skiers: *"I consider skiing as a life-time learning process."*

Life-time planning and career planning have at some moments the same importance as a reflection of metaphoric learning capacities through the various possibilities of experiences through ski racing.

On the other hand, we know that motor control is controlled by minute details of the sensomotoric system that stay partly unconscious. We will hear about that from Mester, Spitzenpfeil at the congress and also, for example, Lippens [10] and many others are at work on such topics.

3.8 Topics that can be integrated very differently

The demands on different methods of psychological training give rise to some sore points in the designing of the psychological interventions:

- Voluntariness versus pressure that is needed to work systematically.
- Individuality of work planning versus economic and time conditions. Individual care seems to be the best way of psychological interventions to allow for individual claims to the training. On the other hand, a basic

introduction to different techniques of psychological training can also be done efficiently in groups.
It is also clear that single impulses alone are not effective but have to be completed by general psychological treatments. Therefore, a differentiation between psychological basic information and experiences on one hand and specific individual treatment on the other hand is suggested.

- Responsibilities: the skiers demand attractivity from the training programme: *"I want to see that it works."* On the other hand some of them also see their own responsibility in the efficiency of the training.

3.9 Acceptance of the psychological training

In general the acceptance of the psychological training is quite high. 90% of the interviewees consider psychological training important and want it to be further developed. If one looks at the context of the interviews analytically and in combination with other statements, different groups of acceptance can be determined (see Table 1).

Table 1. Groups with different structures of attitudes toward psychological training.

	count			
Group	**J n=7**	**EC n=8**	**WC n=21**	**total n=36**
Group 1: The skiers in this group consider psychological training as integral to their personal and athletic development: "Psychological training is a method for me to reach concrete goals." The members of this group take responsibility for the integration of psychological training in training and competition.	3	1	5	9
Group 2: These skiers recognize psychological training as some form of requirement. "Actually I should use it... Psychological training would be important for me, but I need an impulse from outside." They are open to and willing to participate in psychological interventions but need outside support to carry it through.	1	5	3	9
Group 3: Acceptance of the training as something that should be done: "I should do psychological training, I should see to it, I know, but, well, that's the way it is." They have doubts to the actual effectiveness of techniques. In addition a certain tendency to follow the instructions of an influential person is apparent.	-	2	1	3
Group 4: The skiers of this group can hardly accept that they might require or benefit from psychological training. It should be used by "others"*‘, who "have to deal with personal problems"	-	-	2	2
Group 5: These skiers reject psychological training for themselves: "This is nothing for me, I do not know what to do with it, if somebody wants to use it, it's his problem."	1	-	2	3

Group 6: Those skiers refuse psychological training in the form it is currently offered but fail to formulate concrete alternatives. In some cases complaints about training or organization were made.	2	-	7	9
Group 7: Uncategorizable skiers whose statements yield neither positive nor negative outlooks on psychological training.	-	-	1	1

J.............. Junior skiers
EC........... Europe Cup skiers
WC.......... World Cup skiers

Personal trust in the practising sport psychologist is particularly important. Skiers also fear that their psychological training could be used by others as an indication of weakness.

There are different reasons for the big gap between the partially great importance to the mental skill training and actually dealing with it. In clarifying these connections it is possible to motivate the skiers to find out for themselves whether they want to join in the training, stay or drop out of it. Reasons for drop outs are financial causes, lack of confidence in psychological training or in the psychologist, and lack of immediate success.

The question of how to motivate skiers to stay committed to psychological training seems to be the crucial problem. In addition to this question, I want to point out the following considerations:

3.10 Comparison of the results with considerations of Bull [11]

1. Entry to training:

Bull describes some factors that influence the entry stage of the adherence process. Volunteers have demonstrated lower levels of skill in anxiety management. In some kind this corresponds with the fact that racers with high interest in psychological training make a lot of considerations about injury and safety. Those that don't have a certain strategy, avoid thinking about risks or injuries.

In the situational characteristics, time is a strong argument. This is also true for this survey. There is a lot of worrying about stress caused by the additional psychological training on snow camps or condition camps.

2. Adherence to training:

The most important fact is the (self-)motivation on mental training. With an accurate look at the facts of the survey, you can recognize this as an important outcome as well. This corresponds also with my own experiences as a sport psychologist. There are a lot of circumstances you can influence, but the basic motivation of the athlete himself is one of the best predictors of adherence and success. A second important factor is the awareness of being able to make progress through psychological training (perceived efficacy).

The importance of a positive-orientated environment (coach, team-mates, etc.) and the personal acceptance of the sport psychologist is also of strong importance.

4 Consequences and ideas for the future

- It is evident that alpine skiing racers have a high interest in psychological training.
- There are different motivations to this interest that are often not orientated at specific individual problems.
- It is therefore helpful to make a diagnosis of the motivation of the skier and to use this to facilitate starting of and sticking to the training.
- Sometimes the skiers do not seem to be sure why they follow the training. It is therefore necessary to give them on one hand information about the importance and possibilities of psychological training and to help them on the other hand to improve their competence in self-diagnosis.
- It is also necessary to make the skiers aware of the possibility of operationalizing the success of psychological training.
- The interviews show that a certain "pressure" makes the beginning of psychological training easier for many skiers. The coaches demand on the other hand the prophylactic use of psychological interventions. From this, we can conclude that

  1) psychological training should always be used on the principle of information, diagnosis, intervention/practise and evaluation, no matter whether it is used therapeutically or not.

  2) the integration of psychological training to the everyday situation of the skier should be aimed at as soon as possible.
- The general start of psychological training by relaxation techniques should be thought over again.
- In Austria, we should be aware not to push psychological training to pure deficit treatment. Integrative possibilities combined with snow, technique, tactic, and physical-condition training should be preferred.

Last, but not least, psychological training has to prove that it can help to economize the training process rather than to put a strain on it.

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INCENTIVE MOTIVATION, COMPETITIVE ORIENTATION AND GENDER IN COLLEGIATE ALPINE SKIERS

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Keywords: incentive motivation, competitive orientation, alpine skiing, gender.

1 Introduction

Why do individuals participate in sport? What attracts individuals to certain sports? Does an individual focus on winning or on performing well when competing? Which goal, winning or performing well, enhances competence and success for the individual? In order to design practice sessions and physical activities that will meet the participants' needs, coaches and physical educators should be aware of the individual motives and goals. "Coaches who satisfy their athletes' reasons for participation will very likely at the same time enhance the motivation of their athletes. Enhanced motivation may contribute to improved personal satisfaction from participating and improving levels of performance" (p. 7) [1]. Athletes' competitiveness reflects their desire for success and satisfaction when involved in sport competition, through the achievement of their goals [3].

The critical role of motivation in explaining athletic participation, success, and failure has been researched and emphasized in the sport psychology literature. Taylor [4] identified motivation as the only one of three factors (motivation, task difficulty, and ability) that influences a skier's performance and is entirely under her/his control. According to Alderman [5], motivation is a mediating variable in athletic success; talent is important but motivation is what might make the difference between winning and losing, or performing well versus poorly. Weinberg and Gould [6] described motivation as the direction and intensity that characterizes an individual's behavior.

Alderman and Wood [7] included the concept of intensity and direction of behavior in their sport-specific construct of incentive motivation. They defined incentive motivation as "the incentive value that an individual attaches to the possible outcomes of actions which [s/]he chooses to engage in will, in fact, partially determine the courses of actions [s/]he actually chooses" (p. 169). Alderman and Wood [7] based their work on the theoretical model of Birch and Veroff [8] in the area of motivation and behavior and proposed seven systems that may be available and attractive to athletes: affiliation, aggression, arousal, esteem, excellence, independence, and power. These incentive systems operate with or against each other to determine the athletes' unique behaviors in a variety of situations [5].

Alderman and Wood [7] developed a sport-specific instrument, the Alberta Incentive Motivation Inventory (A-IMI), in order to assess the values that athletes place on the seven incentive systems and evaluate which of these systems were more important for each athlete. Wood [1] examined the reliability and validity of A-IMI and revised the seven incentive systems of the inventory in an attempt to refine the instrument and assess the most critical incentives perceived by athletes through their sport participation. The revised incentive systems are: affiliation, aggression, excellence, independence, stress, success, and power [1].

Alderman [9] administered the A-IMI [1] to 2,000 athletes (ages 11 to 18) participating in several sports and reported similarity between the incentives of males and females. Affiliation, excellence, and stress were found to be the stronger incentives, while aggression and independence were the weaker ones. With regard to gender, age, and culture, Alderman [9] did not report any motivational differences.

Wood [1] examined gender and type of sport (team vs. individual) differences on the A-IMI [1], in 400 female and male swimmers and basketball players, ages 11 to 15. The incentives of excellence and stress were valued the same by all groups. Basketball players valued more independence and aggression as compared to swimmers. Female swimmers scored higher on success than female basketball players did. Male basketball players scored higher on aggression than male swimmers did. Wood's [1] results revealed some gender differences which were not apparent in Alderman's [9] study.

MacDonald [10] examined incentive motivation differences between 319 United States and Canadian male and female junior high school athletes and reported significant gender differences on five of the seven incentive systems of the A-IMI [1]. Males scored higher on the aggression, power, stress, and success incentives, while females scored higher on the affiliation incentive [10].

Mowrey [11] investigated the incentive motivation of female and male United States Masters swimmers with the A-IMI [1]. Male swimmers scored higher on the incentives of power, independence, success, and aggression, whereas female swimmers placed higher values on the incentive of affiliation [11]. Schwartz [12] administered the A-IMI [1] to former collegiate, basketball and swimming athletes. No significant differences between swimmers and basketball players were found. However, male athletes placed higher value on the incentive of stress than females did [12].

As Alderman [5] stressed, motivation is a very individualistic construct with different meaning and form for different individuals and different competitive situations. Competitive orientation is another construct with similar unique, individual characteristics. Vealey [2] defined competitive orientation as "a tendency for individuals to strive toward achieving a certain type of goal in sport" (p. 222).

Vealey [2] included a construct (i.e., competitive orientation) in the conceptual model of sport-confidence, which was based upon the goals that individuals strive for when competing. Competitive orientation reflects an athlete's belief that achievement of a performing well- or winning-goal would demonstrate competence and success [2]. Athletes may become performance-oriented or outcome-oriented based on their goals and through their athletic experiences, hence two competitive orientations were conceptualized by Vealey [2]; performance orientation and outcome orientation. Vealey [2] developed the Competitive Orientation Inventory (COI) to assess these two competitive orientations.

Vealey [13] administered the COI to investigate differences on competitive orientation based on participation level (elite, college, and high school), sport type (individual, team), and the athletes' gender. No significant differences emerged for competitive orientation based on sport type or gender. A significant main effect was reported for participation level indicating that developmentally elite athletes (i.e., adults) were more performance oriented than college or high-school athletes. Vealey [13] attributed the participation level differences to the fact that "elite athletes base their feelings of competence and satisfaction on how well they perform instead of whether they win or lose" (p. 476). Elite athletes have learned to focus and evaluate themselves on personally set standards, whereas athletes and coaches at lower levels (college, high school) often ignore the idea that a performance goal and focus can also enhance performance [13]. Vealey [13] suggested that when athletes focus on performing the best they can (a controllable goal), they are more likely to feel competent and satisfied as opposed to focusing on the outcome of winning (uncontrollable goal).

Summarizing some research findings contrary to Vealey's [13], Spence and Helmreich [14] reported that males scored higher than females on competitiveness as measured by the Work and Family Orientation Questionnaire [14]. Gill [15] reported that overall, males scored slightly higher than females on competitiveness as determined by the Competitiveness

Inventory [15], but sex differences were attributed to males scoring higher on the win orientation and females scoring higher on the goal orientation components of her instrument.

The importance of motivation and competitive orientation in order to understand athletic behavior and further facilitate athletes' participation in positive athletic experiences was the primary motive for this study. It was of great interest how Maehr and Nicholls [16] included in their achievement orientation definition concepts similar to the seven incentive systems [7] and Vealey's [2] definition of success via competitive orientation. For Maehr and Nicholls [16], achievement orientation can take a variety of forms, that derive from the individuals' primary participation goals and the meaning they attach to success and failure. Achievement-orientation theories have been widely used by sport-psychology researchers to explain motivation and competitiveness [17] [8] [6].

From the reviewed literature a lack of research on collegiate athletes' motives was identified. In addition, studies on competitiveness reported contrary results [13] [14] [15]. Furthermore, alpine skiers when compared to other sport athletes looked like the endangered species in the sport-psychology research world. This study was designed to investigate what incentive motives and competitive goals female and male alpine skiers value and strive for when participating in Division I intercollegiate championships.

2 Method

2.1 Participants

The subjects (N=93) for this study were Division I, male (n=56) and female (n=37), intercollegiate alpine skiers from seven institutions in the Northeastern region of the United States of America (Maine, Massachusetts, New Hampshire, and Vermont). The athletes ages ranged from 18 to 22 years of age and were all members of varsity and junior varsity teams.

2.2 Measuring instruments

2.2.1 Alberta Incentive Motivation Inventory (A-IMI)

The A-IMI [1] was used to assess incentive motivation values for the seven incentive systems of affiliation, aggression, excellence, independence, power, stress, and success. The A-IMI [1] version used in this study was prepared by Wood [1] for the group of swimmers who participated as subjects in her study where the primary verb to describe the athletes' activity was 'perform'. The reliability and validity of the A-IMI [1] were tested by Wood [1] and found to be at acceptable levels. Validity was established with two independent statistical methods: a multi-trait multi-method analysis and a factor-analysis method. Reliability was determined by an alpha and a test-retest reliability method. The inventory consists of 70 items and each incentive system is represented by 10 statements. There are four alternative responses: always, often, seldom, and never with numerical scores 4, 3, 2, and 1, respectively.

2.2.2 Competitive Orientation Inventory (COI)

The COI [2] was designed to measure competitive orientation based on two goals that athletes strive for when competing: performing-well (performance-oriented), and winning (outcome-oriented). The reliability and validity of the COI were examined by Vealey [2] and demonstrated adequate item discrimination, internal consistency, test-retest reliability, content validity, and concurrent validity. The inventory is presented by a 16-cell matrix construct where each cell represents a sport-specific situation that combines a certain outcome with a certain level of performance. The rows of the matrix describe different levels of performance (very good, above average, below average, very poor), and the columns describe different outcomes (easy win, close win, close loss, big loss). In each cell a number from zero to 10 must be assigned, where "0 represents a 'very unsatisfying performance' and 10 represents a 'very satisfying performance'" (p. 225) [2].

2.3 Procedures

The proposal was reviewed and approved by the Human Subjects Committee, at Springfield College, Springfield, Massachusetts, and written permission was secured from the director of athletics of each institution and the coaches of the participating teams. The inventories were administered by the author prior to the beginning of the 1993–1994 racing season. A classroom setting was initially requested. Only two institutions provided a classroom setting, where the inventories were administered before practice. For the rest of the institutions the instruments were administered in their gymnasiums either before or at the end of practice. Each student-athlete of the alpine ski team was notified by their coach as to the date, time, and place of data collection.

Each student-athlete who wished to participate in this study was asked to sign an informed consent document which outlined the purpose of the investigation, and assured anonymity and confidentiality. A packet containing the informed consent form, the A-IMI [1], and the COI [2] was given to each participant. A copy of the instructions for each inventory was attached to each packet. These instructions were also read aloud to the subjects by the researcher.

2.4 Statistical Analyses

The scores obtained from the A-IMI [1] and the COI [2] were utilized in the data analysis. The independent variable was gender: females and males. There were two sets of dependent variables: incentive motivation with seven incentive systems (affiliation, aggression, excellence, independence, power, stress, success), and competitive orientation with two orientations (performance- and outcome-oriented).

Two multivariate analyses of variance (MANOVA) were calculated to assess possible differences in the mean vectors of the seven incentive motivation systems (A-IMI) and the two competitive orientations (COI) for the male and female alpine skiers. A discriminant function analysis procedure was calculated to determine which variables would be significant in the classification of male and female groups. The discriminant function analysis was utilized here as a multiple comparisons method. The statistical programs were from the Statistical Package for Social Sciences (SPSS) [19] [20].

3 Results

The total number of athletes who volunteered to participate in this study was 93 (56 males, and 37 females). These athletes were all participants inNCAA Division I, intercollegiate, alpine ski teams at the Northeastern region of the USA. Descriptive statistics were computed for the scores obtained from the A-MI [1] and the COI [2]. Mean scores and standard deviations for the A-IMI systems and the COI orientations for males and females, are presented in Table 1.

Table 1. Descriptives for the A-IMI and the COI scores for female and male skiers.

	Mean	Sd	Mean	Sd	Mean	Sd
Variables	All Skiers		Female Skiers		Male Skiers	
A-IMI						
Affiliation	29.00	3.47	29.13	3.44	28.91	3.50
Aggression	22.41	4.23	21.27	3.62	23.16	4.47
Excellence	33.41	2.89	34.21	3.05	32.28	2.66
Independence	17.66	2.83	18.00	3.10	17.42	2.64
Power	23.54	2.94	23.16	3.39	23.78	2.60
Stress	27.91	3.78	27.86	2.09	27.94	3.17
Success	28.72	3.41	28.32	3.56	28.98	3.31
COI						
Performance-oriented	.47	.28	.49	.24	.46	.28
Outcome-oriented	.41	.25	.40	.26	.41	.24

A MANOVA was calculated to determine the differences in the mean vectors of the seven A-IMI systems: affiliation, aggression, excellence, power, stress, and success for males and females. The Wilks' Lambda value computed for the A-IMI indicated no significant differences ($L = .87663; p = .118$) in the mean vectors for the male and female skiers' incentive motivation systems. The univariate F ratios indicated no significant gender differences for five of the seven incentive systems. Female and male skiers valued equally affiliation, independence, stress, and success as motives that attract them to sport participation. However, the univariate F ratios for the excellence ($F = 5.0208; p = .03$) and aggression ($F = 4.5950; p = .04$) indicated significant differences ($p < .05$) between males andfemales.The excellence mean score for females was higher than the mean score for males, whereas the aggression mean score for male skiers was higher than the mean score for female skiers. Since the A-IMI Wilks' Lambda value ($p = .118$) approached the .05 level of significance and two F ratios indicated significant ($p < .05$)gender differences, the discriminant function analysis was considered appropriate.

A MANOVA was calculated to determine the differences in the mean vectors of the COI performance- and outcome-orientations for male and female skiers. The obtained Wilks' Lambda value for the COI indicated no significant gender differences (Λ = .98427; p > .490) on outcome and performance orientation. The univariate F ratios comparing male and female competitive orientation scores indicated no significant differences for both variables between males and females. The discriminant function analysis procedure was not computed for the COI.

For the discriminant function analysis, the independent variables were excellence and aggression, while skiers' gender became the dependent variable. The discriminant analysis results, and the obtained coefficients for the two systems are presented in Table 2. For the excellence-incentive system the higher and more positive the structure coefficient value, the more chance for the skier to be classified as female. For the aggression-incentive system, the more negative the structure coefficient value, the more chance for the participating skier to be classified as male.

Table 2. Discriminant Function Analysis for the excellence and aggression systems.

Variable	Λ	p	Unstandard. Coefficient	Standardized	Structured
Excellence	.9477	.0275	.2757	.7791	.6664
Aggression	.8895	.0051	-1.1811	-.7540	-.6375
		Constant	-5.1542		

The discriminant function analysis procedure was utilized to predict the gender of the actual female and male skiers in this study for the excellence and aggression incentive systems where they had maximum differences. From a total of 37 female skiers almost half of them (18) were predicted to be females and 19 were predicted males, while of the 56 male skiers only 10 were predicted as females and 46 as males. Thus 68.82% of the 93 participating skiers were correctly classified for gender based on their excellence and aggression scores.

4 Discussion

The female and male skiers who participated in this study evaluated the incentive motive of excellence as being the most attractive for their sport participation. Ski racing provided them the opportunity to be very good at something, to excel, and surpass others' skiing performances. Affiliation was ranked second, indicating that the opportunity to build and maintain friendships was an attraction for involvement in ski racing. Success was ranked third as ski racing provided them the opportunity to receive recognition, social approval, and become more prestigious through their racing achievements. Stress was fourth and according to Wood [1] it describes feelings and experiences which are more closely associated with eustress and not distress. Ski racing was perceived as providing exciting and interesting experiences. Power was the fifth incentive motive system for the skiers of this study, reflecting an opportunity to influence and control opinions and attitudes of other people. Aggression was ranked sixth and according to Wood's [1] definition, it suggested that ski racing attracted them as an opportunity to injure, intimidate, or dominate others. Finally, independence was the seventh ranked incentive system, representing an opportunity to do things alone without help and criticism that attracted them to ski racing. The above ranking of the seven incentive systems is in partial agreement with the results of Alderman [9] who found affiliation, excellence, and stress to be the stronger incentives, while aggression and independence were ranked as the weaker incentives.

From the seven incentive motives of the A-MI [1], the excellence and aggression motives were valued differently by males and females. Female skiers placed higher values on the excellence incentive motive than their male counterparts did. Male skiers placed higher values on the aggression incentive motive than female skiers did. The gender differences in excellence, conflict with the findings of numerous researchers who studied incentive motivation and gender [9] [10] [11] [1]. However, the gender differences in aggression as reported in this study, are supported by the findings of Wood [1], MacDonald [10], and Mowrey [11] who also reported males placing higher incentive value on aggression than females. Excellence and aggression were the only two motives that discriminated between the genders. The rank order was identical for male and female skiers, the difference was that although excellence was ranked first, female skiers wanted to excel in ski racing more than male skiers did. Additionally, aggression was ranked sixth by all skiers but the opportunity to injure, intimidate, or humiliate others attracted male skiers more than female ones.

Nonetheless, female and male ski racers reported the same motives as attractive reasons for participation. Division I skiers compete at the elite collegiate level within the USA and internationally. It is possible that upon reaching this elite level of ski racing, both male and female athletes, for the same reasons, want to be the best they can be in order to reach their potential and the highest levels of achievement. Male and female skiers race the same events although often different courses. They spend significant amounts of time together; on the slopes, in the gym, the dormitories and hotels. They practice, live, and socialize in the same areas. All these simple but real facts may give an insight to why male and female skiers are motivated by the same incentive systems.

Competitive orientation as determined by the performance-orientation and the outcome-orientation goals, that athletes focus on when competing did not appear to be different for male and female alpine skiers. Vealey [13] reported similar results in her study: no gender differences for the 200 high school, college, and adult athletes. Contrary to the findings of the present study, Gill [15] reported small gender differences on competitive orientation for undergraduate students enrolled in competitive and noncompetitive classes, as determined by the Competitiveness Inventory [15]. Gill [15] suggested that "competitiveness seemed to reflect different orientation to competition, with males more oriented to win-loss outcomes and females more oriented to personal goals and standards" (p. 245).

The ski racers in this study strove for both winning and performing-well goals, which supported Vealey [2], who suggested that athletes may value both winning and performing well. Later, Vealey [13] found that developmentally elite athletes (i.e. adults) concentrated more on performing well when compared to high school and college athletes who focused more on winning. The results from the present study seem to be contrary to Vealey's [13] findings. However, if we consider that the skiers in this study were developmentally collegiate athletes and not adult/elite athletes, yet they are elite based on their ski-racing performance, then Vealey's [13] results are supported by this study. The skiers' focus on both outcome- and performance-goals can be attributed to the collegiate and elite (due to performance) characteristics they possess. Furthermore, some of the skiers in this study might have made the transition to the elite level's performance orientation, while others are still in the collegiate level's outcome orientation. Nonetheless, these are only speculations as the primary focus of the study was to investigate gender differences.

Summarizing the findings of this study, male and female skiers are attracted to ski racing by similar reasons, with the pursuit of excellence their strongest motive. Gender differences emerged only within the excellence- and aggression-incentive systems. No gender differences were found for competitive orientation, with both male and female skiers striving for good performance and winning at the same time. The findings of this study provide valuable information to alpine ski coaches who wish to be aware of their athletes' needs. Coaches may find these results helpful when working and organizing their teams. These results could be utilized as reference to help the athletes. For example, goal setting that is based on a specific and measurable outcome may contribute to enhanced personal satisfaction and motivation. Motivational and competitive orientation characteristics, just like any other psychological construct, should not be used for judging athletic ability, as criteria for race line-up, or team selection. However, understanding their role can increase the effectiveness of both the coach and athlete.

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FEELINGS OF MOVEMENT IN ALPINE SKIING

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Keywords: psychology, alpine skiing, feelings of movement.

1 Introduction

Feelings of movement can be perceived in exercising alpine skiing, however scarcely included as conscious learning contents in motor processes. That is caused by the difficulty in describing feelings of movement concretely on the one hand, and in consciously perceiving them as supplemental to the motor demands (multiple demand). Another problem is caused in the attempt to deduce the perception of feelings of movement from theoretical positions. As feelings are considered emotions, we inspected some theories of emotion concerning feelings of movement. Additionally, we checked the holistic tendencies of "Gestalt" theory, because the perception of feelings of movement is more than only a part of human action and experience. We considered positions of the sport science, and discussed individual and internal open-loop controls. They show a possible way to grasp feelings of movement.

Objects (e.g. skis, balls, or tennis rackets) or the environment (e.g. in downhill skiing, over bumpy ground) will be discovered through movement. The experiences made during movement on skis will be translated into valuations of the objects, and stored in memory as new experiences.

The main interest of sport-scientific research is frequently an externally oriented way of thinking: that means, the methods were developed to describe and analyse movements exactly. Many sport scientists and trainers prefer valuations of movements from an externally oriented standpoint, because it seems "easy" to classify movement solutions as "wrong" or "right" on the basis of external characteristics. The athletic standards are based upon more or less closely on ideals of movement in the varying types of sport.

Movements seen from an internally oriented way can not be observed or to classified directly. Most athletes are not able to perceive, observe, or describe their internal emotional feelings. Thelack of linguistic ability and the fact that athletes do not possess corresponding words for those states could be the causes for problems of expression and description. Frequently one can observe that athletes use metaphors to describe their feelings. There has been theoretical reflection and empirical research on internal ways of thinking (e.g. BIETZ/SCHERER 1994, KOHL 1956, LIPPENS 1992, SCHOCK 1995, WIEMEYER 1993, 1994).

It is possible—as a result of subjective valuations of perceptions—to add the movement feelings to the emotions in a wider sense. But the theories of emotions are often very general, they refer to the "great" emotions such as anxiety, joy, hope, etc. They do not suffice for explaining special feelings of movement and their origin. We believe that we have found a possible model for the description of feelings of movement on the basis of a modified model of BAUMANN (1993, 228—Fig. 1).

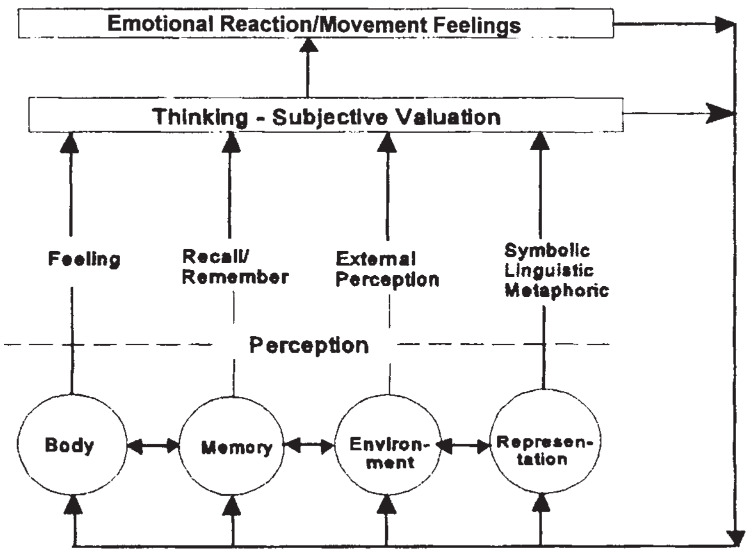

Fig. 1. Origin of feelings (mod. cf. BAUMANN 1993, 228).

This model for the systematization of feelings of movement can only be a descriptive conception, because we find ourselves on a descriptive level. A feeling of movement, however, is formulated as a construction. It is assumed that phenomenal objects cannot be named directly. For this reason cognitions are used to name the feelings; for example, the construction "feelingof rhythm" characterizes the totality of all perceptions concerning rhythm while skiing. The construction includes, for instance, the existence or non-existence of the ability to internalize rhythm.

After preliminary inquiries we have tried to demonstrate on the basis of theories of emotions and movements (collecting survey in EGGERT 1995) that feelings of movement can be consciously differentiated in alpine skiing and by contrasting ski materials (Big Foot; alpine skis). Movement tasks that were given as descriptionof feeling in the form of metaphors are able to produce holistic movement processes by their holistic quality (for example, skiing downhill like a snake). People will be diverted from technical details and the perception will be concentrated on feelings accompanied by technical processes.

It is wellknown that the variable insertion of materials in the sense of learning by contrast makes possible a differentiation of movement perception (cf. HOTZ/WEINECK 1983, SCHOCK 1995). The ability to be able to perceive differentially, however, is dependent on the learner's level. Experts in certain types of sport have more differentiated perceptions on the basis of various experiences. They anticipate and notice the smallest troubles and react immediately to them. It was tested in our investigation whether the feelings of movement described in our systematization are dependent on the ski types alpine skis and Big Foot and whether differences can be referred to different levels of performance.

2 Method

According to present investigations (e.g. GATTERMANN et al. 1987, KUCHLER 1980/1987, TREBELS 1990 etc.), a standardized questionnaire was developed and evaluated with the categories: feelings of joy-anxiety/ security and insecurity (WSU), feelings of joy/delight and harmony (GHH), feeling of balance (GGG), feeling of rhythm (RHY), feeling of pressure (DRU) and feeling of the edge (KAG). The quality criteria were checked by objectivity, reliability, validity and the usual procedures for statistical tests (e.g. Cronbachs alpha, corrected part-whole correlations, factor analysis, product-moment correlations, etc.). The correlation of feelings of movement concerning the first and the second measurement on alpine skis showed high correlations. We drew our inferences from the test values that the individuals did not interpret the items distinctly at different moments and, therefore, the items measured the same indicator with high probability. It is obvious by the product-moment correlations that the feelings of movement are not isolated and cannot be interpreted for themselves, but that they are closely connected with the other feelings of movement.

The questionnaire consisted of 41 items (in the form of closed questions) and could be answered by a ranged scale from "it is absolutely correct" (6) to "it is not correct" (1). The items corresponding to the categories were extensively formulated as metaphors. The same questionnaire was given to students of physical education (aged from 20 to 25 years) of different classifications—beginners (n=26) and advanced students (n=20)—at three different testing times (cf. Table 1). The beginners answered it at the end of the introductory phase on Big Foot (after two/three days), after the second day on alpine skis and once more at the end of the skiing days for alpine skis. The advanced skiers completed it after one day on alpine skis, after a phase of experiments on Big Foot (normally after one day), and once more at the end of the course for alpine skis. The Big Foot is a special ski (63 cm length) and constructed a little bit broader than an alpine ski and with steel edges.

Table 1. Testing times of the standardized questionare.

	Beginners	Advanced
1st Testing time	after 2-3 days on Big Foot	after 1 day on alpine skis
2nd Testing time	after 2 days on alpine skis	after 1 day on Big Foot
3rd Testing time	after end of course (12 days) on alpine skis	after end of course (12 days) on alpine skis

The contents and methods of training of the four ski instructors within the course were not dependent only on the conscious application of metaphoric tasks, but they also accorded with a mixed kind of training. Therefore, it is possible that the slightly different instructions of the ski instructors could have exercised influence on the results of the individuals.

3 Results and discussion

The suggestion of "Gestalt" psychological theories is that the quality of perception depends on the level of the individuals. That means individuals of different levels indicate differentiated perceptions concerning the types of ski (Fig. 2).

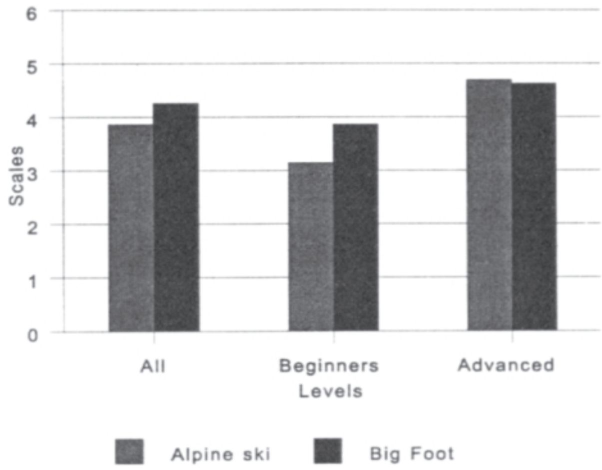

Fig. 2. Comparison of mean values: levels—types of ski.

One can derive from the results that different materials (Big Foot and alpine skis, Fig. 2) as well as the development of learning can influence the perception of feelings of movement positively. The differences of the whole group on alpine skis and Big Foot is significant (p=.003). That means both groups perceive the different types of ski: it is obvious regarding the levels. While beginners estimate their feelings of movement on Big Foot higher than on alpine skis (p=.000), advanced learners estimate them lower than on alpine skis (p=.677).

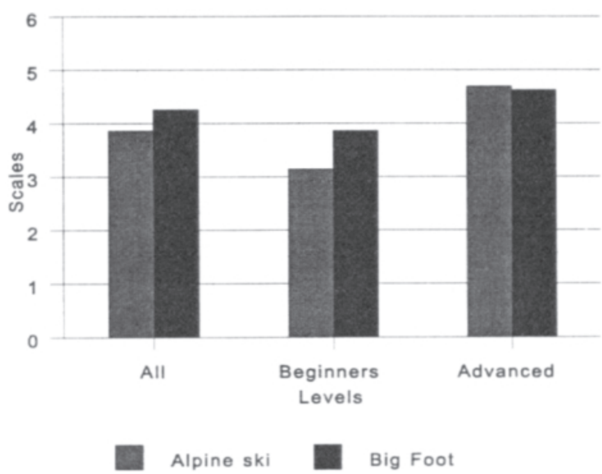

Fig. 3. Comparison of mean values on alpine skis: testing time 1—testing time 2.

Fig. 3 shows the comparison of two testing times on alpine skis. A clearly higher estimation of feelings of movement is confirmed from the first to the second testing time within the whole group (p=.000). It is valid for the beginners (p=.000) as well as for the advanced skiers (p=.000). The improvement of the advanced skiers is not so clear, because their level was already high at the first time of testing.

The following figure (4) shows the differences of the types of ski concerning the six categories of feelings and the levels of the individuals. It also shows the whole mean value for all feelings of movement to elucidate the derivation of the different feelings of movement from the whole mean value.

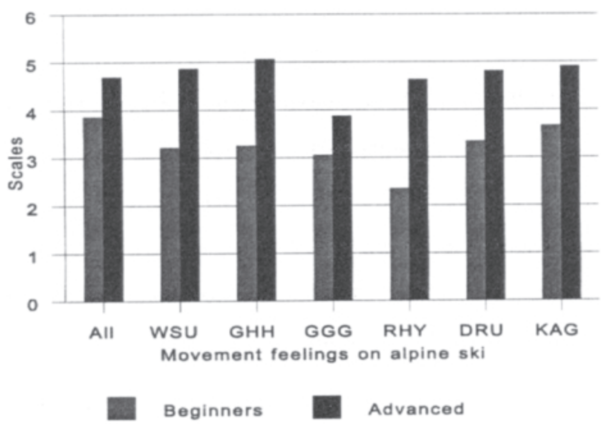

Fig. 4. Comparison of feelings of movement and levels on alpine skis.

There are significant differences (p=.000) in all categories of feelings of movement between beginners and advanced skiers; this is the same for the categories WSU (feelings of joy-anxiety/security and insecurity), GHH (feelings of joy/delight and harmony), RHY (feelings of rhythm), DRU (feelings of pressure) and KAG (feelings of the edges). In the category GGG (feeling of balance) there are significant differences as well (p=.014), but their level is lower than for all other categories. It is still to be explained why the feeling of balance is positive for walking and running, but not so distinctly marked for skiing. The results point at the fact that feelings of movement are differently perceived and that the quality of perception is dependent on the level of the individuals.

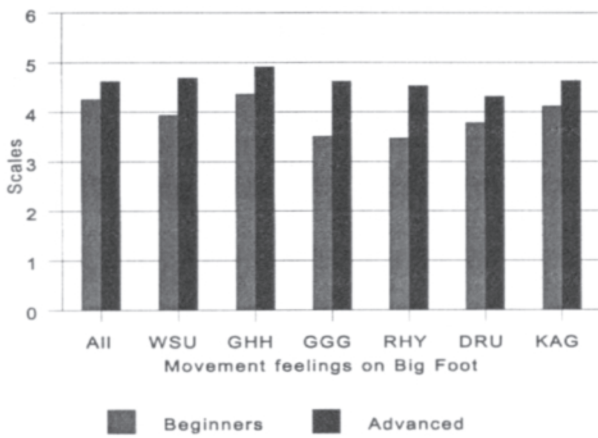

Fig. 5. Comparison of feelings of movement and levels on Big Foot.

Fig. 5 shows the comparison of feelings of movement between beginners and advanced learners on Big Foot. There are significant differences in all feelings between beginners and advanced skiers (p=.001), the same in the categories WSU (feelings of joy-anxiety/security and insecurity—p=.001), GHH (feelings of joy/delight and harmony—p=.034), GGG (feeling of balance—p=.003), RHY (feelings of rhythm—p=.000) and KAG (feelings of the edge—p=.021). In the category DRU (feelings of pressure—p=.058), there is only a tendency, but no significant difference between beginners and advanced skiers on Big Foot. That could point to the possibility of beginners perceiving feelings of pressure on Big Foot from the very beginning. In contrast to skiing on alpine skis, the values of the beginners are closer to those of the advanced. That could mean beginners are able to perceive feelings of movement concretely from the beginning of their skiing, because movement tasks are not so difficult to solve on Big Foot as on alpine skis.

In the following figures (6 and 7), the feelings of movement are presented as dependent on level and at different testing times. The beginners (Figure 6) present highly significant differences for all feelings together (p=.000) and in the categories WSU (feelings of joy-anxiety/security and insecurity—p=.000), GHH (feelings of joy/delight and harmony—p=.000), RHY (feelings of rhythm—p=.000), DRU (feelings of pressure—p=.000) and KAG (feelings of the edge—p=.000). In the category GGG (feeling of balance—p=.056), there is only a tendency toward differentiation to be seen. That could mean beginners aimed their attention more at technical details than at their feelings.

In conclusion it can be said that beginners are able to perceive feelings of movement precisely on the basis of available motor and cognitive processes. All different feelings are obviously improved from the first to the second time of testing.

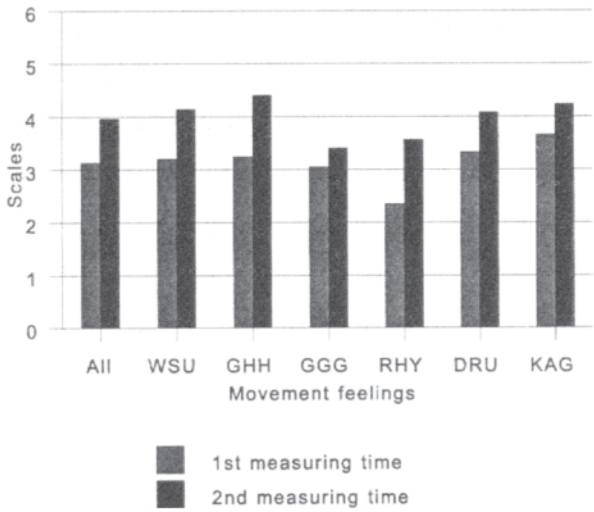

Fig. 6. Comparison of feelings of movement of beginners on alpine skis at two testing times.

In Fig. 7, one can recognize that the advanced skiers have improved their performances of perception on alpine skis from the first to the second testing time. But the improvements are not so clear as the improvements of the beginners. There are significant differences in all categories but DRU: altogether (p=.000), WSU (feelings of joy-anxiety/security and insecurity—p=.032), GHH (feelings of joy/delight and harmony—p=.004), GGG (feeling of balance—p=.001), RHY (feeling of rhythm—p=.004) and KAG (feelings of the edge—p=.003). In the category DRU (feelings of pressure—p=.509) there is no significant difference; that could mean advanced learners improve their feelings of movement, but it seems to be more difficult in the category DRU. All values signal that even advanced learners can improve their perception of feelings of movement by learning processes and by special lessons for sensory adaptation.

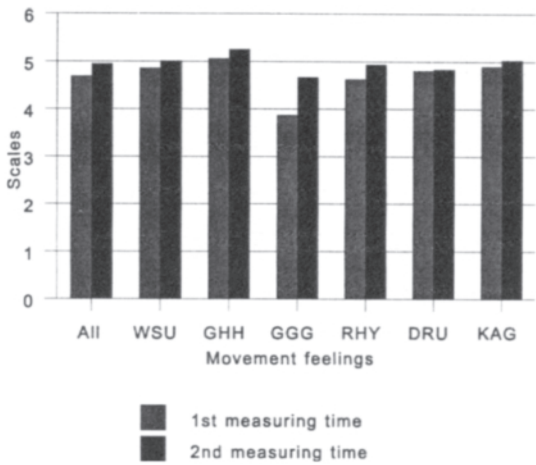

Fig. 7. Comparison of feelings of movement of advanced learners on alpine skis at two testing times.

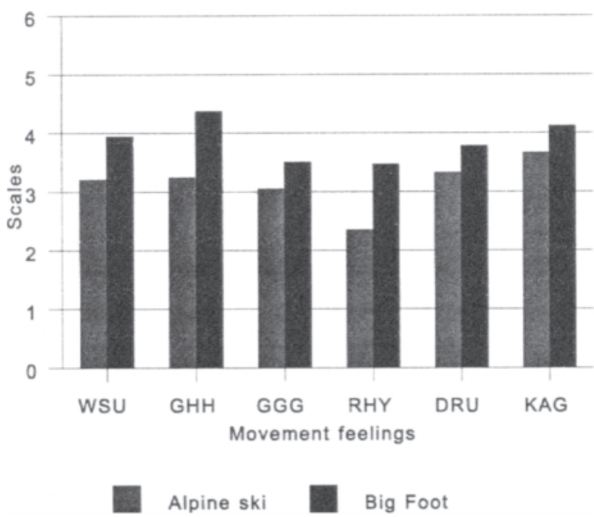

Fig. 8. Beginners: Comparison of alpine skis and Big Foot.

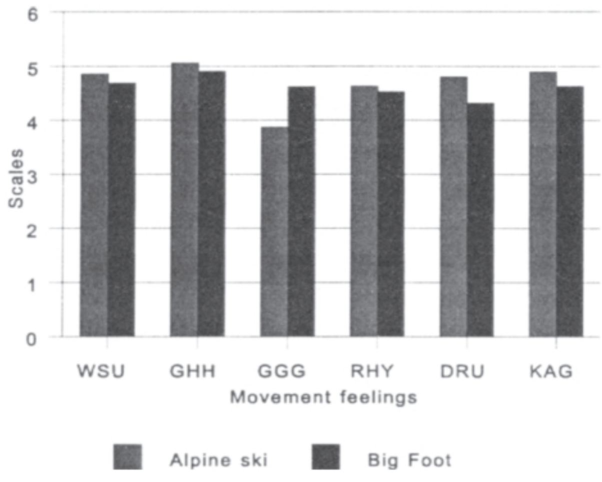

Fig. 9. Advanced learners: Comparison of alpine skis and Big Foot.

In Figures 8 and 9, one can see the special feelings of movement of beginners and advanced learners on alpine skis and Big Foot. The beginners (figure 8) show significant differences in all categories: WSU (feelings of joy-anxiety/security and insecurity—p=.000), GHH (feelings of joy/delight and harmony—p=.000), GGG (feeling of balance—p=.041), RHY (feeling of rhythm—p=.000), DRU (feelings of pressure—p=.020) and KAG (feelings of the edge—p=.001). The values for feelings on Big Foot are higher than on alpine skis. That means beginners can perceive different feelings better on Big Foot than on alpine skis. It seems to be an important argument for the first steps on ski and to start skiing on Big Foot.

Advanced learners (Fig. 9) give higher but not significant values to feelings on alpine skis with the exception of the feeling of balance (p=.012): WSU (feelings of joy-anxiety/security and insecurity—p=.299), GHH (feelings of joy/delight and harmony—p=.490), RHY (feeling of rhythm—p=.695), DRU (feelings of pressure—p=.018, significant) and KAG (feelings of the edge—p=.126). These estimations indicate that advanced learners control their alpine skis better than Big Foot after a short time of experience (one day).

It appears from the results (among other things) that different materials (Big Foot and alpine skis) and the improvement in learning can positively influence the perception of feelings of movement. In the perception of the feeling of balance, the rates (on a rating scale from 1 to 6) are situated in the middle of the scale. They ascend distinctly from the first to the second questioning, whereby the value is higher on Big Foot than on alpine skis questioning, whereby the value is higher on Big Foot than on alpine skis after the first days. There are also similar results for the advanced learners, albeit with higher rating scales. The feeling-of-balance rates are situated approximately one point lower than the results of the other feelings of movement. That indicates that the feeling of balance is already very good trained through walking/running, but it seems to be capable of improvement in alpine skiing.

For the rhythm feeling the beginners have the highest values for skiing on Big Foot, equally high to the second questioning on alpine skis. For the advanced learners who normally use rhythmical movement processes for their alpine skiing, the values of both questionings on alpine skis are situated distinctly higher than the values on Big Foot. That allows the interpretation that advanced learners have not yet found their rhythm for certain movement processes (for example for quicker skiing) after a relatively short time on Big Foot

For the feeling of pressure, beginners feel a distinct increase in their perception from the first to the second questioning. They become safer on their skis and obviously recognize the importance of feelings of pressure for skiing. Here the advanced skiers altogether have the highest ratings. The values change inessentially from the first to the second questioning about alpine skis. It can be interpreted that the feeling of pressure seems to remain high and constant during the course. The beginners reach similiar values on Big Foot that they had reached during the first experiences on alpine skis. Advanced learners have distinctly lower values for Big Foot than for alpine skis. Here, a higher speed of skiing on alpine skis seems to be responsible for better perception of feelings of pressure.

The beginners' feelings of the edge seem to be developed very well, they indicate relatively high values. The values on Big Foot are situated distinctly higher than the values of the first questioning on alpine skis and a few under the second questioning on alpine skis. An interpretation could be that they do not estimate themselves skiing on the edge. That accords extensively with common experiences that beginners especially favoured skiing on a plain position. The values of the advanced skiers hardly changed; they all are situated distinctly over those of the Big Foot. The relatively short experimental phase on Big Foot and the missing guided testing of skiing on the edge up to "carve" can be adduced for those value statements.

In conclusion it can be said that conscious movement perceptions can be produced by learners of all levels. They should be combined with movement tasks without any difficulties during the execution. One of the possible feelings of perception should be focussed on before feelings of movement feelings of movement into the systematic training of motor skills and abilities in skiing can have an important influence on holistic learning.

Our research showed that it is possible to improve feelings of movement by conscious insertion of different materials such as Big Foot and alpine skis (by contrast). If ski instructors are able to use symbolic and metaphoric instructions for their lessons, skiers can also turn their attention to different feelings of movement.

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OPTIMAL EMOTIONS IN ELITE CROSS-COUNTRY SKIERS

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Keywords: optimal emotions, Olympic skiers, training, competition, IZOF model, cross-country skiing.

1 Introduction

1.1 Emotions and athletic performance

The importance of emotions in athletic performance has been recognized widely both in research and applied work in sports psychology. Despite an increased interest in emotion-performance relationships, particularly in competitive and elite sport, it is surprising that so little empirical research has actually been conducted on the topic. The major focus in sport psychology until quite recently was primarily on examining the relationship between pre-competition anxiety and performance [1], [2], [3], [4], [5], [6]. Various nomothetic (group-based) theoretical approaches to performance anxiety, initially developed in other settings than sport, contend that anxiety exerts a unifom effect on performance in different athletes; however, there is a growing consensus in sport psychology that most of these models fail to recognize the multidimensional nature of anxiety or arousal [1], [3], [5], [6]. They do not provide an acceptable explanation of anxiety-performance relationships in sport and furthermore, often make the application of findings to individual performers ineffective and even misleading.

1.2 The individual zones of optimal functioning (IZOF) model

An alternative idiographic (individual-oriented) approach to the study of emotions in sport was proposed by Hanin [6] through the individual zones of optimal functioning (IZOF) model. The IZOF model was developed in an elite-sports setting and combines the within- and between-subjects analysis of situational emotional experiences related to individually optimal and non-optimal performances. The IZOF model was initially used to study optimal levels and zones of pre-competition anxiety and later was extended to the analysis of positive and negative emotions or affects (PNA) in different sports

[7], [8], [9], [10]. As applied to pre-competition anxiety, this approach indicates that each athlete has an individually optimal level (high, moderate and low) and the zones of anxiety which facilitate an athlete's performance. Successful performance, especially in short-duration tasks, occurs when current pre-competition anxiety is near or within the optimal zones. When pre-competition anxiety falls outside the zones, higher or lower, performance usually deteriorates. Thus, within-individual comparisons provide a more accurate picture of the anxiety-performance relationship than between-subject cross-sections in the same and different sports [6].

A procedure including recall, current, and anticipatory assessments to identify the individually optimal level and zone of anxiety was also developed in the IZOF model. Several standardized scales were used to identify optimal anxiety and its cognitive and somatic components following the IZOF methodology [6], [11], [12], [13], [14], [15], [16]. Irrespective of the instruments used, the findings provided empirical support for validity of the individual-oriented and multidimensional conception of anxiety-performance relationships. Theoretical and practical utility of the "in-out of the zone" concept predicting individual performance was also demonstrated; however, all these studies of pre-competition anxiety were idiographic to the extent that individual levels of optimal anxiety were identified for each individual athlete. A strong nomothetic element was still retained, since an identical set of researcher-generated anxiety items was presented to all subjects and their content was implicitly treated as having the same significance for all athletes.

Thus several new features were included in the IZOF model extended to the study of positive and negative emotions facilitating and harmful for individual performance [7], [8], [9], [10]. First, the framework of five basic dimensions (penta-basis) for the systemic description of emotions as a part of an individual's mental state was proposed. These dimensions included form, content, intensity, time and context. Second, the emotion content was conceptualized within the four global categories: positive, pleasant, facilitating emotions (P+); negative, unpleasant, facilitating emotions (N+); positive, pleasant, debilitating emotions (P-); and negative, unpleasant, debilitating emotions (N-). Third, a new procedure for idiographic recall, current, and anticipatory assessments using individualized scales with athlete-generated items was suggested. This included sampling of a personally relevant set of positive and negative emotions for each subject based on his or her previous performance experiences.

Most of the IZOF research at this point is focused on the content and intensity of positive and negative emotions that are helpful and harmful for performance. Specifically, it was demonstrated that optimal and non-optimal patterns of PNA in different athletes were individual. Furthermore, the facilitating or debilitating impact of emotions on athletic performance was related to their idiosyncratic meaning, intensity, and function [8], [9], [10]; however, the idiographic analysis of the PNA content and intensity in these studies was focused mainly on sports activity with an emphasis on competition situations. Specific tasks, conditions or settings within the sports activity were not examined.

This study attempted to examine optimal and non-optimal emotions in elite cross-country skiers experienced in competition (CO), hard-work training (HWT) and in technical-skills training (TST). Following the basic assumptions of the IZOF model, we hypothesized that the content of positive and negative emotion items the athletes chose would differ in their degree of similarity or overlap given the sport setting. Specifically, we expected relatively greater similarity in contrasts of words chosen in competition with hard-work training compared with technical-skills training. We also expected a low overlap between words chosen for the two types of training.

2 Method

The participants were 12 Finnish skiers (8 male and 4 female) preparing for the 1994 Winter Olympics in Lillehammer, aged 23–38 years (mean=27.8). All were members of the Finnish National team from 1 to 12 years (mean= 8.5).

2.1 Recall idiographic scaling

The content of individually optimal and non-optimal PNA patterns in competitions and practices was assessed using the idiographic recall method suggested by Hanin [6], [7], [8], [9], [10]. This methodology identifies positive and negative emotions that are subjectively meaningful in terms of the individual's past performance history and significant emotional experiences. In idiographic recall, athletes generate individually relevant emotion that best describe their optimal (helpful, facilitating) and non-optimal (harmful, debilitating) positive and negative emotions. To help athletes to generate individual items, the PNA stimulus list including positive and negative emotions typically experienced in performance was used. The English version of the PNA list was developed based on the content analysis [7] of the ten existing global PNA scales [17]. These PNA items were then translated into Finnish, and three judges evaluated the item content by selecting most appropriate synonyms used in currently spoken Finnish. The final version of the PNA list included 41 positive emotions and 37 negative emotions. Examples of positive-affect items include "active", "calm", "confident", "pleased", "determined", "excited", while negative affect items include "nervous", "angry", "annoyed", "irritated", "dissatisfied", "uncertain".

Recall scaling includes several steps. First, optimal PNA patterns are identified. Athletes, using the PNA stimulus list, select 4 or 5 positive and then 4 or 5 negative items that best describe their emotions related to individually successful performances in the past. Then non-optimal PNA patterns are identified by selecting 4 or 5 positive and 4 or 5 negative items that describe their emotions related to individually unsuccessful performances. In order to elicit a pattern, repeated experiences on several occasions are emphasized rather than one specific situation. Athletes use the PNA stimulus list to generate individually relevant positive- and negative-emotion descriptors and can also add emotion words of their own choice.

A separate scale was used alongside each of the emotions selected by individual athletes that related to intensity. The intensity scale asked: "How much of this feeling or emotion is usually helpful (or harmful) for your performances in competition (or in practices)?" Athletes could indicate either a level or a range of intensity (minimum and maximum amount of the emotion that was helpful or harmful). The intensity was measured on the Borg's Category Ratio (CR-10) scale [18] based on the range principle and constructed to avoid the ceiling effect. The CR-10 permits ratio comparisons to be made of intensities as well as determinations of direct intensity levels. Other research [19] has shown it to be useful in quantifying stimuli such as exercise capacity and pain. In this study a standard format of the CR-10 scale (11–13) was used with the following verbal anchors: 0=*nothing at all,* 0.5=*very, very little,* 1=*very little,* 2=*little,* 3=*somewhat,* 4=*moderately,* 5=*much,* 7=*very much,* 10=*very, very much,* #=*maximal possible* (no verbal anchors were used for 6, 8, and 9).

2.2 Study design

The study was a part of the assessment program used in the psychological preparation of the Finnish Olympic cross-country skiing team for the Lillehammer Olympics (from July 1993 through February 1994). Idiographic recall scaling of performance emotions, following the procedures described earlier, was administered in July and October 1993. In the first assessment, all team members were asked to think back about their effective and ineffective performances in hard-work training. Then they generated a list of positive and negative emotions that were helpful and harmful for these practices. The intensity of each individual emotion (level or range) was determined on the

CR-10 scale. This procedure was repeated in the same group session to identify athletes' idiosyncratic positive and negative emotions that were optimal and non-optimal for their technical-skills training. Both types of practices were relevant for skiers at the time of assessment. Detailed information about athletes' individual scores was provided in the follow-up individual sessions with skiers and coaches. Each athlete and both coaches were also given a personal copy of the PNA individualized scale for both practices.

In the second assessment at the beginning of the competitive season (end of October 1993), the skiers developed a PNA list of emotions related to their successful and unsuccessful competitions. The same procedures were used to generate PNA items and to determine their intensities. As a result, each skier had PNA profiles of individually optimal and non-optimal emotions and their intensities for the three settings: competitions, hard-work training, and technical-skills training. One skier was not able to attend the second session due to illness and his data was used only for comparison of hard-work and technical-skills training.

2.3 Statistical analysis

The similarity of emotion content was established by computing the amount of overlap in terms of shared items (worded exactly the same way) in the PNA lists generated by each skier for competition and practices. The following formula, suggested for the study of individual perception of situations [20], was used with slightly modified notations to calculate intraindividual overlap scores:

$$\text{overlap (ij)} = \text{nc (ij)} : \text{sqrt}\,[\text{n(i)} \times \text{n(j)}]$$

where: nc (i, j)=number of shared (similar) items for condition i and j; n (i)=number of emotion words for condition i; n (j)=number of emotion words for condition j. Conceptually, the overlap measure represents how similar emotion lists generated by individual skiers in condition i and j are. The IZOF model indicates that more similarity in emotion content is expected in describing functionally similar tasks, such as races and hard-work training. Less overlap might be expected in functionally different tasks, such as races and technical-skills training. Individual overlap scores vary in the range from 0 (all items are different) to 1.0 (all items are similar). The overlap values are equal to percentages expressed in decimal form when contrasted PNA lists have the same number of items.

3 Results

3.1 Frequency of emotion selection

Percentages of emotions selected as facilitating, debilitating, or both for each of the three performance settings are reported in Table 1. In the case of positive affect, the athletes perceived over 50 % of all emotions as facilitating their performance in competitions and technical-skills training. In the case of negative emotions, 14.2 % of items were reported as facilitating in technical-skills training. From 20 to 45.7 % of positive and negative emotions in different settings had either facilitating or debilitating effect on athletic performance. The total number of emotion words selected by individual skiers to describe their optimal and non-optimal emotions had a mean of 35.08 (SD=5.48), with a range of 24 to 43 words. However, 67.5 % of all words were used for one setting only (M=23.67, SD=6.14, ranging from 9 to 34). The mean number of words used for two settings was 9.33 (SD=3.52), with a range of 1 to 13. In addition, the mean for all three settings was 2.08 (SD=1.68), with a range of 0 to 4 words.

Table 1. Emotions selected as facilitating, debilitating or both in competitions and practices (N=12 skiers)

Performance settings/items	N	Emotional impact		
		Facilitating (%)	Debiliatating (%)	Both (%)
Competition				
Positive	37	51.4	27.0	21.6
Negative	29	34.5	41.4	24.1
Hard-work training				
Positive	31	35.4	32.3	32.3
Negative	35	22.9	31.4	45.7
Technical-skills training				
Positive	30	56.7	23.3	20.0
Negative	28	14.2	42.9	42.9

3.2 PNA content in competitions and practices

Mean intraindividual scores of overlap between facilitating and debilitating emotions were quite low both in positive (M=0.08, ranging from 0.00 to 0.28) and in negative (M=0.20, ranging from 0.7 to 0.36) emotions. The mean overlap for emotion words selected by the skiers for competitions and hard-work training was moderate (M=0.41, SD=0.28, ranging from 0.0 to 1.00). The mean overlap scores for technical-skills training contrasted with hard-work training ranging from 0.0 to 0.87 (M=0.31, SD=0.22). In the case of competitions contrasted with technical-skills training, the overlap was even lower (M=0.27, SD=0.23, ranging from 0.0 to 0.71). The Friedman Two-Way Anova revealed significant differences among these three pairs of contrasts (Chi Square=5.83, df=2, P=0.05). In other words, relatively greater similarity in contrasts of words chosen in competition with hard-work training compared with technical-skills training was found. The lowest overlap in content, as expected, was observed between words chosen for the two types of training.

3.3 Intensity of optimal and non-optimal emotions

In order to compare the intensity of optimal and non-optimal emotions in different settings, similar and different PNA items selected by skiers for competitions and practices were contrasted. The means and standard deviations of these findings are reported in Fig. 1.

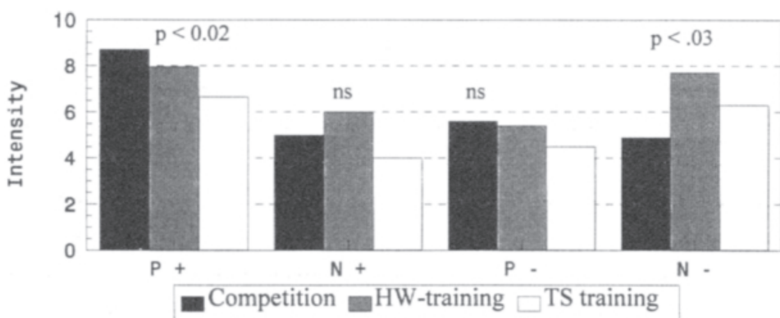

Fig. 1. Intensity of skiers' emotions in three settings

The Friedman Two-Way Anova revealed significant differences in the intensity for similar positive facilitating (Chi square=8.75, df=2, P<0.02) and negative debilitating emotions (Chi square=7.3, df=2, P<0.03). Significant differences (Chi square=8.68, df 2, P<0.02) were also revealed for combined positive and negative facilitating emotions (CO: M=7.64, SD=2.41; HWT:

M=7.39, SD=2.15; TST: M=6.04, SD=1.91); however, the differences in the mean intensity for combined debilitating (positive and negative) emotions between these settings at the group level were not significant (P> 0.1).

In contrasting matched pairs of similar PNA items, the Wilcoxon test revealed that the optimal positive emotions in competitions (M=8.43, SD=0.96) were significantly (P<0.02) more intensive than in hard-work training (M=7.43, SD=1.65). The intensity of combined facilitating (positive and negative) emotions in competitions (M=7.05, SD=2.35) as well as in all four combined emotion categories, was also significantly (P<0.03) higher than in hard-work training (6.44, SD=2.24). As expected, significantly higher (P < 0.03) was also the intensity of positive facilitating emotions reported for competitions (M=8.33, SD=0.9) as contrasted with the technical-skills training (M=6.94, SD=1.07). In other PNA categories these differences were not significant at the group level.

In within-individual comparisons independent t-tests revealed significant differences (t=3.92, P<0.01) in the intensity between positive facilitating (M=6.42, SD=2.4) and positive debilitating (M=3.37, SD=2.04) emotions. In the case of negative affect, the intensity of facilitating emotions (M=3.9, SD=2.57) was significantly (t=4.5, P<0.01) lower than the intensity of debilitating emotions (M=6.39, SD=2.04). The differences in the intensity of dissimilar PNA items across three and two settings, as revealed by the Kruskal-Wallis One-Way Anova and Mann-Witney U-test, were not significant.

4 Discussion

The results of this investigation provide support for the multi-dimensional conception of affect in sports [6], [7], [8], [9], [10] from which the content, intensity and context (setting) dimensions were derived. Results revealed that Olympic-level skiers were able to identify individual patterns of emotions that were helpful and harmful for their performance in three different settings: competitions, hard-work training, and technical-skills training. As we hypothesized, greater similarity in contrasts of words chosen in competition with hard-work training compared with technical-skills training was found. Also low overlap between words chosen for the two types of training was revealed. The intensity of positive optimal emotions was higher in more demanding tasks, such as competition and hard-work training. In contrast, the intensity of negative harmful emotions in races was lower than in hard-work and or technical-skills training. In addition, within-individual comparisons revealed that the intensity of positive facilitating emotions was higher than that of positive debilitating emotions. The intensity of negative facilitating emotions was lower than the intensity of negative emotions that were harmful to performance.

The findings from this study are also consistent with the previous research [7], [8], [9], [10] that has found that optimal and non-optimal patterns of emotions were individual within and across different sports. This investigation replicated the idiographic-recall procedures using individualized PNA scales with athlete-generated items and extended the IZOF model to three performance settings in Olympic-level cross-country skiers. Specifically, it was found that optimal and non-optimal emotions were individual and different for the same skiers in each of these three settings. Similar to previous research [7], [8], [9], this study also revealed a "reversal" effect of emotions on performance. Specifically, 23.3 % of positive emotions were chosen as debilitating in TST, while 27.0 % had the same effect in CO and 32.3 % in HWT. In the case of negative affect, 14.2% of emotions were facilitating in TST, while 22.9% were facilitating in HWT and 34.5% in CO. Also consistent with other research [8], [9], three types of emotion descriptors were found. They included (a) sports-specific items reflecting task demands selected by 40–50% of the skiers, (b) idiosyncratic items used by 1 or 2 athletes, and (c) non-specific, irrelevant items not selected by athletes.

The present study focused on the PNA optimal and non-optimal patterns that represent prototypes of performance-induced sports-specific emotions characteristic for three settings within the same sport. The findings revealed that each skier's idiosyncratic PNA profile included individually facilitating and debilitating emotions that athletes could experience at the same time. Earlier IZOF studies [6], [11], [12], [13], [14], [15], [16] identified only individually optimal emotions, such as pre-competition anxiety. The present findings together with recent research [7], [8], [9], [10] suggest that the 'in-out of the zone' concept, suggested to predict individual performance, can be extended to both individually optimal and non-optimal emotion zones. This provides a check on the possibility of conflicting impact of facilitating and debilitating emotions usually resulting in average or below average performance [7].

The results seem to contradict the hypothesis about the impact of task characteristics on arousal-performance relationships [21]. This conception contends that there exists "the same for all" optimal level of arousal for a given activity as a function of the task complexity and the energy needed to perform. In contrast to this view, the present findings indicate that the content-and intensity-optimal and non-optimal patterns of emotions are individual and vary greatly within and across different settings of sporting activity.

In conclusion, the findings from this study indicate that Hanin's multi-setting hypothesis appears to be valid for the description of the PNA content and intensity in competition and practices in Olympic-level cross-country skiers. Apparently, performance-related emotions can be examined at the general level of sports activity (for instance, in skiing), or within a performance setting (in practices or competitions), or at the level of the specific task (in a particular race). New insights might be also gained through the investigation of temporal patterns [2], [6], [7] of PNA content and intensity in different performance situations, such as up-hills and down-hills or in races of varying distances. The findings suggest that a more differentiated approach to the study of performance affect in such multi-task sports as Nordic combined and biathlon might be in order. Additional research will also be needed to provide mechanisms explaining why optimal and non-optimal emotions are individual across different athletes within the same performance settings.

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STRUCTURING CROSS-COUNTRY SKIING TECHNIQUES ON THE BASIS OF MOTOR-PROGRAM THEORY

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Keywords: classic techniques, cross-country skiing, motor-program theory, skating techniques.

1 Short historical overview

The early history of cross-country skiing is not very well documented (Polednik 1969). Rock paintings in the northern part of Europe and in Asia prior to the Christian Era have been the basis for the conclusion that primitive forms of skis were used in travelling and hunting more than 4000 years ago. Illustrations from Lappland show that two skis of different length were used in wolf hunting. The long ski provided the glide while the short one served to push off. The latter was generally fur-covered on the underside for a better grip. Thus, a change from gliding leg to push-off leg and vice versa was not possible. It is noteworthy that the push-off ski was placed at an angle like in the modern one-leg skate technique. It also looks as if the hunter tried to coordinate the push-off from the ski and the spear to reach a maximum amount of speed. Ski poles were unkown as hands had to be free for use of a weapon (e.g. sling, club, bow or spear). The spear was also used as a braking device in descending a hill or simply for locomotion on flat terrain. Hence, it can be assumed that a primitive form of the one-leg skate technique (without poles and with a long pole) is more than 4 000 years old. There are also illustrations of hunters of the Stone Age who were partially dressed up as reindeer. During these times the primary objective was to move on skis, not to play on them.

Although skiing for hunting and travelling remained popular over the centuries very little progress was made in ski technique until the 19th century, due to the state of early boots and bindings. Two events had a major impact on furthering nordic skiing and propelling it into a national movement in Norway in the second half of the 19th century:

1. The foundation of the Christiana ski club in 1877. This club was in charge of

organizing cross-country skiing events of various distances. Considering the equipment of those days (e.g. ski-binding-shoe system, one-pole technique) the achievements were outstanding. By the turn of the century, two poles were used by all competitors. It is reasonable to believe that diagonal step and double poling were the techniques most frequently employed. When kick double-poling appeared, is unknown.
2. The two polar expeditions on skis in Greenland by the Swede Nordenskjøld (1883) and by the Norwegian Nansen (1888). Both had a major impact on the development of cross-country skiing as two skis with equal length and two poles were used. Nansen's book "On snowshoes through Greenland" was translated in many languages and brought the ski movement from Norway to Central Europe.

The beginning of the 20th century is characterized by several important events: regular contests in nordic skiing in Scandinavia and in many other countries, increased specialization, steady progress in the manufactering of skis and bindings and the establishment of national and international ruling bodies. From a technical standpoint very few changes have occurred since 1990. The diagonal step with slight variations (Finnish/Swedish style) and double-pole technique have been dominant in racing. Changes of directions in racing are carried out with stepping techniques and one-leg skate techniques, home stretches are negotiated with the double-leg skate technique. Thus, a variety of techniques is applied in competition. After a longer period of transition and exchange of arguments the FIS finally decided in 1985 to introduce separate competitions in both classic technique and free-style technique in 1985/86. In order to stage separate competitions both terms had to be defined clearly. The classic technique (C) was defined as follows: all variations of diagonal step, double-pole push with and without kick, herringbone without gliding phase and downhill techniques. All forms of skating were prohibited except for changing tracks, overtaking and quick changes of direction, likewise in descents without tracks. In free-style technique (F), skating and classic techniques were allowed, i.e. all movement forms of cross-country skiing that do not destroy the prepared terrain, endanger other competitors and which are feasible with the prescribed cross-country equipment (Verb. Schweiz. Langlaufschulen 1988, introduction). The increasing popularity of skating techniques can be attributed to three factors:

1. They are easier to learn than classic techniques; especially alpine skiers have a great transfer potential of their skiing abilities.

2. There are no waxing problems of the kicking zone.
3. They are faster than classic techniques: with the diagonal step technique, the maximal speed is about 5.5–6 m/s, with skating techniques on even terrain, over 8 m/s are possible. Both double-skate and one-leg skate techniques have proven to be faster than the double-pole technique (Nilsson and Löfstedt, 1984).

In order to explain the finding that skating is faster than classic skiing several hypotheses have been postulated:

1. The VO_{2max} is higher in skating than in classic skiing. However, a review of research studies by Bergh and Forsberg (1992) has indicated conflicting results.
2. Skating is metabolically about 10 % less costly than classic techniques (Zupan et al. 1988). Skating also produces a higher velocity at a given blood lactate concentration than classic techniques (Nisson/Löfstedt 1984). Bergh and Forsberg put forward several possible explanations: forces resisting the forward progression are lower; less work is performed against gravity; increases in kinetic energy are smaller; there is better transformation of energy between body segments.

2 Purpose of the study

The purpose of this study is to compare inductive and deductive concepts in structurring cross-country skiing techniques. Inductive approaches are based upon observations and biomechanical analyses, whereas deductive approaches refer to theoretical models. The question of how closely they fit each other needs to be answered.

3 Inductive approaches

An investigation into the structure of classic techniques revealed a more or less uniform picture in the literature (Bergh and Forsberg, 1992; Dtsch. Verb, f.d. Skilehrwesen 1984, 1996; Maier and Reiter, 1977; Verb. Schweiz. Langlaufschulen, 1988). Authors distinguish between diagonal step on flat terrain and in step ascents, double-pole push with and without kick, (half-) herringbone, transition and downhill techniques. There is less uniformity with regard to skating techniques. One of the earliest attempts to structure skating techniques was undertaken by Skard (1986). Classification although experimental in nature has already laid down major guidelines for the future. Skard differentiated eight different forms of skating:

1. Double skate—double-pole push on each second leg push-off with leading arm (“Padling”)
2. Double skate—double-pole push on each leg push-off (“Dobbeldans”)
3. Double skate—double-pole push on each second leg push-off without leading arm (“Enkeldans”)
4. Double skate—double-pole push on each second leg push-off with pronounced armswing and bending of the upper body (“Russerdans”)
5. Double skate—without pole push: pronounced pushing of the knees, arms towards the legs (“Kneskyv”)
6. Double skate -without pole push: speed skater position (“Skøyteløperen”) or with skipoles pointing to the front (“Kombiskøyt”)
7. One-leg skate (“Sporskøyting”)
8. Diagonal skating (“Diagonalskøting”)

With the exception of the two techniques mentioned under 6. all forms can still be found in present-day competition. They are illustrated in Fig. 1. The first traces symbolize the one-leg skate with the left leg as the push-off leg. Several synonyms are common: Siitonen step, Finn step or half-skating step. The second traces refer to a skating technique with one double-pole push for each leg push. The third traces point to a skating technique without the use of poles. The fourth traces show a skating technique with one double-pole push for two-leg pushes. The fifth traces demonstrate the same pattern as before except that the left arm is leading. And the sixth traces outline the diagonal skating technique: one single pole push for each leg push.

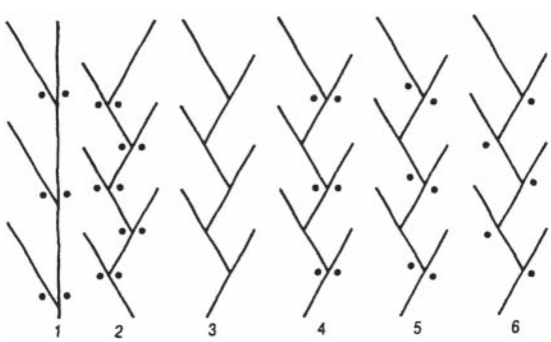

Fig. 1. Traces of skis and poles of major forms of skating techniques (from: Wenger and Wöllzenmüller, 1992, 125).

During a workshop held in Bischofsgrün (Germany) in 1992 experts involved in coaching and teaching put forward models to help structure the different skating techniques. The model postulated by Zipfel and Schwirtz (1993) from a coach's viewpoint is shown in Fig. 2. Phases of movement were analyzed biomechanically by means of video tape from different angles and by means of snow tracings of skis and poles. The model is based upon three levels of distinction: ski/leg work, pole/arm work and direction of push.

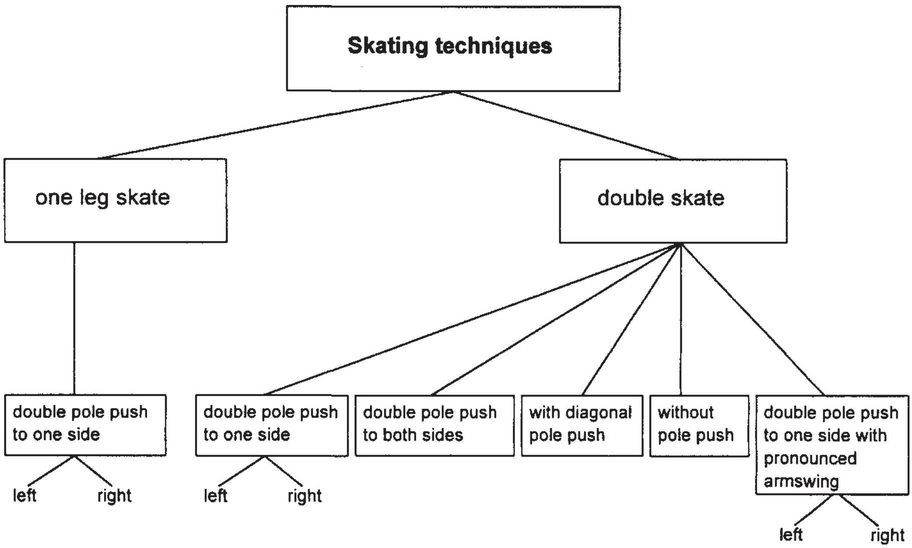

Fig. 2. Structure of skating techniques (Zipfel and Schwirtz 1993, 16; translated by author).

On the first level the one-leg skate and double-skate technique are differentiated. On the second level six different skating techniques are identified. Three forms make use of a double-pole push to one side, one form each of a double-pole push to both sides, of a diagonal pole push and of no pole push. The sixth form in Fig. 2 is the result of a pronounced arm swing in order to support the gliding phase. The authors point out that it is justified to speak of a technique of its own because of the arm movement and because of the temporal structure of the push-off and gliding phase of the skis in relation to the pole push. Further subgroups can be formed for three techniques if the direction of push is taken into consideration.

The structure of skating techniques (Fig. 3) proposed from the ski instructors' viewpoint by Scherrer (1993) has similarities to the Zipfel and Schwirtz model on the first level. Both authors differentiate between one-leg skate and double-skate techniques. Scherrer, however, breaks the double-skate technique down into symmetrical and asymmetrical, the difference being identical and different opening angles, arm/pole work and strength impulses. He further points out that weight shift from the push-off leg to the gliding leg occurs simultaneously with the pole push for the quasi-symmetrical double-skate technique whereas for the asymmetrical double-skate technique weight transfer from the push-off to the gliding leg happens before the pole push. Overall, there are six skating techniques: one-leg skate, four symmetrical double-skate techniques and one asymmetrical double-skate technique. Critique was voiced against the term symmetrical as it is believed that from a biomechanical standpoint correct identical opening angles, arm/pole work and strength impulses are practically impossible to achieve. Zipfel and Schwirtz (1993, 19) also argued against the term leading arm: stressing one arm would mean that the other arm would become relatively unimportant. Biomechanical rationale demands planting both poles simultaneously and on the same level. According to their view, small differences due to the position of skis, do not justify to speak of a new technique.

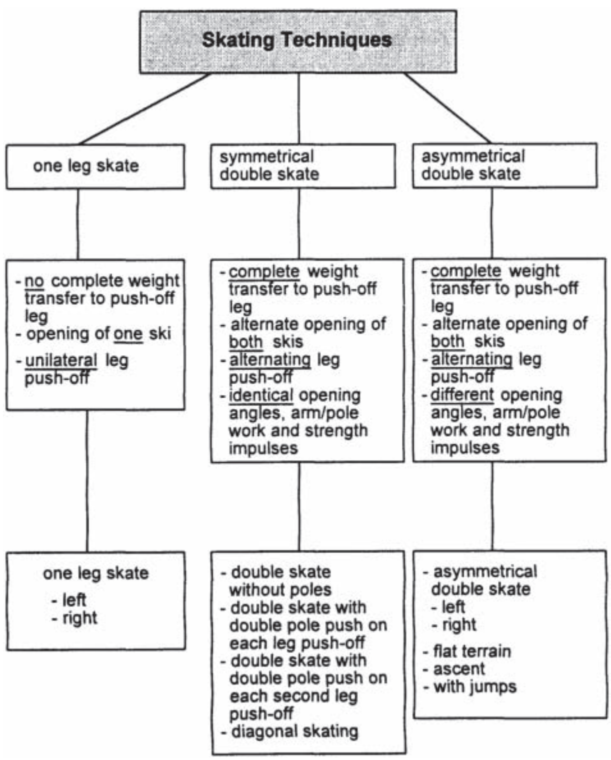

Fig. 3. Structure of skating techniques (Scherrer 1993, 22; translated by author).

After the discussion of both models, a new hierarchical structure of skating techniques was offered by Scherrer. Based upon five criteria of distinction (leg push-off, arm push-off, frequency, variation and direction) five techniques and three variants were identified (Fig. 4). The five techniques are one-leg skate, double skate without double-pole push, double skate with double-pole push on each leg push-off, double skate with double-pole push on each second leg push-off (details unspecified) and double skate with diagonal pole push. The three variants are part of the double-skate technique with double-pole push on each second leg push-off. The specifications are: with arm swing, with leading arm, and with leading arm and jumping.

Overall, the structure proposed is sound but not above any criticism. One weakness is that the five techniques cannot be identified at first glance in the very complex model. Besides, there is some overlap at the level of variants between the categories arm swing and leading arm. A skating technique carried out with a leading arm also requires an arm swing. The contrasting conceptual terms would be either with/without arm swing or with/ without leading arm. Although it must be admitted that the line of distinction is not easy to draw, from a phenomenological point of view, this author would tend to favor the former. Some competitors preferred the leading arm or paddling technique in steep ascents in competition until recently. From this standpoint it is justified to speak of a technique variation. The leading-arm technique has been replaced by the active armswing.

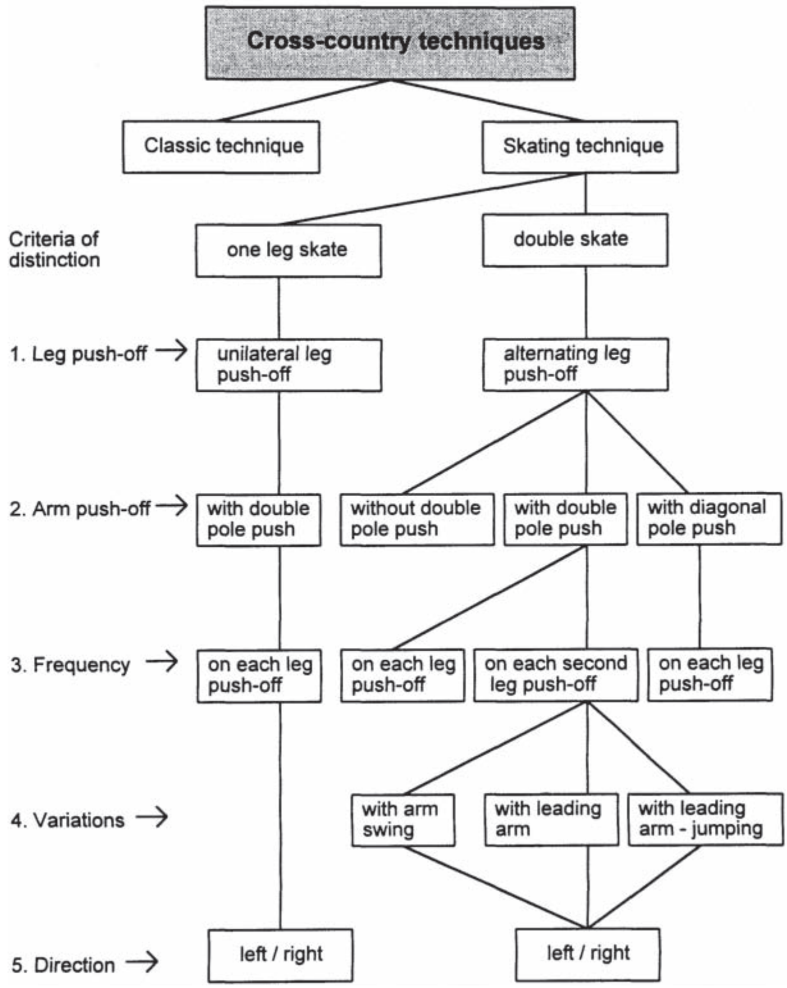

Fig. 4. Structure of skating techniques (Scherrer 1993, 37; translated by author)

The latest attempt to classify skating techniques was undertaken by *the Deutscher Verband für das Skilehrwesen* in 1996. With regard to form and contents, it obviously parallels previous models (Fig. 5). Overall, it displays a clear and detailed structure which is easy to read. Abbreviations are used for the double-skate technique with double-pole push on each leg push-off (1:1), for the double-skate technique with double-pole push on each second leg push-off (1:2) and for the double-skate technique with double-pole push on each second leg push-off with active arm swing (1:2 with active arm swing).

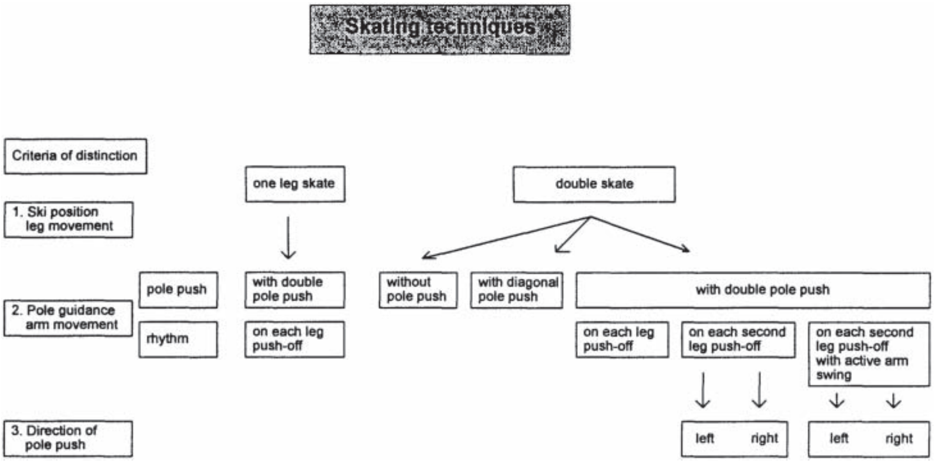

Fig. 5. Structure of skating techniques (*Deutscher Verband für das Skilehnvesen* 1996, 76; translated by author).

5 Deductive approach: Motor-program theory applied to cross-country skiing techniques

According to Schmidt (1988) a generalized motor-program is supposed to regulate a whole class of movement with the application of specific parameters. He postulated certain invariant characteristics that mark the pattern of neural activity of a program and at the same time define empirically a class of movement. The following invariants of generalized motor-programs are hypothesized:

1. order of elements of a motor skill
2. phasing—i.e., the temporal structure of the muscle contractions and
3. relative force—i.e., the amounts of force produced by muscles during a motor skill.

Thus, a motor-program controls force and time (impulse-timing hypothesis).

Program parameters or variants are overall duration, overall force, muscle selection and position of the limb towards the body. They can be read into a motor-program without changing its invariants.

This model which has been successfully applied to several open skills will be used for the classification of cross-country skiing techniques. A simple model of invariants and variants of major classic techniques used in present-day competition is illustrated in Fig. 6. Six techniques can be identified as different classes of movement: diagonal step in flat terrain and in ascents, double-pole push with and without kick, herringbone and transition techniques. The parameters total speed and total strength are relevant for all six techniques, the parameters opening angles for herringbone and transition techniques, the parameter jet movement of one leg or both legs for double-pole push with and without kick, the parameter pronounced weight on toes and direction of push (left/right) for double-pole push with and without kick.

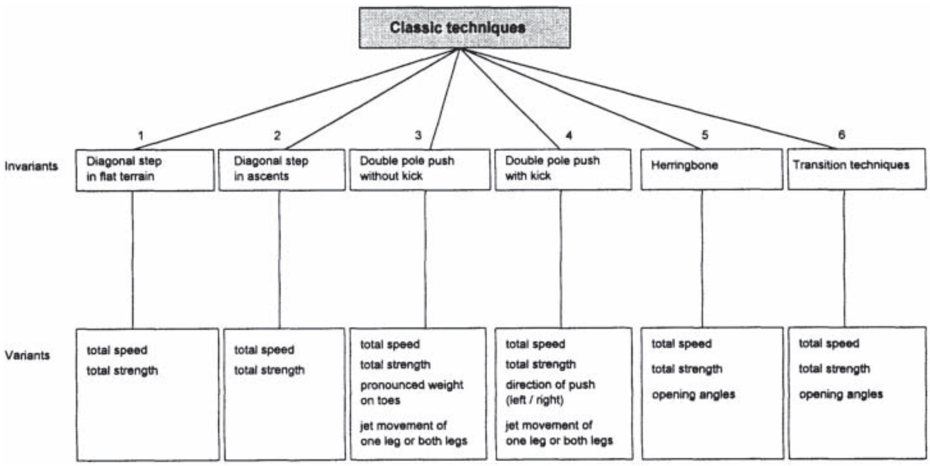

Fig. 6. Overview of invariants and variants of classic techniques used in present-day competition.

Comparing the results of both inductive and deductive approaches it can be concluded that there is practically no difference at the motor-program and parameter level.

Based upon the generalized motor-program concept, six movement classes can be identified in actual skating competition: one-leg skate with double-pole push, double skate without pole push, double skate with double-pole push on each leg push-off, double skate with double-pole push on each second leg push-off (arms/poles parallel), double skate with double-pole push on each second leg push-off (arms/poles parallel, active arm swing) and diagonal skating (Fig. 7). They are marked by different sequencing and/ or different relative timing and/or different relative strength impulses. The variants referring to the total speed, total strength and opening angle(s) are relevant for all six movement classes. Furthermore, the variants arms/poles oblique and direction of push (left/right) pertain to the two movement classes double skate with double-pole push on each second leg push-off (No. 4 and 5). Comparing Fig. 2, 3, 4 and 5 with Fig. 7 demonstrates that there are only minor differences between both approaches at the level of variants, e.g. the parameter direction of push (left/right) is missing in some models as well as the parameter arms/poles oblique.

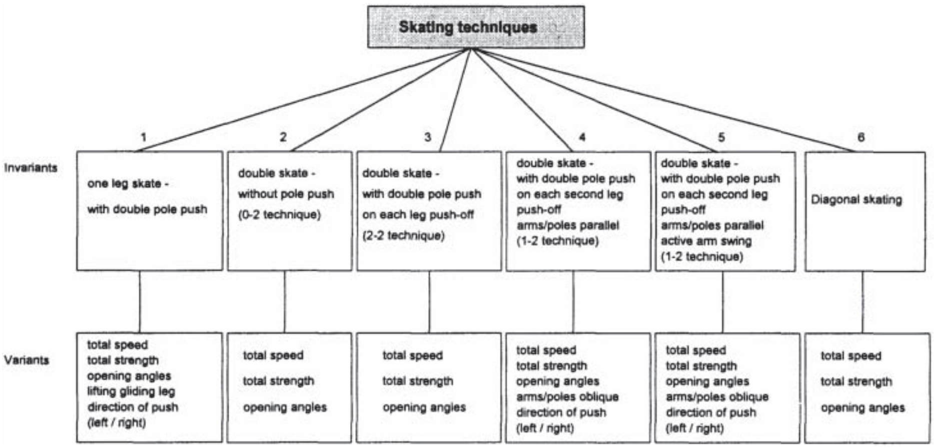

Fig. 7. Overview of invariants and variants of skating techniques used in present-day competition.

In the process of communication between coach/athlete or instructor/pupil, it is common to use numbers as abbreviation for certain techniques, e.g. 1–1 for the double-skate technique with double-pole push on each leg push-off or 1–2 for the double-skate technique with double-pole push on each second leg push-off. A closer look at these numbers reveals that they are either based upon a whole basic cycle (e.g. 1–2) or a half cycle (e.g. 1–1). One basic step cycle in the double-skate technique without the use of poles is made up of the following phases: leg push-off from the right ski, gliding on the left ski, leg push-off from the left ski and gliding on the right ski. As operation with numbers is desirable, it is felt that the whole basic cycle should be used as common denominator. Consequently it would be more adequate to use the numbers 1–2, 2–2 or 0–2 (for double skate without pole push).

6 Teaching Implications

Both cross-country skiing techniques can be classified as open skills as they are performed in relatively unstable and unpredictable environmental settings. In order to meet the environmental demands, many skills are required with a lot of variations. In teaching two main approaches can be identified:

- linear approach

It is costumary in cross-country skiing classes to have one or two teaching units (2 hours) a day. After a short introduction into elementary skiing skills, the teacher chooses his progression of skills, such as diagonal step in flat terrain (2 hours), double poling with and without kick (2 hours), etc. It is important to note that one movement class is in the center of each teaching unit and that the highest level of perfection is attempted. Empirical evidence shows that variable practice will result in greater learning (variability of practice hypothesis). Therefore, the teacher should be encouraged to use a variety of parameters with the same program. Practice variability will provide a widely based set of experiences upon which a rule or schema can be built (Schmidt 1988, 488).

- concentric approach

In contrast to linear learning, the concentric approach emphasizes the teaching of several skills in one unit from the very beginning. For example, the learner is given several trials in the diagonal step before moving on to double poling etc. The progression of skills can be fixed or randomized. The principle of variable practice of parameters can also be implemented. The goal of the first day is not striving for perfection but exposing the learner to several motor-programs. On the following days the same routine is maintained entailing a steady improvement in performance. The advantages are obvious: positive transfer from skill to another, fewer learning plateaus, less monotony, more positive experiences and independence from a cross-country ski stadium. Evidence based upon positive effects from contextual interference (Schmidt 1988, 395 ff.) would make it worthwhile to set up a study comparing the following experimental conditions:

- randomization of classic and skating techniques,
- randomization of classic techniques and
- randomization of skating techniques.

If propositions of contextual interference hold true, the first condition should turn out to be the most effective way to learn.

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Part Four

Physiology of Skiing

37

THE PHYSIOLOGY OF COMPETITIVE C.C. SKIING ACROSS A FOUR DECADE PERSPECTIVE; WITH A NOTE ON TRAINING INDUCED ADAPTATIONS AND ROLE OF TRAINING AT MEDIUM ALTITUDE[1)]

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[1)] This article includes previously unpublished data continuously collected since the early 1970's. P.D.Gollnick was a co-investigator in the first studies together with Eva Jansson and Bertil Sjödin, and lately Bengt Stattin and his junior skiers have made decisive contributions.

Keywords: aerobic capacity, cross-country skiing, anaerobic energy yield, muscle fibre types, altitude and training.

In Northern Europe c.c. skiing has a long tradition as a mode of transportation in winter times. Skis have been found in a peat moss in Scandinavia, dated back thousands of years. Very interesting is that the very old skis closely resembles those made early this century and which most of this century's older generation used when they were taught the basic skills of c.c. skiing. In this perspective the changes which have occurred over the last half a century are dramatic. They are closely linked with c.c. skiing nowadays barely being important for transportation, but instead a competitive sport where survival at the international scene to a large extent depends upon its attraction for the media. Some of these technical developments have had a significant, positive impact on the recreational skiing, both when performed leisurely in the home terrain as well as when exploring mountain areas.

In this article some of the effects of these technical "developments" on the training and the bodily adaptation of the competitive c.c. skiers will be analyzed. Special focus will be on the last four decades, one reason being that a broad range of reasonable measurements on good c.c. skiers are available over this time span. Another is that skating was introduced as a separate discipline in c.c. skiing in this period which has markedly affected the training performed by the c.c. skiers. The harmonic interaction between arms and legs has always characterized the skilful c.c. skier, but today's skiing has put a greater demand not only on the arms, but on the whole upper body as well as the gluteal muscles. Thus, a major focus will be on the adaptation induced by the more pronounced whole body involvement in c.c. skiing with training of arms, shoulders and muscles of the torso and hip region. Moreover, as training and competing at medium altitude is an integrated part of all competitive c.c. skiers' yearly programme, this subject is also touched upon.

1 Aerobic capacity and its utilization in c.c. skiing

Maximal oxygen uptake: C.c. skiers have always been in the lead among endurance athletes in regard to maximal aerobic power. Some of the first measurements in the 1960's revealed for male c.c. skiers values between 80–85 ml kg^{-1} min^{-1} among those winning the major races. Gradually higher levels close to 90 ml kg^{-1} min^{-1} have been reached and the very best may even be above this level today (Fig. 1; see also Ingjer, 1991). Female c.c. skiers have also a very high maximal oxygen uptake (Vo_2max), but at about 10 ml kg^{-1} min^{-1} lower level. In the 1960–1970's a Vo_2max of 70–75 ml kg^{-1} min^{-1} was sufficient to be a world leader whereas the very best today most likely are around 80 ml kg^{-1} min^{-1} or just above. In comparison with other athletes the c.c. skiers have the highest reported Vo_2max' normalized for body weight (power 1, 3/4, or 2/3). Rowers and possibly bicyclists and swimmers are in the same range as the c.c. skiers when the Vo_2max is expressed in 1 min^{-1}, but they usually have a larger body mass except for the bicyclists (Bergh, 1987; Gullstrand, 1992; Mikkelsen, 1980; Secher, 1992).

Some skiers are also heavy, but still very successful. One example is Juhani Mieto who when in training (1970's) had a Vo_2max of 7.40 1 min^{-1}, weighing 96 kg, giving a value per kg body weight considerably lower than found among his competitors. Nevertheless, he was most successful. This highlights the difficulty in c.c. skiing to properly adjust for body mass when evaluating performance capacity and efficiency (Bergh, 1987). It is easier in running (on the flat) when normalizing for body size to power, 2/3 or 3/4 appears to be the best predictor (Svedenhag, 1995) or in rowing where as high values as possible in 1 min^{-1} has a good predictive value (Secher, 1992). In c.c. skiing, snow condition and the profile of the track influence whether the total or a weight normalized value is the best predictor. A hilly track and poor gliding favours the smaller skier. Skiing on the level with superb gliding favours the tall and more heavy skier. Skating may minimize the role of variation in body size among c.c. skiers which means that oxygen uptake in 1 min^{-1} is more critical than in ml kg^{-1} min^{-1} (or ml $kg^{-2/3}$ min^{-1}. In fact, up until the 1989's few if any c.c. skiers have won medals in a major championship without being very close to or above 6 l min^{-1} in Vo_2max regardless of body size (Bergh and Forsberg, 1992, and unpublished data).

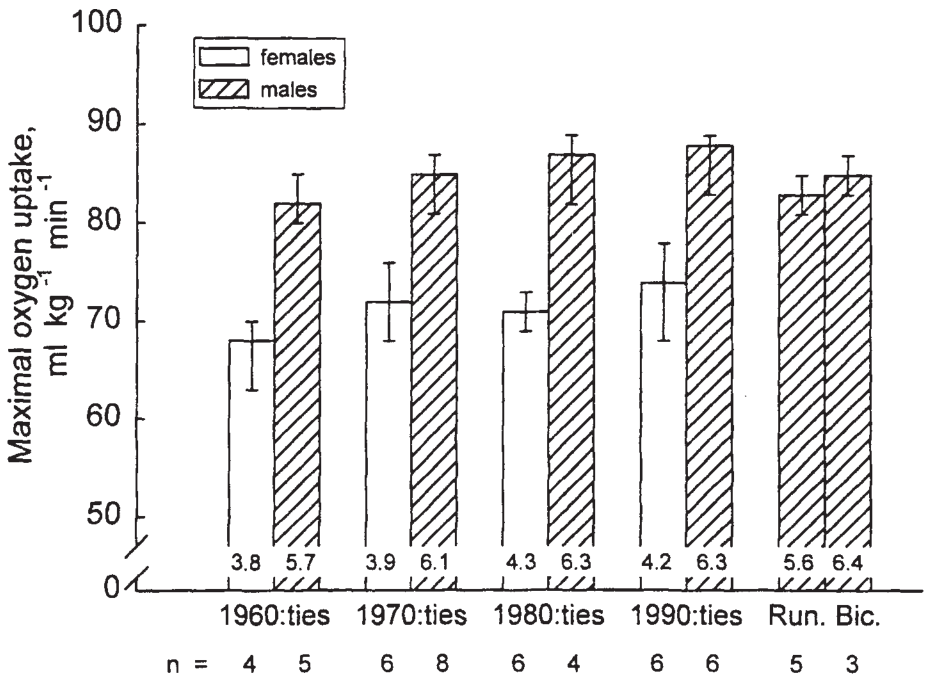

Fig. 1. Maximal oxygen uptake in female and male elite skiers in Sweden (the 1970 data also include 4 Finish skiers (3 and 1) studied during uphill running). Note that male skiers have in each decade belonged to the winners in major championships whereas the females only did in the 1970's. In the 1990's the Swedish female skiers are within 5% of the winners' time. Far to the right are the highest observed maximal oxygen uptake values observed in runners and bicyclists studied in our laboratory in the 1980–90's. Data from Bergh and Forsberg, 1992; Mikkelsen, 1980; Saltin and Åstrand, 1967; Saltin, Larsen et al. 1995, Sjøgaard et al., 1982; and unpublished data.

Relative exercise intensity: In running and bicycling it is quite well established at which relative exercise intensities (Vo_2 in percent of Vo_2max) athletes are operating in different events. In competitions lasting up to 15– 20 minutes they utilize their whole Vo_2max (Noakes, 1991). Still in events lasting 30 min they are at or above 95% of Vo_2max (Savard et al., 1987) and some are able to complete a marathon with a relative oxygen consumption of around 90% (Costill et al., 1973; Noakes, 1991). Indeed, the mean value for top level marathon runners is 88% with a rather narrow range. Of note is also that not so well-trained people can exercise above 80% Vo_2max for two hours (Costill et al., 1973; Savard et al., 1987). A difference in performance in endurance events is then primarily a function of maximal aerobic capacity, which can vary with a factor of two, whereas the utilization of this capacity only varies within a range of up to 10 percent at the most. Although the difference between the one being able to use a high compared to a low fraction of Vo_2max during a long race is not that impressive, its role in competitive c.c. skiing should not be underestimated. It may mean a difference in time of 3–6 min in a 30 km race.

It could be anticipated that a c.c. skier could exercise closer to his/her Vo_2max than for example the runner as the exercise is performed by a larger muscle mass. However, the limited number of measurements available in c.c. skiing suggests that this is not the case. With the reservation that available measurements properly represent the average load, the relative intensity that can be maintained in c.c. skiing is very similar to the one observed in running and bicycling. This means that like in running the skier operates at or close to Vo_2max throughout a 5 km race. The fraction of Vo_2max utilized at 10–15 km would average close to 90–95% of Vo_2max (Fig. 2), and at 30 and 50 km the relative exercise intensity ought to be 90–95 and 85–90%, respectively (Fig. 3). Available data indicate no major difference in this variable comparing the classic and the skating techniques (Fig. 2). Whether today's c.c. skiers not only have higher Vo_2max, but also can maintain a higher fraction of Vo_2max during longer races is unknown. Large volume training has always been characteristic for c.c. skiers which would argue for the c.c. skiers always being among those in the upper range in regard to utilizing a very high fraction of the Vo_2max when competing also in the past.

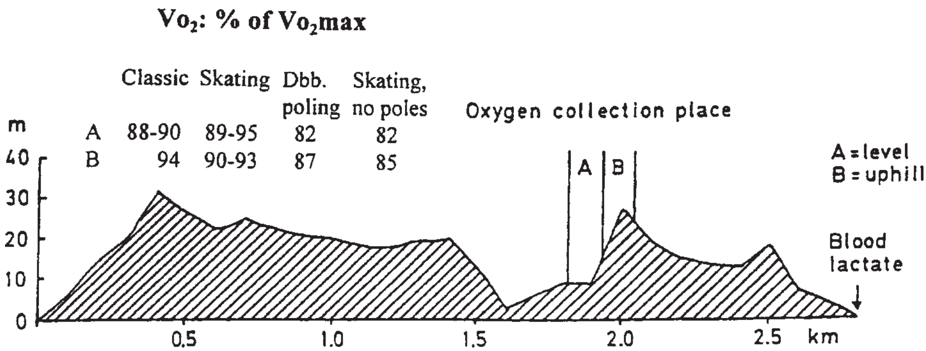

Fig. 2. Graph adapted from data from Mygind et al. (1994) giving the track profile and relative oxygen uptake (Vo_2: % of Vo_2max) for international elite junior skiers when using different techniques in c.c. skiing. The length of the lap was 2.75 km and the total distance was 13.75 km (5 laps).

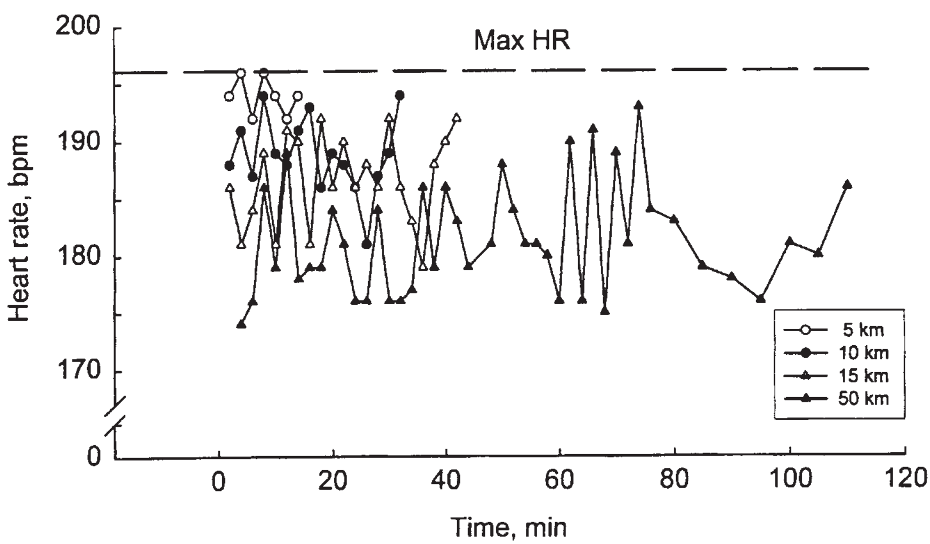

Fig. 3. Heart rates for elite skiers racing (skating) over different distances. Five and ten km=♀(n=3); 15 and 50 km=♂(n=4). Mean blood lactate concentration was 11.2, 12.6 and 10.8 mmol l^{-1} after the 5, 10 and 15 km race, respectively, and 8.6 $mmol^{-1}$ after the 50 km race (unpublished data).

Efficiency: In bicycling the mechanical efficiency is easy to determine very precisely and is found to be similar comparing the novice with the Tour de France winner (Sjøgaard et al., 1982). In running where the measurement of efficiency is more an estimate it appears that there may be vast differences in running economy, not only comparing physically inactive people with experienced runners, but also between competitive runners (Saltin, Larsen et al., 1995; Svedenhag, 1995). The very best may be running (>10.000 m) at racing speeds of up to 10% more economically than more mediocre runners. One would anticipate that in c.c. skiing, being technically demanding, that the energy costs for a given speed and technique also could differ markedly between good c.c. skiers. The problem is that it is difficult to prove. In part this relates to the problem above of normalizing for body size (Bergh, 1987). In addition, the gliding of the skis can be difficult to equalize not to mention that various skiers may prefer differences in this respect, although snow condition, track and technique are identical. This being the case, it is no surprise that our knowledge about the energy costs of c.c. skiing is very limited using different techniques under various snow conditions and with skiers having different body size (for a more thorough account, the reader is referred to Bilodeau et al., 1991, 1992; MacDougall et al., 1979; Sabiene et al., 1989; Smith et al., 1989; Smith, 1992). Here will only be mentioned that the racing speed maintained in skating is higher than with the classic style (Mygind et al., 1994). The difference varies between some few up to 10–15% (Mygind, 1994) with the largest difference observed on the level narrowing down in steep uphill where the diagonal produces the same speed as the skating. Although there is this difference in speed, the energy costs are more similar, almost negligible, which points at skating being the most economical technique (for the skilled c.c. skier) albeit the condition of the tracks being decisive for the energy costs.

Upper vs. lower body exercise: The predominant technique in c.c. skiing was traditionally the diagonal which was very rhythmical, and only occasionally this rhythm was broken using double poling with or without a gliding step instead. In races where this nowadays called “classic style” is mandatory this pattern is still there, but the variation between the use of the diagonal or the double poling is much more frequent today. What has contributed to this development is that the tracks are more varied and the gliding is improved, but also that c.c. skiers have improved their upper body exercise capacity quite markedly. The introduction of roller skis in the training brought this about, but equally important is that in skating, arm and upper body capacity is so critical for optimal performance that the c.c. skier had to pay special attention to such training. It is this improvement in upper body function that has made it possible also in a "classical" race to use double poling in parts of the track where earlier the diagonal was the preferred technique.

One good verification of this improved upper body exercise capacity is that close to the Vo_2max obtained during uphill running or skiing can nowadays be reached when only the arms, shoulders and torso perform the exercise (Fig. 4).

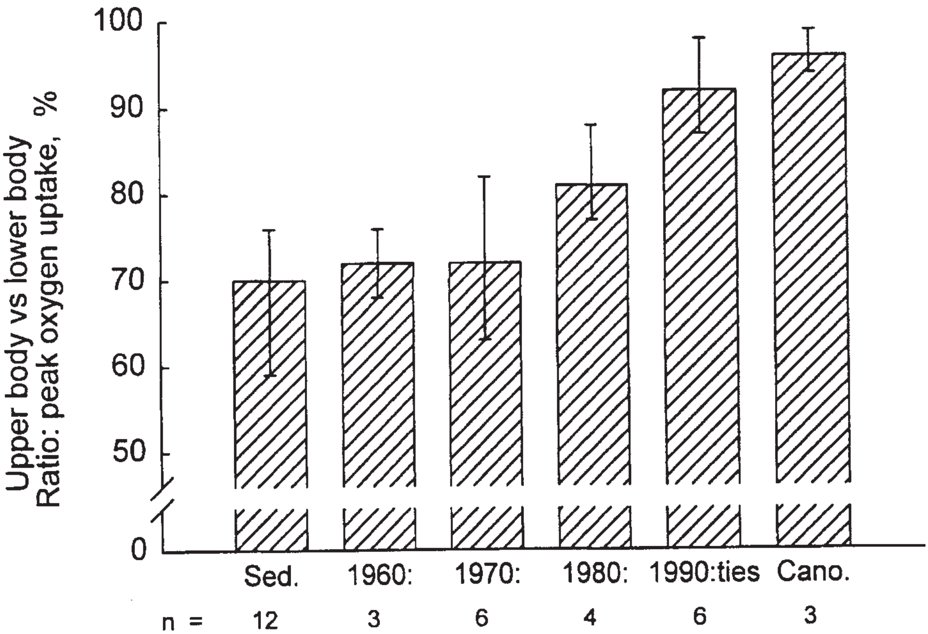

Fig. 4. The ratio between peak oxygen uptake for lower and upper body in elite c.c. skiers and sedentary persons. For this latter group, in the 1960's and 1970's, the upper body exercise consisted of "arm bicycling" with the shoulders below a horizontal line through the arm. Lower body exercise was running uphill on a treadmill or bicycling. In the 1980's and 1990's the upper body exercise was double poling in a ski ergometer (Mygind et al., 1991) or on roller skis on a treadmill. There are female c.c. skiers in all groups and they were not different from the male skiers. Data from Åstrand and Saltin, 1961; Bergh and Forsberg, 1992; Mygind et al., 1994; Saltin and Åstrand, 1967, and unpublished data. The data on the canoeists are from Dal Monte et al., 1992 and Saltin, 1968.

In sedentary man, upper body exercise reaches a Vo_2 peak around 70% of Vo_2max. C.c. skiers were around that level in the 1960's and 1970's whereas today's' skiers may indeed reach 90% or more of Vo_2max when exercising with the upper body alone. In Scandinavian skiers this ratio between upper and lower body has been found to vary during a year being the highest during the skiing season (Dittmar et al., 1980; Sharkey and Heidel, 1981). Obviously the specific upper body training which has become mandatory in recent years has made the c.c. skiers, especially when performing well, similar to the canoeists, i.e. these latter athletes have an upper body Vo_2 peak which almost approaches their Vo_2max, although there is the important difference that the skiers have a much higher Vo_2max than the canoeist (~85 vs ~65 ml kg^{-1} min^{-1}).

What limits maximal oxygen uptake: It is impressive that just by using upper body exercise it is possible to utilize almost the whole Vo_2max, which has important performance-related consequences, but also raises the question of what limits Vo_2max of man. Since the experiments by Taylor et al. (1955) who had a subject to perform arm cranking when walking-running on a treadmill there has been and still is a heated unsettled debate on this topic. What they demonstrated was that Vo_2 peak was higher when the larger muscle mass was engaged in the exercise. Others have found the same trend. Hermansen (1973), for example, had his subjects running on the treadmill and performing arm exercise using ski poles. The difference he found, however, was only 3%, which is similar to what was found by Strømme et al. (1977) when comparing uphill running with skiing. Later studies have confirmed that with the proper combination of arm and leg exercise, most subjects reach the highest Vo_2 when the largest muscle mass is engaged amounting to an increase of 0–10% (Bergh et al., 1976; Secher et al., 1974). The question is how to interpret this finding. It appears that peak cardiac output is not higher in maximal arm and leg exercise than in maximal leg exercise, which means that the a-v O_2 difference is wider due to a lower O_2 content in the venous blood (Åstrand et al., 1965). The larger O_2 extraction is probably a function of longer mean transit time when the blood is passing through the muscles, as the blood flow is less when it is distributed in a larger muscle mass (Saltin, 1988).

It is a question of definition whether Vo_2max is said to be limited by muscle mass or not. The critical finding is that cardiac output is not further elevated when more muscle mass is engaged in the exercise above a given amount which appears to be 10–15 kg of muscle (the topic is discussed in more depth elsewhere, for review, see: Saltin, 1990). With the pumping capacity of the heart setting an upper limit for oxygen transport it is easy to explain the high oxygen uptake in upper or lower body exercise/skiing that is observed in c.c. skiers compared to combined arm and leg exercise/skiing. With the proper training either one is sufficient to tax close to or peak cardiac output.

There is one more point to be highlighted. Most skiing is performed using both arms and legs. There has then to be an appropriate balance between the force developed by the various muscle synergies to optimize speed, and not completely fatigue one or all of them which will occur if the total energy demand surpasses the peak capacity for oxygen delivery for more than very brief periods (~30s?). Very precise regulations are operating where the maintenance of the blood pressure appears to be the key regulated variable (Rowell, 1980). The practical aspect which is worthwhile to emphasize is that c.c. skiing is a unique discipline which allows the technically skilful athlete to choose the optimal technique at any given moment of the race, involving upper or lower body in different combinations of the two to obtain the highest possible speed. Another advantage is that the variation in loading the various muscles minimizes fatigue development, to which can be added the brief "relief" offered in the downhill parts of the track, at least for the arms. C.c. skiing is very different in this respect, compared to for example distance running or bicycling as well as a sport like rowing, which also strongly engages all muscles of the body.

Role of skeletal muscle aerobic potential: The role of the pump capacity of the heart is emphasized for a high Vo_2max and the superiority of c.c. skiers in these respects are well documented. Less data are available on skeletal muscle adaptation and its role for maximal oxygen uptake. Some early studies revealed that various enzyme activities were markedly higher in skeletal muscle of c.c. skiers than what was found in muscles from sedentary subjects (Table 1). Of note, however, was that the difference was slightly less marked for the arm as for the leg muscles. Compared to other endurance athletes, the c.c. skier were similar to road bicyclists, but somewhat above runners (long distance and orienteers) in their leg muscles, which means 2–3 fold higher oxidative enzyme activities than observed in untrained muscles (Gollnick et al., 1972). Comparing the thigh with the gastrocnemius muscles of c.c. skiers, the two muscles are similar. Arm muscles are in the 1990's still not at the same high level as the leg muscles. Over the last three decades the arm muscle enzyme activities have been approaching the level observed in the leg muscles, at least judged by comparing m. triceps brachii and vastus lateralis in elite junior skiers and in Danish elite (Mizuno et al., 1990; Mygind, 1994).

Table 1. Some characteristics of elite c.c. skiers in the early 1970's, including % ST fibres and SDH activity in a leg (vastus lateralis) and an arm (m. deltoideus) muscle. Enzyme activities were run at 25°C (unpublished data).

Group	Body weight, kg	Vo_2max ml kg^{-1} min^{-1}	Ratio upper vs. lower body, %	% ST fibres		SDH activity, mmoles kg^{-1} min^{-1} w.w.	
				Leg	Arm	Leg	Arm
1970's; Finish and Swedish elite							
♂, n=13	76	80.3	74	76	68	9.8	7.8
	63-91	75-86	65-86	63-91	61-79	7.8-11.2	5.5-9.2
♀, n=2	60	72	68	77	64	9.9	7.0
	59-61	69-75	65-71	75-79	63-65	9.4-10.4	6.9-7.1
Sedentary, n=11	72	43.1	69	48	46	4.1	3.6
	55-95	31-56	54-76	28-95	26-64	3.5-4.8	2.9-4.1

Skeletal muscle mitochondrial enzyme activities appear to adjust more quickly and more pronounced with physical activity-inactivity than Vo_2max, shown nicely in road runners (Houston et al., 1979) and already in the early 1970's in c.c. skiers (Fig. 5). This has led to the still in part unproven hypothesis that the major role of an enhancement in muscle mitochondrial oxidative capacity is not a prerequisite for elevating Vo_2max, but rather that it affects muscle metabolism (Gollnick and Saltin, 1982). Lipid oxidation can cover a larger proportion of the energy turnover and the carbohydrates are spared with less lactate formed and an increased capacity to utilize lactate as a substrate (Kiens et al., 1992). With the extraordinary adaptation observed in trained muscles of c.c. skiers, they are able to utilize a large amount of fatty acids although the relative work load is 90% or above as indicated by very low RER values while skiing at such a high relative intensity (Table 2), and most likely concomitantly producing lactate continuously while skiing.

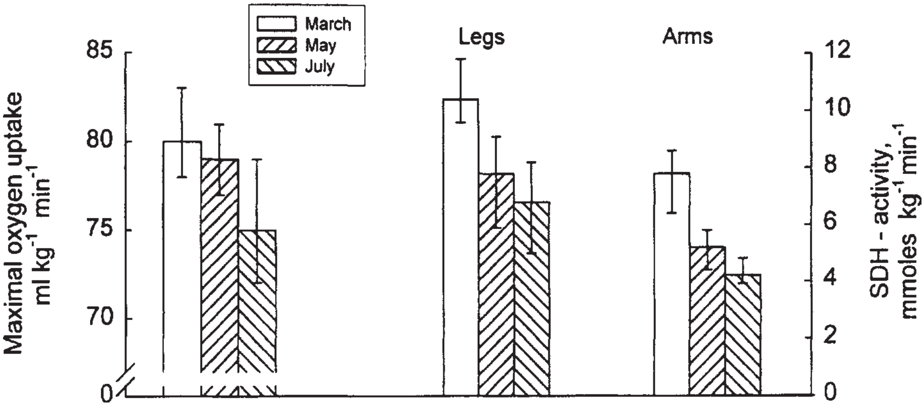

Fig. 5. Data on maximal oxygen uptake and SDH-activities (25°C) in leg (vastus lateralis) and arm (m. deltoideus) muscles in elite skiers studied in the early 1970's at the end of the season (March) after at least a month of no skiing and very little training (May) and just before the training started again (July) (unpublished data).

Table 2. Respiratory exchange ratios when skiing with different techniques in racing speed on the flat and in the uphill (steep). The relative exercise intensity is given (%Vo_2max). The Vo_2max of the subjects was 5.61 min$^-$ (76 ml kg^{-1}min^{-1}). The mean ventilation was around 150 l min-1 and blood lactate was 8 mmol in the different conditions (Mygind et al., 1994).

	Classic				Skating	
	Diagonal		Double poling			
	% Vo_2max	RER	% Vo_2max	RER	% Vo_2max	RER
Level	88	0.89	88	0.89	91	0.91
Uphill	93	0.92	93	0.93	91	0.93

2 Anaerobic energy yield

Lactate: Mygind et al. (1994) has performed the study that challenges the concept that c.c. skiing is a mere endurance event where only the aerobic energy yield is of significance and no lactate is accumulating. In simulated races over 14 km they found that blood lactate concentration was between 5–10 mmoles 1^{-1} after 5–10 minutes of skiing and the level had an upward slope reaching between 10–20 mmoles l^{-1} at the end of the race lasting some 40 min (Fig. 6). Measurements during and after competitive races confirm that today's c.c. skiers have high blood lactate throughout a race, mean values being above 10 mmoles l^{-1} in races over 5–15 km (see legend to Fig. 3). Classical skiing and skating alike. Studies in the 1960's indicated that in longer races, the blood lactate concentration in the finish was quite low (Åstrand et al., 1963), but in today's races this is hardly the case (see also Fig. 3). The higher speed and shorter racing times as well as more of a variation of the track have contributed to lactate being accumulated, also in races lasting well above an hour.

There is the possibility that the c.c. skiers produce this lactate early in the exercise with only very small amounts being produced in uphills later during the race. The high degree of accumulation in the blood should then be due to a low rate of lactate turnover, and thus the total amount of energy released from anaerobic glycogenolysis in c.c. skiing is quite small. Some biomechanical data challenge this interpretation. During the Winter Olympic Games in Calgary the skiers were filmed and analyzed in order to biomechanically estimate the energy turnover in different parts of the track (Norman et al., 1989). The very interesting finding was that in short steep uphills (<20 s) the estimated energy turnover in O_2 Eq amounted to 110–120 ml kg^{-1} min^{-1}. This surpasses even the very best skiers' Vo_2max by some 20 ml kg^{-1} min^{-1}. The tracks in the Calgary games contained many of these short uphills. Can it be that the skiers in the uphills add arms and upper body to the leg kick to the extent that on the top of using the Vo_2max, the anaerobic energy repeatedly supplements the aerobic energy yield with an additional ~20 ml kg^{-1} min^{-1} O_2 Eq? For this to occur, the turnover of lactate in the body has to be quite high. It is known from the work of Essén et al. (1975) that lactate can be taken up by working muscle and that most likely the lactate can function as a substrate, i.e. it is after conversion to pyruvate oxidized in the mitochondria. There is indeed evidence for lactate being taken up by exercising muscle in sufficient amounts to account for a substantial metabolism of lactate during continuous exercise at a high relative exercise intensity.

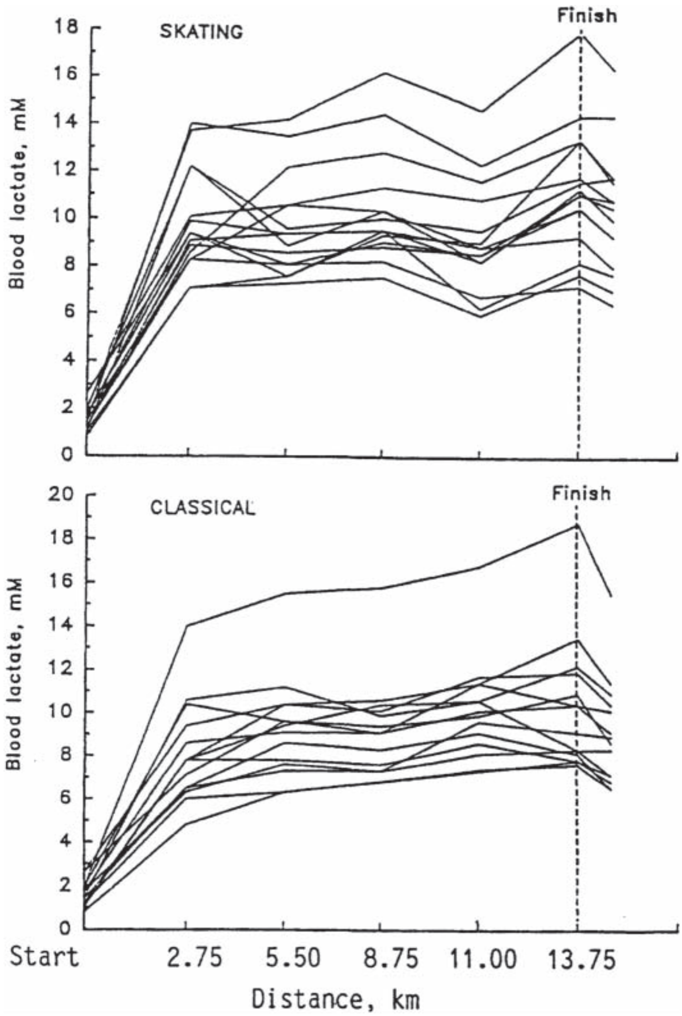

Fig. 6. Blood lactate concentrations during a simulated race over 13.75 km hr-1 in elite junior Swedish and Danish c.c. skiers. Measurements was performed after each 2.75 km (see Fig. 2). Adapted from Mygind et al., 1994.

When legs are exercising at ~ 80% of Vo_2max there is a substantial lactate release over the leg (Fig. 7). When the arms are added and the work load adjusted to just reach Vo_2max, the release of lactate over the leg is changed to an uptake which amounts to 5 and in some subjects up to 10 mmoles min^{-1} and lasts for several minutes. Moreover, the lactate uptake by the exercising legs continues when supra-maximal exercise is performed by adding more work to the arms. When the arm exercise is terminated a release of lactate from the legs is again observed. Thus, the answer to the question raised earlier of whether anaerobic energy contributes significantly in c.c. skiing is that it probably does! The relative contribution is naturally the largest in 5–10–15 km races, especially on very varied tracks in regard to up- and downhills. However, it most likely plays a major role also in today's 30 and 50 km races provided the skier is technically skilful and can vary the technique to maintain the very high speed, by intermittently unloading legs or arms to allow for lactate to be taken up and metabolized in either the legs or the arms. It needs, however, to be proven that arm muscles are able to take up and metabolize lactate similarly to the leg muscles. Although there is good support for the notion that lactate is produced and metabolized during ongoing skiing at racing speed the dominant energy release comes from mitochondrial oxidation. Based on the values for lactate uptake by leg muscles in the experiments cited above, the anaerobic contribution in a 15 km race may amount to 10% of the total energy utilized, increasing at the most to 20% in 5 km.

The limits of the anaerobic energy production is to be found within the skeletal muscles. Critical factors could be glycogen stores, glycogenolytic enzyme activities including lactate dehydrogenase, buffer capacity and membrane transport of protons and lactate. The stores of substrate are sizeable and after a carbohydrate rich diet trained muscles can double or triple the glycogen content, reaching 150 mmol kg muscle (wet weight) or even more (Bergström et al., 1973). Thus, the primary limitation is not substrate until the distance is above 30 km. It is of note that depending upon the loading of the arms and legs, the glycogen can be depleted earlier in one of the extremities than in the other (Bergström et al., 1973). The relevant enzymes in the breakdown of glycogen (glucose) to pyruvate are not limiting either as they only have to be activated to some 10–15% of their V_{max} to produce peak rates of glycogenolysis (Gollnick et al., 1978).

More difficult to answer is why lactate is formed in the first place. Why is not all the pyruvate that is produced used by the mitochondria? With the recent findings that the activation of pyruvate dehydrogenase is maximal at Vo_2max, it appears that there is a major mismatch between pyruvate production in intense exercise and the capacity for pyruvate to be decarboxylated (Timmons et al., 1996). The formation of lactate from pyruvate follows the law of mass action with lactate dehydrogenase (LDH) as the catalyzing enzyme (Huckabee, 1958). There are five isoforms of LDH and the dominant isoform is LDH_{4-5}, but LDH_{1-2} can also be found (10–20%) in human skeletal muscle (Fig. 8). Whether lactate is formed depends upon substrate (pyruvate) availability and the NAD/NADH ratio. To favour the opposite reaction, i.e. lactate to pyruvate, there is not only the need for lactate as substrate, but also a very high NAD/NADH ratio, which means that the muscle must be well oxygenated.

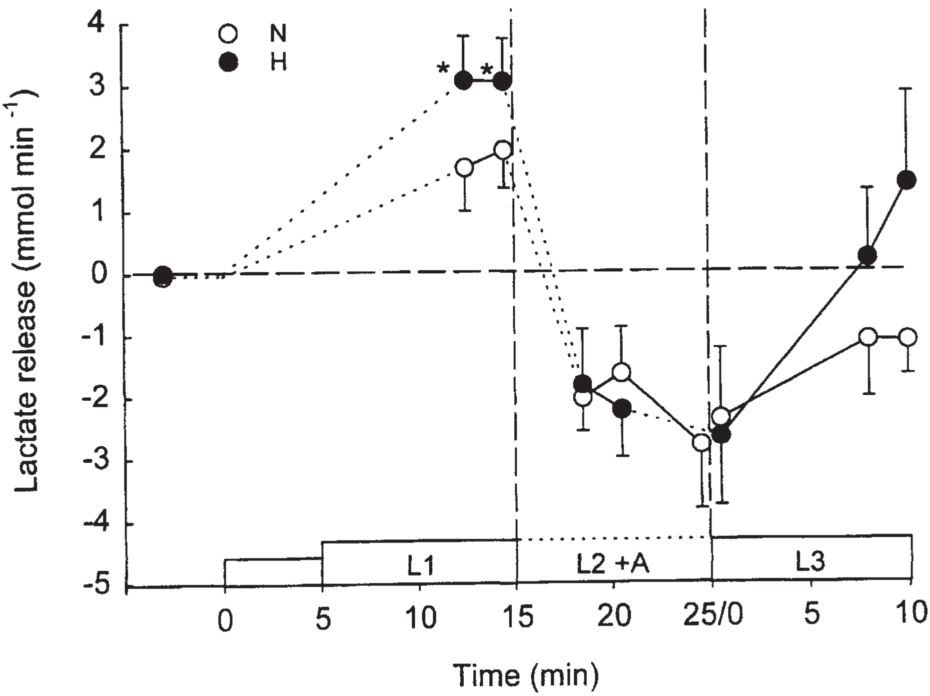

Fig. 7. The uptake or release of lactate over exercising legs when performing only leg work at ~80% Vo_2max (L1), leg+arm work (L2+A) with a Vo_2 demand above maximum, and again with only the legs (L3; Vo_2 ~80% Vo_2max). The unfilled circles denote normoxia and the filled hypoxia (~15% 0_2 in N_2; ~2000 m.a.s.l.). Note that during L1 there is a release of lactate from the legs, but in spite of the fact that the legs continue at the same work rate, the release turns to a substantial uptake when the arms are added. This uptake continues for a while during L3, especially in the normoxic condition (Bangsbo et al., 1996).

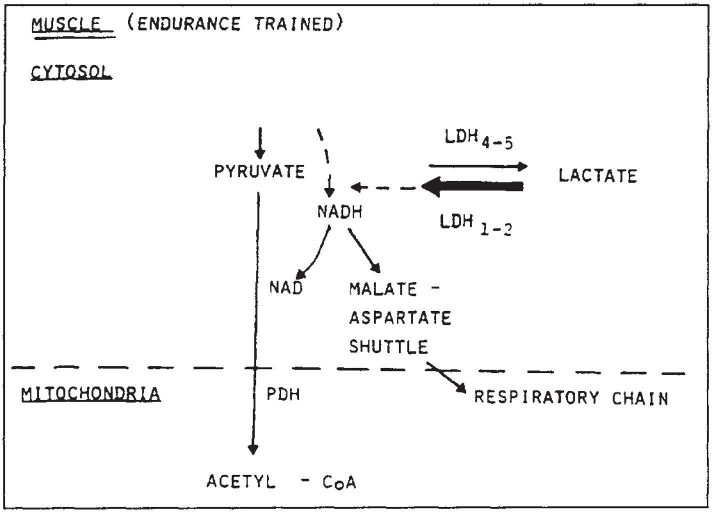

Fig. 8. A schematic presentation of the fate of pyruvate and the role of the LDH isoforms. Note also the pyruvate dehydrogenase and its critical role for the pyruvate being processed by the mitochondria. The arrow from lactate to pyruvate is marked especially to highlight that this reaction can occur in skeletal muscle of man. Quantitatively the LDH_{4-5} activity is, however, 3–5 times higher.

Runners specialized in 400–1500 metre races have considerably higher V_{max} for LDH_{4-5} than 10000 and marathon runners (Svedenhag et al., 1991). In contrast, LDH_{1-2} is higher in the long distance runners. Typical ratios for LDH_{1-2}/LDH_{tot} are 0.20–0.25 (middle-distance) to 0.30–0.35 (long-distance). C.c. skiers are like the long distance runners in their leg muscles, but more like middle-distance runners in their arm muscles (Table 3). However, a clear trend for arm muscles in c.c. skiers to be more similar to the leg muscles are observed in today's c.c. skiers. Moreover, focus on upper body training in the pre-season can substantially enhance the LDR_{1-2} fraction (~20%) in the m. triceps brachii elevating the ratio to ~0.35 (LDH_{1-2}/LDH_{tot}).

It appears then that critical for the glycogenolytic anaerobic energy yield is not only oxygen availability (NAD/NADH ratio), but also the mitochondrial oxidative potential as well as the LDH_{1-2}/LDH_{4-5} ratio. In regard to the mitochondrial enzymes there may be just one enzyme being critical, namely PDH, that, if it is trainable, which we do not know, could affect the fraction of formed pyruvate being a proton acceptor instead of decarboxylated and oxidized.

Table 3. LDH activity in arm (m. deltoideus) and leg (vastus lateralis) muscles in elite male skiers in the early 1970's and the middle of the 1990's. Mean values ±SE are given and ranges for the ratio (unpublisheddata).

	1970's		1990's	
	Arm	Leg	Arm	Leg
	(n=4)		(n=12)	
LDH_{1-2}	142±11	184±14	174±9	179±8
LDH_{tot}	589±34	496±28	552±21	487±23
Ratio	0.24	0.36	0.32	0.38
	0.21-0.29	0.32-0.39	0.28-0.36	0.32-0.42

In relation to the role of the muscle buffer capacity and proton and lactate efflux from skeletal muscle for the anaerobic metabolism, only limited knowledge is available. Muscle buffer capacity can be enlarged by training (Sharp et al., 1986). However, whether the proton and lactate exchange mechanisms over the sarcolemma are also affected by training is presently unsettled. In recent work the only group of athletes who has been shown to have an enlarged presence of lactate transporters are successful velodrome bicyclists, whereas short and middle distance runners, as well as road bicyclists, are insignificantly different from sedentary people (Pilegaard et al., 1994). The velodrome bicyclists are characterized by a high Vo_2max (~80 ml kg^{-1} min^{-1}) and a good finishing ability. C.c. skiers may be similar and have an elevated lactate (and proton) extrusion capacity, which will favour an enlarged lactate turnover. This is, however, still unproven.

It can be concluded that probably several variables are of importance for the lactate metabolism in skeletal muscle of c.c. skiers; muscle PDH activity, the LDH isoform ratio and the lactate transporters and possibly the muscle buffer capacity. This could mean that the anaerobic energy yield may be larger after special training. The problem is that we do not have the specific knowledge to design the optimal programme. The c.c. skiers to benefit most would be those who compete in 5–15 km races where anaerobic glycogenolysis is decisive in today's races. Thus, from being a purely aerobic event, c.c. skiing has developed to become more dependent upon an anaerobic energy release. This is true for both the classic and the skating techniques at the shorter distances, but as glycogenolysis most likely in the successful c.c.

skiers contributes energetically in the uphills also in 30 and 50 km races, the anaerobic capacity needs attention when training for all c.c. skiers.

3 Skeletal muscle

Muscle fibre types: C.c. skiers have a predominance of slow twitch (ST) fibres in their leg muscles (vastus lateralis and m. gastrocnemius) as well as in their shoulder muscles (m. deltoideus and triceps brachii; Table 1 and 4). Their muscle fibre profile is the one for an endurance trained athlete, but not as a group as extreme as seen among marathoners who may be at or above 80% ST fibres in their leg muscles (Gollnick et al., 1972; Saltin and Gollnick, 1983). The c.c. skiers are more around 70–75% ST fibres with only some skiers having a predominance of even more ST fibres. The question that as of yet cannot be answered is to what extent the observed muscle fibre composition is the result of the skiers' extreme endurance training. Junior skiers have similar muscle fibre composition as the successful seniors (Table 4). Moreover, today's skiers have the same fibre composition as those in the 1970's. The only, although weak, indication of an adaptation to occur is the arm muscle fibre composition observed in c.c. skiers. This is similar in m. deltoideus and in m. triceps brachii. Sedentary people may have some 5–20% less ST fibres in arm than in the leg muscles (Table 4).

No longitudinal studies on hard training in c.c. skiers are available to settle the problem of whether muscle fibre type transformation does occur. The closest is Schantz' studies (1986) of young adults skiing daily for 100 days with muscle biopsies taken before, during and after this 1000 km or longer ski-trip. They obtained signs of transformation of the fibre types, but no increase in ST fibres. In fact, there is no study available with a proper technique to determine fibre type composition (myosin heavy chain (MHC) isoforms), demonstrating complete transformation of fibres with the fast MHC isoform to only containing the slow MHC isoform. A small increase in the slow MHC isoform in fibres expressing predominantly the fast MHC isoform has been reported (Klitgaard et al., 1990). Thus, the slow MHC isoform can be made in all fibres, but the stimulus may need to be present for a very extended period; even longer than the time that c.c. skiers train. Experiments on rats indicate that 8 hours of daily running is sufficient for conversion to slow fibres at least in this species (Green et al., 1984).

Table 4. Comparison of relative occurrence of ST fibres in muscles of elite c.c. skiers since the 1970's. As very few (<5%) FTb fibres are observed in c.c. skiers, almost all FT fibres are of the FTa type. Female c.c. skiers are included in some of the groups, having muscle fibre compositions very similar to the males. Data from Bergh and Forsberg, 1992; Mizuno et al., 1990; Mygind, 1994; Saltin and Gollnick, 1983, and unpublished data.

	Vastus Lateralis	Gastrocnemius	Deltoideus	Triceps Brachii
Senior Skiers				
1970's				
n=9	-	75	75	-
	-	65-91	58-100	-
n=5	74	-	61	-
	63-84	-	45-74	-
n=7	72	69	-	-
	64-83	58-81	-	-
1980's-90's				
n=8	-	61	-	48
	-	57-72	-	32-61
n=10	68	-	-	53
	44-80	-	-	32-73
n=12	74	-	-	54
	57-85	-	-	38-60
Sedentary, n=8	52	53	60	36
	30-76	40-65	43-78	18-62

Muscle fibre area: C.c. skiers have a large muscle fibre area (see Table 5). This is true for arm and leg muscles, and for the female c.c. skiers as well. In contrast to muscle fibre types, fibre area is easily trainable (Andersen and Henriksson, 1977; Dudley et al., 1986). C.c. skiers in the 1990's have 15–25% larger fibre areas than those who were successful in the 1970's, which is most apparent for the arm muscle. The large muscle fibre area is probably a sign of high force demand in certain parts of a track for successful racing, but it is of note that not only FT, but also ST fibres have a large cross-sectional area. Thus, in addition to muscle endurance, there is a need for a muscle strength component as well, not the least for the upper body. Successful junior skiers trying to further improve their performance, who were engaged in a project where the upper body was trained significantly more than in ordinary pre-season training, obtained an enlarged muscle fibre size in m. triceps brachii with 10–20% for ST and fast twitch a (FTa) fibres with less of an effect on the FTb fibres. Female and male skiers were alike. Leg muscle fibre size (vastus lateralis) only changed marginally. In these junior skiers performance tests were applied, i.e. both peak power output of the upper body and the 2 km time in double poling on roller skis was determined. There was a positive coupling to fibre size not only when related to power output, but also to speed.

Table 5. Muscle fibre sizes (m^2 10^3) and capillary number per fibre ratio in groups of elite athletes before and after staying at various altitudes for different periods of time. Data from: Mizuno, et al., 1990; Svedenhag, et al., 1991; Svedenhag, et al., 1996.

Altitude m.a.s.l.	Duration weeks	Muscle	Physical Activity Level at Altitude	Mean Fibre Size Before/After	Cap Fibre^{-1} Before/After
~2100-2700	2; skiers	gastrocnemius	very high	5.2/4.7	2.6/2.7
		triceps brachii	very high	6.0/6.3	2.5/2.6
~2100	4; skiers	vastus lateralis	very high	5.9/5.6	2.8/2.7
~2100	2; runners	vastus lateralis	very high	4.9/4.8	2.7/2.7

Capillaries: Skeletal muscle of man contains some 300 cap per mm^2 which means ~1 cap per fibre. Endurance training causes a marked proliferation in muscle capillaries (Andersen and Henriksson, 1977). C.c. skiers are among the groups of athletes that have the highest number, similar to what is found in muscles of runners and road bicyclists (Mizuno et al., 1990; Mygind, 1994; Parsons et al., 1993; Saltin, Kirn et al., 1995; Sjøgaard et al., 1982). These athletes have up to or above 3 cap per fibre or above 600 cap per mm^2. The latter number is fibre size dependent whereas the former is not. In skiers with enlarged muscle fibre size, cap per fibre or capillaries found around a fibre or fibre type may be functionally most critical. In well trained leg muscles of skiers the various fibre types have similar numbers of capillaries (~ 5–7) whereas if the c.c. skiers have any FTb fibres, they only have 3–4 cap.

Important for the endurance of the muscle is that any enlargement of the muscle fibre size is matched with an enhancement of the number of capillaries. High resistance strength training results in an increase in fibre size, but in no or only a minor capillary proliferation (Dudley et al., 1986). Contracting monotonously for "endless" time with low resistance contractions induces an elevation in the number of capillaries and possibly fibre size reduction as sometimes observed with this type of training (Nygaard and Nielsen, 1978). C.c. skiers as road bicyclists cannot give up on fibre size as high force output is intermittently very important when racing. Thus, not only the endurance, but also the force component when training has to be considered to obtain a balance between fibre size and proper capillarization.

4 Altitude and c.c. skiing

C.c. skiing demands snow. This is available year round in mountain areas. Training on snow on glaciers at medium altitude in summer time was unheard of in the childhood of preparing for competitive c.c. skiing. Since the last couple of decades it has become mandatory! In the beginning the purpose was for maintaining discipline related training. Soon, however, several skiers felt that their performance became enhanced to an extent that could not be attained by similar training at s.l. Their personal experiences became beliefs and today it is accepted as a fact among not only c.c. skiers, but most athletes and coaches that training at medium altitude adds something that cannot be accomplished by training at s.l. or that it is achieved faster when hypoxia is added to the ordinary training stimulus. As training at medium altitude is an integrative part of the successful c.c. skiers' training schedule, the available research findings will be briefly reviewed (for more detailed coverage, the reader is referred to Saltin, 1996). Moreover, in c.c. skiing important events are frequently located at altitudes up to~1800 m.a.s.l., bringing up questions of how best to prepare for optimal performance at such an altitude.

5 Acclimatization to medium altitude

Maximal oxygen uptake: The aerobic capacity is quite sensitive to a lowering of oxygen availability, and endurance trained athletes are especially susceptible. They experience a lowering of their Vo_2max at an inspired pO_2 ~130 mmHg (~800–900 m.a.s.l.), whereas sedentary subjects are unaffected up to at least 1200 m.a.s.l. (Terrados et al., 1985). Thus, endurance performance deteriorates as a function of altitude above a threshold altitude being around 1000 m.a.s.l.. Of note is that a stay at altitude has barely any effect on Vo_2max (Table 6).

Table 6. Maximal oxygen uptake (1 $min^{-1)}$ obtained during bicycle exercise in nine s.l. elite athletes, representing different sports (8 m and 1 f) studied at sea level and at different times at altitude (~580 mmHg). Mean body weight (~ 78.8 kg) was 1–2 kg lower at altitude compared to s.l. (Saltin, 1968).

	Sea level (before)	Altitude Acute	Day 3	Day 18	Day 25	Sea level (after)
Maximal oxygen uptake (1 min^{-1})	4.87	4.11	4.17	4.23	4.32	4.76

The difference between s.l. and altitude is significant, but not the elevation while at altitude (6 out of 9 athletes did increase).

It stays lowered in spite of the quick and rather pronounced elevation in hemoglobin concentration [Hb] that occurs within days after arrival to altitude (Fig. 9). At higher altitudes this lack of enhancement of the Vo_2max is well documented and explained by two factors. One is that the immediate increase in [Hb] is due to a reduction in total blood volume as plasma volume diminishes, which in turn causes stroke volume to be lowered when exercising at altitude (except for the very first hours after ascent to altitude; Stenberg et al., 1968). There is also another, even more critical factor. Peak heart rate (HR_{peak}) becomes reduced the longer and the higher the altitude exposure (for ref., see: Saltin, 1988). Thus, the improved oxygen delivery capacity due to elevation in [Hb] and a trend for a normalization of the stroke volume is offset by the lowering of HR_{peak}. Until recently there were no data in the literature demonstrating an effect of lower altitudes (<3000 m.a.s.l.) on HR_{peak}. Therefore, it was anticipated that a period of acclimatization at medium altitude would enhance the lowered Vo_2peak to approach s.l. value. However, Vo_2max does not increase in all athletes after two or four weeks of altitude exposure at about 2100 m.a.s.l. (Saltin, Kim et al., 1995; and Table 6). The explanation is related to whether HR_{peak} is reduced or not. In ongoing experiments on c.c. skiers training at altitude (2–2.700 m.a.s.l.) it has become quite apparent that HR_{peak} may be reduced in some athletes even at these low altitudes especially if the performed training is of long duration (Svedenhag et al., 1996). In these c.c. skiers training daily up to ~2700 m.a.s.l., a lower HR of up to 10 bpm has been observed rather early during the stay. Thus, a similar mechanism, ie. reduced maximal HR, appears to be at play also at medium altitude, offsetting at least some of the acclimatization effect on maximal aerobic power.

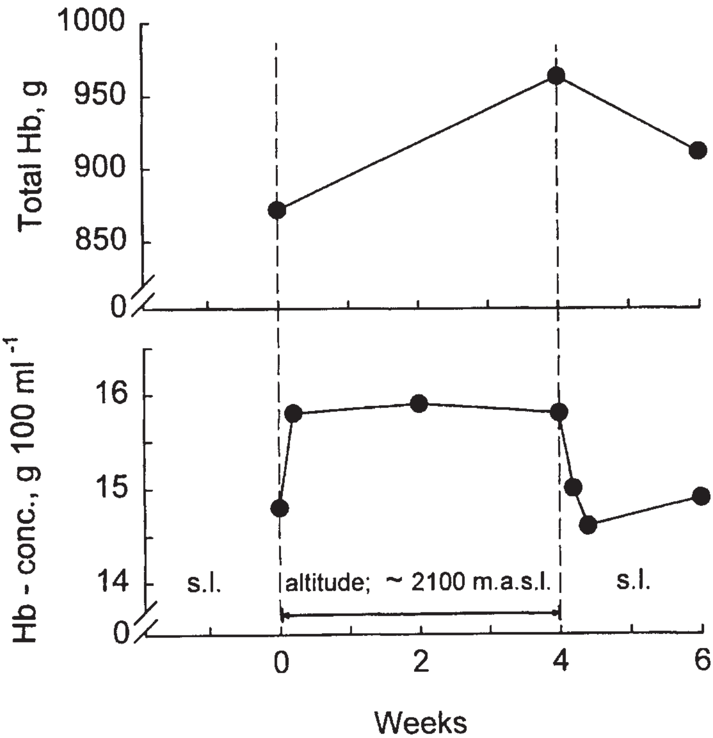

Fig. 9. Hb-concentration and total amount of Hb in nine champion athletes (7♂, 2♀) preparing for a competition at 2100 m.a.s.l. (Data from Saltin, 1968). As mentioned in the text, almost identical findings are available in an unpublished study by Grover and Johnson on altitude (~3000 m.a.s.l.) residents going to s.l. and in a study (also unpublished) by Svedenhag et al. (1996) on elite c.c. skiers staying for 4 weeks at ~2000 m.a.s.l.

An area of interest has also been the adaptation in muscle related to its oxygen utilization which may be induced by hypoxia. Results from many studies are available and they all point in the same direction (see Saltin, 1996). Mitochondrial capacity either expressed in relative values for the mitochondrial volume or as an oxidative enzyme activity do not change when living and training at medium altitude or living at higher altitudes. The total number of capillaries does not become elevated. However, at higher altitudes (>3000 m.a.s.l.) and prolonged stays a significant reduction in muscle fibre size does occur, which is, although to a minor extent, also apparent at lower altitudes (Table 5). Capillary number per fibre is not altered, but due to the changes in fibre size, capillary per unit area is. This partly compensates for a lower O_2 gradient between the blood in the capillary bed and the muscle fibre and a possibly faster blood velocity. This adaptation most likely also occurs at medium altitude, but is minor. It is quite apparent, however, that the alterations in muscle aerobic potential is far from large enough to completely compensate for the hypoxemia.

Despite the fact that there may be a lack of effect on aerobic metabolism, altitude performance improves by the acclimatization process. To some extent this is reflected by a gradual lowering in the submaximal exercise response of heart rate and blood lactate, which relates to the subject's perception of well being and an improved performance (Table 7). However, it is noteworthy that the absolute values observed at altitude cannot directly be compared with those observed at s.l. as the scale for the heart rate and blood lactate responses (rest—maximal exercise) is compressed. Thus, it is difficult to give specific advice regarding both training intensities at altitude and optimal acclimatization time when preparing for competition at altitude. Training intensity will be too high if adjustments are not made. At altitude a given submaximal heart rate or blood lactate concentration above 2 mmoles l^{-1} would represent a gradually increasing higher relative work intensity. The order of magnitude would be 15–20% already after the first week at altitude. Easier to use as a "rule of the thumb" may be to reduce the absolute exercise load by 5–10% for each 1000 m.a.s.l., if the training is to be performed at the same relative intensity.

Table 7. Heart rate (beats min^{-1}) and blood lactate (mmol l^{-1}) responses during submaximal and maximal exercise in nine athletes (same as in Fig. 9) at sea level and various times at altitude (~580 mmHg).

	Sea level			**Altitude**			**Sea level**
	(before)	Acute	Day 3	Day 7	Day 18	Day 25	(after)
Heart rate:							
Max⁰	193	192			190	189	194
240 Watt	156	171¹	172	165²	164²	159³	157
Blood lactate:							
Max⁰	13.5	14.8	14.3	13.0	12.6	14.1	
240 Watt	2.8	4.6⁴	4.8⁴	3.6	3.0⁵	2.6	

0) No significant differences between mean values
1) $p<0.001$ s.l. - acute
2) $p<0.01$ acute - day 3 or day 18
3) $p<0.01$ Day 7 - day 25; $p>0.05$ Day 25 and s.l. after
4) $p<0.001$ s.l. - acute/day 3
5) $p<0.05$ acute/day 3 -- day 25 ; $p>0.05$ Day 25 -- s.l. before and after

Anaerobic capacity: The maximum amount of energy produced by glycogenolysis forming lactate as well as the rate by which the anaerobic capacity can be utilized is probably not affected by a stay at medium altitude (<2000 m.a.s.l.) if the stay is not very long (<3–4 weeks). Muscle glycogen storage is insensitive to hypoxia and the Vmax for enzymes such as muscle phosphorylase (a+b) and phosphofructokinase (PKF) is unaltered. Indeed, factors controlling the activity of these enzymes such as catecholamines (posh a+b) and ADP (PFK) are most likely enhanced by exercise at altitude, increasing the rate by which anaerobic energy is released and lactate formed. The lactate dehydrogenase (LDH) activity in skeletal muscle behaves "strangely" at altitude (Saltin, Kim et al., 1995; Svedenhag et al., 1991, 1996). As acute exposure to hypoxia accelerates glycogenolysis, it could be anticipated that the Vmax for LDH would be elevated, primarily due to an increase in the activity of the LDH_{4-5} isoform. This does not happen. Instead a higher LDH_{1-2}/LDH_{tot} ratio is observed when staying at medium altitude

(Svedenhag et al., 1991). This adaptation is quite fast as it is observed after two weeks at 2100 m.a.s.l. and is not markedly higher when staying for 4 weeks (Svedenhag et al., 1996). This change in LDH ratio does not appear to affect the peak blood lactate response at altitude. However, it cannot be excluded that lactate turnover is enlarged, and thereby possibly enlarging the anaerobic capacity.

Muscle buffer capacity increases at altitude which also could contribute to a larger anaerobic capacity (Mizuno et al., 1990). As for the LDH activity the change is observed as early as after two weeks (Svedenhag et al, 1991). Data are not available for athletes at four weeks, but findings on climbers indicate no relation, either to the duration of stay, or to the level of elevation (Svedenhag et al., 1991). Taken together several variables of significance for the anaerobic capacity are increased as a result of exposure to hypoxia. However, it cannot be stated at present whether there is a true increase in the maximal anaerobic capacity as no reliable method to quantify the anaerobic energy release during exhaustive exercise exists (Saltin, 1990; Zoladz et al., 1995). The frequently used method to determine maximal oxygen deficit underestimates the anaerobic capacity, but it is unclear to what extent.

Practical advice: When acclimatizing for competitions in endurance events above ~1200–1500 m.a.s.l., a week would be a minimum, whereas a full month is needed at ~2000 m.a.s.l. However, a stay for such a long period at this altitude may compromise optimal preparation for the actual event. The key for acclimatization to occur is to spend a dominant portion of time at altitude. Thus, to live at altitude, but train for brief hours at a lower level, seems to be effective. This may also minimize the reduction in peak HR, allowing for obtaining the full benefit of an elevation in [Hb] and blood volume.

6 Performance at s.l. after training at medium altitude

Anaerobic energy release: Upon return to s.l. most muscle adaptations which are induced at altitude persist at least for a fortnight. This relates definitely to muscle fibre size, but also to the anaerobic capacity. A relation between improved running time and change in muscle buffer capacity has been reported by Mizuno et al. (1990) upon return to s.l. during the first week and performance in an anaerobic exercise test is also elevated (Nummela et al., 1996). Moreover, an enlarged anaerobic capacity was maintained in c.c. skiers and in runners for a fortnight while at s.l. (Svedenhag et al., 1991).

Aerobic energy release: Whether s.l. Vo_2max can be enlarged by training at altitude to levels not attainable by only training at s.l. is still being debated. The results of several studies with top-trained athletes and with control groups training similarly at s.l. do support the notion of no special effect of the hypoxic stimulus (Table 8). The claim has been made that the stay at altitude has to be quite long. Two weeks would not be sufficient and as seen from the data in the table, a full month, however, adds nothing. The hot issue today is that the optimal combination may be to live at medium altitude, but train at a low altitude (<1000 m.a.s.l.). Levine et al. (1996) have explored this possibility and found a small, but significant increase in Vo_2max in a group living "high" and training "low" as compared to other combinations, as for example living "low" and training "high", or both living and training "high". The athletes in these studies were well-trained runners, but they had a mean Vo_2max in the range of only 60–70 ml kg^{-1} min^{-1}. Thus, it remains to be proven that top endurance athletes may also benefit in this respect by living at altitude and training "low". As the scheme has already been adapted by many athletes after the creation of special houses/flats where a simulated altitude is obtained by increasing the N_2-content, a final answer may soon be found. The athletes live there overnight (>10 hours) and are training at sea level during the day.

The reason for a possible elevation in maximal aerobic power would be that there has been an alteration in one or more of the factors limiting Vo_2max. The most likely would be an elevated [Hb] with unchanged or elevated blood volume. Returning to s.l. [Hb] concentration falls quickly. Grover and Johnson have unpublished data convincingly showing a reduction in [Hb] to normal s.l. values within 1–2 days (see also Fig. 9). Their subjects had a high total red cell volume, being truly adapted to ~3000 m.a.s.l., and the lowering of [Hb] resulted from an expansion of the plasma volume. The total blood volume increased by a litre, and it occurred during the first 48 hours at s.l. Very similar results on c.c. skiers training for 4 weeks at medium altitude have been observed by Svedenhag et al. (1996). Thus, any sustained elevation in [Hb] cannot be anticipated upon return to s.l. after an altitude stay. It can be argued that the larger blood volume, which is gradually normalized over 2–4 weeks as red cell mass declines, would allow for an enlargement of the peak cardiac output via an elevated stroke volume. It has been shown that plasma expansion (700 ml) induces a larger stroke volume and cardiac output during exhaustive exercise (Kanstrup and Ekblom, 1982).

Peak oxygen uptake (Vo_2peak) was, however, unaltered in this study and peak oxygen delivery was also unchanged due to the drop in [Hb] caused by plasma expansion. Moreover, the lack of an elevated mitochondrial capacity as well as true proliferation of capillaries in skeletal muscle when training at medium altitude would not favour either a higher Vo_2max or an aerobic metabolism enhancing lipid oxidation and reduce the glycogen utilization.

Table 8. Sea level maximal oxygen uptake (ml kg^{-1} min^{-1}) in elite athletes after living/training at moderate altitude. In the first two studies, females were included in the groups (two in each). They behaved similarly to the males.

	n	**Altitude**	**Weeks**	**Pre**	**Post**		
		m.a.s.l			1-5	6-13	20-30
Svedenhag et al, 1991;	7	2100	2	74	73	74	-
runners	7	0 (C)	2	68	69	69	-
Svedenhag et al, 1996;	9	(0)-2700	4	76	76	77	79*
c.c. skiers		-	-	-	-	-	-
Rusko et al. 1996;	14	1600-1800	3-4	80	81	-	-
c.c. skiers	7	0 (C)	3-4	80	83*	-	-
Telford et al, 1996;	9	1800-2000	4	73	74	-	-
runners	9	0 (C)	4	72	73	-	-

From the above it is clear that the available scientific data does not support the "myth" that training at medium altitude adds something significant to an athlete's maximal aerobic power and metabolism. Whether just living at altitude, but training at normoxia or close to it would do, will hopefully soon be proven right or wrong.

7 Conclusion

C.c. skiing has gone through remarkable changes through the last three decades. Stronger and more firm or flexible materials are now used to make the skis, the bindings, the boots and the ski poles lighter and more functional. Skating has been introduced as a separate discipline and the tracks have been adjusted to meet all these new demands. In addition the racing courses require more technical skill. The c.c. skier has adjusted to this. The most impressive adaptation is the enlargement of the upper body capacity brought about by more and intensified upper body training including specific strength training. Today, successful skiers can utilize either legs or the upper body and tax the aerobic capacity fully or close to. Another critical adaptation is an enlarged contribution of anaerobic energy release. For this to be of quantitative significance, the c.c. skiers must be able to vary the loading of the upper and the lower body. A track with many short up- and downhills will further contribute to the role of the anaerobic energy yield. The anaerobic capacity appears to benefit from training at medium altitude, but any definite prove for such "training" to positively influence the aerobic capacity awaits to be demonstrated.

The improvement in racing velocity over the last 70–80 years is more pronounced in c.c. skiing than in other sports. The improvement amounts to 60–80%. For comparison, in distance running the speed has only become around 10% faster over the same time period. The maximum rate of energy yield that can be maintained may have been enlarged with 15, or at the most 20% (aerobic ~10%, anaerobic 5–10%) over these eight decades. The economy (Vo_2 at a given speed) must then explain the remaining larger portion of the faster speed development. The "development of the equipment" including the tracks explain most (more than half) of the improved performance, but more efficient skiing technique contributes as well. By how much cannot be stated, but hardly with more than ten percent.

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PHYSIOLOGICAL INDICES OF ELITE JUNIOR-I ALPINE SKIERS

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1 Introduction

Assessment of physiological status is important for training, competitive success and injury prevention in alpine skiing[1] [2]. Slalom and giant slalom ski racing events require a combination of endurance and power, and therefore depend on the utilization of both the aerobic [1] [2] [3] [4], and anaerobic energy supply systems [1] [4] [5]. High maximum oxygen uptakes (VO_{2max}) of 70 $ml.kg^{-1}.min^{-1}$ in older European racers [5] and 66 $ml.kg^{-1}.min^{-1}$ in male alpine skiers from the United States Ski Team have been reported [1]. Furthermore, Saibene et al. determined that Italian national team members' energy utilization was 120% or greater of VO_{2max}, and Veicsteinas et al. indicated 60% of the energy for alpine skiing is derived from anaerobic metabolism. Moreover, several studies document that isometric, isotonic, and isokinetic contractions are performed by older experienced alpine racers [1] [4] [7] [8]. To date, there is a paucity of data describing the physiological capabilities of elite adolescent slalom and giant slalom competitors. This study, therefore, describes anthropometric characteristics, isokinetic muscle function, cardiorespiratory, and metabolic indices among Junior-I (JR-I) alpine skiers.

2 Methods

Ten subjects representing a ski academy team located in the New England region of the United States served as subjects for this investigation. Subjects' age, height and weight, body composition, and cardiorespiratory values (Table 1), and muscular and metabolic indices were measured. Informed consent statements were obtained from the guardian of each subject prior to the administration of all tests. The test battery order was fixed and arranged to minimize fatigue effects.

Table 1. Physiological characteristics of JR-I alpine skiers.

Variable	Mean		SD	Range
Age (yr)	15.4	±	1.4	13-17
Height (cm)	171	±	10	157-186
Body mass (kg)	63.9	±	5.2	42.9-73.6
Body fat (%)	15.4	±	5.2	10-25
VO_{2peak} ($ml.kg^{-1}.min^{-1}$)	63.2	±	6.1	54.1-70.7
V_{Epeak} ($1.min^{-1}$)	135.8	±	17.5	117.3-169.1
HR_{peak} ($b.min^{-1}$)	201	±	4.0	195-206

All physiological assessments were conducted prior to preseason snow ski training. Pre-season activities varied. The JR-I skiers tended to be good all-around athletes and participated in activities such as soccer, cross country running, football and mountain biking. The subjects did not participate in any formal weight training program prior to the test date.

Body composition data were obtained by applying Lange skinfold calipers to the subscapular and triceps skinfold sites [9]. Maximal voluntary knee extensor and knee flexor isokinetic strength at 60 and 120°.s^{-1} were assessed with a Biodex B-2000 isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, New York, USA). Standard procedures were used as the subjects were seated, restrained, and the right knee joint was aligned with the machine's axis of rotation [10] [11]. Five submaximal warm-up repetitions of progressing intensity were allowed prior to performing five maximal repetitions at both velocities, with a one minute rest period separating the two testing velocities. The above procedures were repeated for the left leg.

Peak oxygen uptake (VO_{2peak}) was determined by open-circuit spirometry using a graded treadmill exercise test to exhaustion [12]. Concentrations of expired O_2 and CO_2 were measured by paramagnetic and infrared absorption analyzers, and expired volumes were measured with a mass flow meter. All instruments were calibrated prior to each subject's test (Sensormedics 2900

System, Yorba Linda, California) [13]. Heart rate was continuously monitored with a Polar Accurex II heart rate monitor (Polar CIC, Inc., Port Washington, New York, USA) and recorded at one-minute intervals. Peak heart rate (HR_{peak}), VO_{2peak}, and ventilation (V_{Epeak}) were defined as the highest values calculated during the last two minutes of exercise.

Immediately following the treadmill test, subjects recovered by walking on the treadmill at 80.4 $m.min^{-1}$. At minutes 1, 3, 6, 9, 12 and 15, a 25ul sample of blood was obtained from the finger tip for lactate analysis. Blood samples were immediately added to a lysing/clamping solution containing Triton-X and sodium fluoride and stored at -20° C until analysis could be performed in duplicate. Peak blood lactate (BLa_{peak}) and the time to clear half the lactate concentration ($t^{1/2}$) were determined from analysis of these samples.

3 Results

Mean (±SD) for percentage of body fat was 15.4±5.2% with a lean body mass of 53.9 ±7.2 kg. Isokinetic function of the knee extensors and flexors are shown in

Table 2. Descriptive isokinetic knee extension and flexion function.

		PT[a] (Nm)		PT ($Nm.kg^{1}$ LBW)		AP[b] (Watts)	
		Right	Left	Right	Left	Right	Left
Extension	60°/s	216.0	220.9	3.99	4.05	132.8	135.2
		±43.5	±54.6	±0.34	±0.60	±27.1	±28.1
Flexion	60°/s	107.3	104.4	1.98	1.91	76.4	72.0
		±24.2	±26.5	±0.21	±0.25	±7.4	±17.8
Extension	120°/s	166.5	173.4	3.08	3.20	201.5	212.5
		±37.6	±40.4	±0.35	±0.45	±50.5	±47.7
Flexion	120°/s	91.4	90.0	1.69	1.66	120.8	111.1
		±16.8	±17.9	±0.13	±0.14	±24.2	±22.2

[a]PT=Peak torque; [b]AP=Average Power

Peak torque flexion $extension^{-1}$ ratios were 49.6 and 47.2% at $60°.sec^{-1}$, and 57.5 and 53.3% at $120°.sec^{-1}$ for the right and left leg, respectively.

The knee flexor bilateral peak torque deficit was 2.7 and 1.5% (left weaker), respectively, at $60°.sec^{-1}$ and $120°.sec^{-1}$, whereas the knee extensor bilateral deficit was 2.2 and 3.9% (right weaker).

Cardiorespiratory and metabolic indices indicate that subjects' aerobic and anaerobic capacities were highly developed. Treadmill time to exhaustion was 14.3±1.3 min, range 11.3–16.0 min, which evoked a VO_{2peak} and V_{Epeak}, respectively, of 63.2±6.1 $ml.kg^{-1}.min^{-1}$, range 54.1–70.7 $ml.kg^{-1}.min^{-1}$, and 135.8±17.5 $l.min^{-1}$, range 117.3–169.1 $l.min^{-1}$.

Mean HR_{peak} and BLa_{peak} following exhaustive treadmill exercise and during recovery are shown in figure 1. HR_{peak} and BLa_{peak} were, respectively, 201 ±4 $b.min^{-1}$, range 195–206 $b.min^{-1}$ and 14.6 ±1.9 mM, range 12.1–17.9 mM. The time to reach BLa_{peak} during walking recovery at 80.4 $m.min^{-1}$ was 2.1 ±1.6 min. Regression analyses during recovery indicated that HR and BLa decline, respectively, were significantly curvilinear, r^2=0.91, and linear r^2=0.96. The $t^{1/2}$ for BLa to decline 50% during the 15 minute recovery was 8.1±1.1 min (Fig. 1).

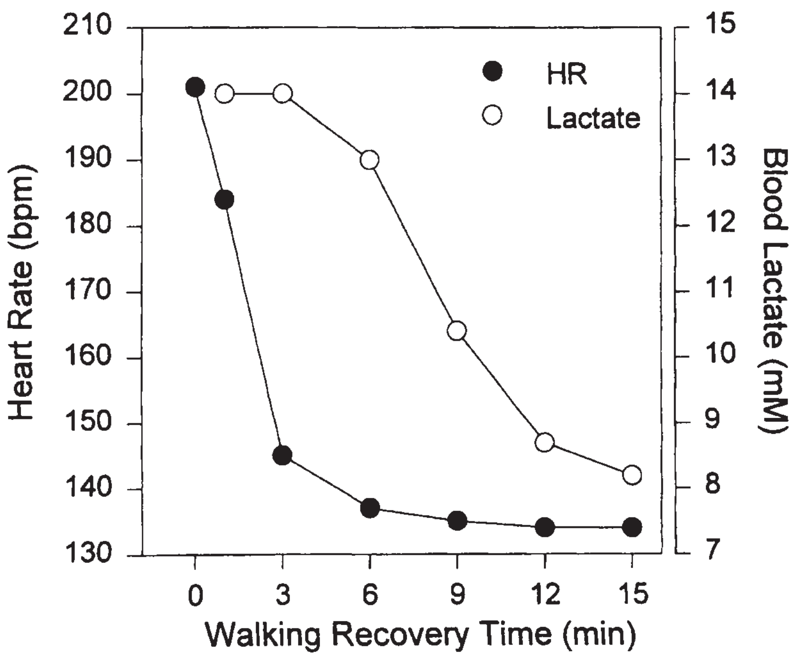

Fig. 1. Mean heart rate and blood lactate concentration during recovery.

4 Discussion

Body composition

Body fat values for the JR-I skiers were similar but slightly lower than those reported for older skiers (20.6 yr) [1] and slightly higher than junior skiers (16.5 yr) [2]. These data suggest that a desirable, predictable body composition for elite alpine racers may be attained by early adolescence.

Isokinetic strength

Strength data from the JR-I skiers reflect a mean peak torque of 218 Nm at $60°.sec^{-1}$ for knee extension compared to a peak torque of 259.7 Nm at $30°.sec^{-1}$ among adult skiers [1], Given the speeds are different in the two studies, the adolescent skiers produced 84% of the adults peak torque at a faster velocity, and when torque was measured per kg of LBW the adolescent skiers were slightly stronger than the adult skiers.

Bilateral strength deficits in the present study were within the previously reported limit of allowable non-pathological side-to-side variation of 10–12% [14], although the JR-I skiers tested in the present study had significantly lower hamstring $quadriceps^{-1}$ ratios than reported in national, divisional and club skiers [8]. This is a notable point in light of the important role the knee flexors play during skiing. Hintermeister et al. have shown peak amplitudes of 220.0±111.7 and 232.7±129.6% of the biceps femoris' maximum voluntary contraction, respectively, during slalom and giant slalom skiing. Furthermore, knee extensors produce strong subluxing forces on the knee joint during alpine skiing. A low hamstring $quadriceps^{-1}$ ratio may prevent the JR-I skier from optimally opposing the subluxing force and consequently may increase the risk of knee injury [15].

Relative to performance, the isokinetic profile of JR-I skiers appears to be important for several reasons. Dynamic strength is necessary for the balance and control required to successfully compete. Technical turning radii are of critical importance to skiing excellence. Since forces created during turns can reach several thousand newtons [17], specificity of leg strength and power development becomes obvious. Furthermore, the JR-I skiers' isokinetic profile is a relationship of efficiency and fatigue. A fully developed ratio upper leg strength permits the athletes to perform downhill maneuvers at submaximal efforts, thus minimizing the percentage of isometric contraction. This, allows an increased blood flow within the exercising muscle, and a greater utilization of aerobic metabolism, which should delay fatigue from anaerobic by-products [6]. Finally, the question of safety may be addressed. Since youthful competitors appear to possess dynamic strength comparable to their adult counterparts, strength profile assessment is a valuable training and coaching tool in evaluating team members' physiological adaptations to the training process.

Maximal oxygen uptake

The VO_{2peak} of the JR1 skiers was greater than that of a group of Italian National team competitors [4] and was similar to the "very best" Swedish and American adult ski competitors [5] [1]. The aerobic capacity of subjects in this study was also comparable to Canadian junior alpine skiers [2].

Peak and recovery blood lactate

The subjects' BLapeak of approximately 15 mM elicited during exhaustive treadmill exercise falls within the range of maximal field lactates reported by Karlsson et al. for older, more experienced skiers. These data agree with findings from Inbar and Bar-Or that youths' peak anaerobic capacity increases with age and is almost fully developed by early adolescence. However, data have also shown that youth are unable to tolerate high levels of acidosis and as a consequence muscle contractile capacity diminishes as pH declines [20]. Therefore, a well trained anaerobic glycolytic system, although essential to successful competition, may cause early fatigue from excessive lactic acid during repeated training runs. This is supported by data from Richardson et al. [21] in which skiers were unable to perform a third trainingrun at the same intensity as the initial run. It was suggested that increased blood lactate levels were partially responsible for the decrement in performance [21].

A compensatory mechanism against increasing acidosis in adolescence is an underdeveloped sympathetic nervous system which allows more blood flow to the liver and an enhanced lactate clearance during exercise. Therefore, to maintain training intensity and delay fatigue, a rapid efflux of lactate from the muscle into blood, and delivery of lactate to clearing tissues, such as the liver, is essential during recovery. The short time to attain BLa_{peak} and $t^{1/2}$ in JR-I skiers indicates an appropriate compensatory mechanism to complement their developed anaerobic capacity.

We hypothesize the mild walking rate of 80.4 $m.min^{-1}$ was responsible for the rapid lactate clearance because it approximated an exercise intensity corresponding to the initial onset of blood lactate accumulation (IOBLA). Data on elite adolescent swimmers indicate the IOBLA is an optimal recovery intensity which occurs at approximately 71% of maximal heart rate and has a $t^{1/2}$ of 8.1 minutes[22]. Our data compare favorably with these data in that the JR-I skiers recovered at 68% of maximal heart rate and a similar amount of lactate was cleared in an equal $t^{1/2}$. It appears this intensity induces a blood flow past the exercising muscle which maintains an optimal lactate efflux gradient from muscle to blood and provides an effective delivery rate of lactate to clearing tissues.

In general, manifestation such as improved cardiorespiratory and metabolic functions resulting from a high aerobic capacity seem to be in symbiosis with the anaerobic system offsetting the potential deleterious effect of an inadequate buffering capacity. With the knowledge that recovery occurs rapidly at very mild intensities, the coach and athlete can rest assured that training capacity can be maintained, and more importantly, the risk of injury should be less from lactate build-up and fatigue.

5 Practical Applications

Since the hamstring muscle group is the antagonist muscle group of the knee extensors, improved strength and power will enhance skier control of repeated turns at high velocity and help prevent knee injuries. High blood lactate levels in JR-I skiers and of more experienced skiers contribute to muscle fatigue [21]. Introduction of very mild recovery exercise between training runs will allow repeated maximal effort and delay fatigue, and at the same time, may reduce the potential for knee injury.

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AN INCREMENTAL EXERCISE TEST SIMULATING THE MUSCULAR ACTIVITY OF SLALOM

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Keywords: alpine skiing, heart rate, lactate, oxygen uptake, ergometry.

1 Introduction

A number of laboratory tests has been applied to characterise the performance capacity of alpine skiers. According to the parameters of interest they can be divided into two groups: tests dealing with physical parameters such as performance time (Kornexl 1977, Mc Ginnis et al. 1981) or maximal repetitions of a task (Bosco et al. 1983, Kornexl 1977) generally simulate the duration and muscular requirements of a race. By contrast, when physiological parameters such as heart rate, maximal oxygen uptake, or lactic acid concentration are of interest, incremental exercise protocols with bicycle or treadmill ergometers are normally used (Haymes and Dickinson 1980, White and Johnson 1991). The latter tests do not reflect the motor demands of alpine skiing. That may be the reason why the results of these tests show no consistent correlation with actual skiing performance (White and Johnson 1991).

In the present paper we introduce a test, which determines physiological parameters during alternating lateral sliding at frequencies encountered during competitive slalom.

2 Methods

Two different series were performed. In series 1 the reproducibility of the present slalom test was assessed. Series 2 was conducted to compare the results of an incremental cycle ergometry with the slalom-specific test.

2.1 Series 1

Six physically active subjects participated in the test [5 male and 1 female sport students; mean age 25±2 years, mean weight 72±4 kg, mean height

176±5 cm]. Three of them were not familiar with alpine skiing. Exercise consisted of lateral sliding on a commercially available “slider” (Reebok ™; range of movement 175 cm). Subjects wore sport shoes for indoor activities. The soles were covered with the friction reducing tissue delivered with the slider. The sliding frequency was given by a metronome. In the end position of each slide the knee angle was flexed to 110°–130°, which could be optically controlled by the subjects by means of a mirror. In order to investigate the reproducibility of results each person performed the test three times on three consecutive days (tests A, B, C).

Test schedule: After three minutes of rest the subjects performed four exercise intervals separated by five minutes of recovery. During recovery the subjects remained standing. The first three exercise intervals lasted one minute during which 60, 70, and 80 slides had to be performed. The fourth interval (80 slides per minute) was continued over 5 minutes or until subjective exhaustion. A schematic representation of the schedule is given in Fig. 1.

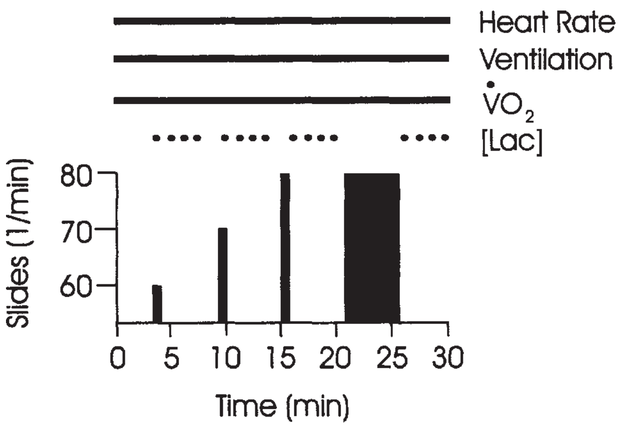


Fig. 1. Schematic presentation of the slider experiment protocol.

2.2 Series 2

Six male D-kader athletes and one former A-kader athlete volunteered in series 2 [mean age 20±3 years, mean weight 76±6 kg, mean height 178± 4 cm]. The slider test was identical to series 1 except that the subjects wore ski boots. During the cycle-ergometry, power increased by 50 W every 3 minutes until subjective exhaustion. Before and after exercise, subjects sat quietly on the ergometer for 3 and 5 minutes, respectively. The slider and the cycle tests were applied in random order with at least two days of rest between both trials.

2.3 Measurements

Heart rate (HR), ventilation, and oxygen uptake (VO_2) were continuously recorded throughout the tests. HR was measured by means of standard ECG leads. VO_2 was analysed breath-by-breath as difference between inhaled and exhaled air (Essfeld et al. 1987). The subjects breathed room air through a mask connected to a Fleisch sensor (Fenyves and Gut, Basel). Pneumotachogram and mass spectrometer readings for N_2, O_2, and CO_2 were recorded by a microprocessor system. During a final off-line analysis the mass spectrometer readings were corrected for transportation delay, response time, and vapour pressure. Blood samples for the determination of whole blood lactate concentration [lac] were taken from hyperaemic earlobe before the onset of exercise and at 1.5 min intervals during the recovery periods. During cycling additional samples were taken in the last minute of each workload. The 20 µl samples were analysed by an encymatic method (test combination, lactate, Boehringer Mannheim, Germany) immediately after the tests. Power at 4 mmol*l^{-1} [lac] during the incremental cycle ergometry was determined by means of linear interpolation.

2.4 Statistics

Unless otherwise stated data are presented as mean and standard deviation. Differences in series 1 were examined by the Wilcoxon test for repeated measurements and were regarded as significant if $p<0.05$.

3 Results

3.1 Series 1

All subjects were able to perform the first three exercise bouts of the sliding test completely. The mean values of all physiological parameters decreased from day 1 to day 3 with the main effect occuring between the first two tests. The differences between all tests were not significant. The decrease in VO_2 from the first (Fig. 2) to the third day amounted to about 0,2 1*min^{-1} at all sliding frequencies (not significant). These decreases were only due to three subjects not familiar with alpine skiing. Fig. 3 presents the mean [lac]-curves of the sliding tests performed on three consecutive days (tests A,B,C).

Mean exercise time of the final exercise bout at 80 slides*min^{-1} increased from 2±0.18 minutes (test A) to 3.1±0.48 minutes and 3.55±0.66 min in test B and C, respectively. The differences in performance time between all tests were statistically significant. Peak values during this exercise period ranged between 187 min-1 and 190 mm-1 (HR), 2.42 1*min-1 and 2.61 1*min-1 (VO_2), 9.0 mmol*l-1 and 9.5 mmol*l-1 ([lac]).

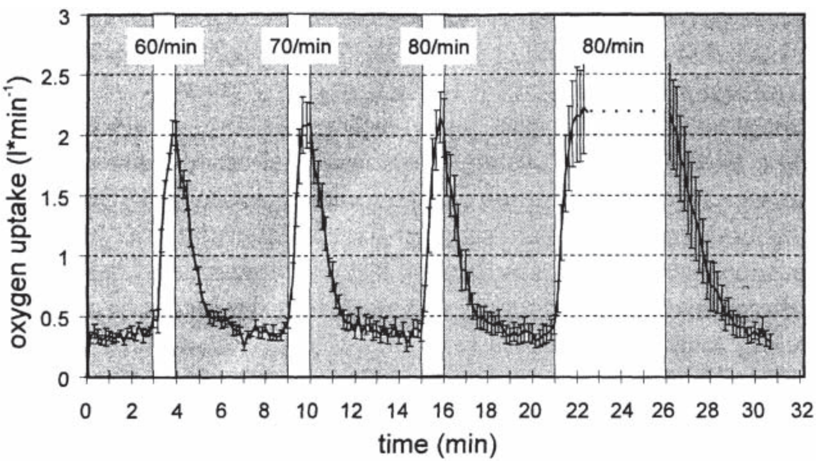


Fig. 2. Mean values of VO_2 in the first test (test A). White areas indicate excercise and sliding frequencies, shaded areas represent resting periods. The dotted line in the last exercise interval marks the period where some subjects stopped exercising. The recovery values of the subjects were shifted in such a way that all recovery periods start at minute.

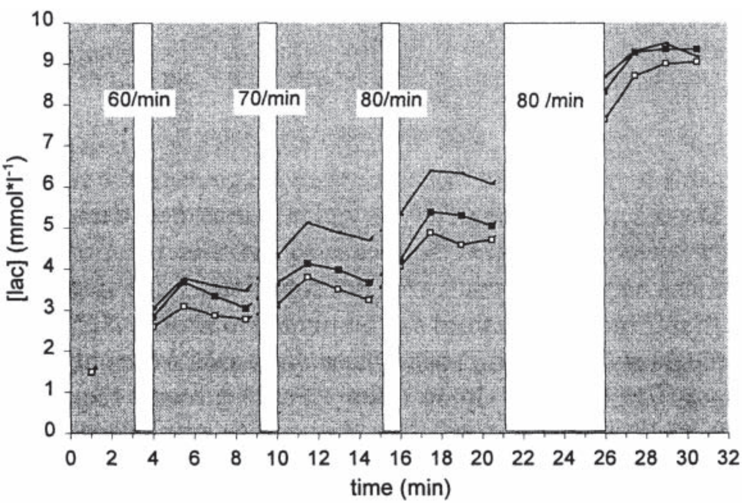


Fig. 3. Mean values of lactic acid concentrations on the first day (test A, upper curve), second day (test B, closed symbols, middle curve) and third day (test C, open symbols). White areas indicate excercise and sliding

frequencies, shaded areas represent resting periods. The dotted line in the last exercise interval marks the period where some subjects stopped exercising. The recovery values of the subjects were shifted in such a way that all recovery periods start at minute 26.

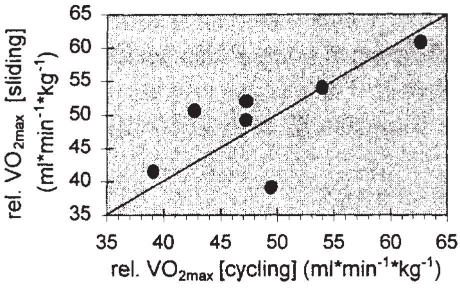
3.2 Series 2

Also in the slider experiments with ski boots, all subjects managed to perform the complete sequence of the one-minute exercises. The maximal duration of the final 80 slides*min$^{-1,}$ however, was reduced to 1,9±0,69 min. The peak values of VO_2, [lac], and heart rate of each exercise interval are presented in Table 1.

Tab. 1. Peak values of VO_2, [lac], and heart rate during slider ergometry with ski boots (series 2). $\bar{x}$+SD (n=7).

sliding frequency (slides*min^{-1})	exercise duration (min)	peak VO_2 (l*min^{-1})	peak [lac] (mmol*l^{-1})	peak heart rate (min^{-1})
60	1	3,20 ± 0,34	5,4 ± 1,3	177 ± 16,4
70	1	3,32 ± 0,42	7,5 ± 1,8	189 ± 9,5
80	1	3,65 ± 0,48	9,7 ± 2,4	190 ± 10,1
80	1,9 ± 0.69	3,78 ± 0,47	12,5 ± 1,9	192 ± 6,9

The incremental cycle ergometry yielded a mean maximal performance time of 19±2,1 min corresponding to a VO_{2max}, of 3,69±0,271*min^{-1}, [lac] values of 14,7±1,4 mmol*1^{-1}, and HR values of 195±8 min^{-1}. The power at 4 mmol*1^{-1} [lac] averaged 215±12 W. The linear correlation between the relative VO_{2max} of the slider and cycle ergometry was not significant (Fig. 4). Submaximal intensities in the two ergometries even showed no correlation with respect to the physiological responses. In Fig. 5 the anaerobic threshold during cycling is plotted against the maximal [lac] after 70 slides*min^{-1}. The independence of both tests also applies for 60 and 80 slides*min^{-1} with absolute lower and higher [lac], respectively.



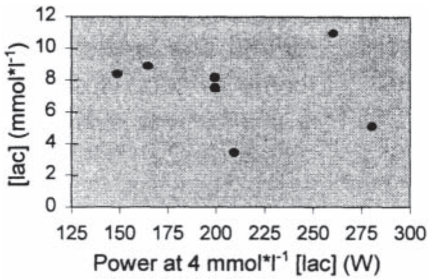


Fig. 4. Individual relative VO_{2max} during cycling and sliding. Line marks the curve of identity.

Fig. 5. Individual power at 4 mmol*1^{-1} [lac] evaluated with cycle ergometry plotted against the peak [lac] during slider ergometry at the frequency of 70 min^{-1}.

4 Discussion

If maximal oxygen consumption or other physiological parameters are to be used as a measure of general physical fitness, then cycle ergometry appears as the method of choice. This approach requires no particular motor skills and it involves large muscle groups engaged in antigravity activities during everyday life. On the other hand, if the aim of a test is to quantify a subject's ability to perform a specific motor pattern over a longer period of time, then specific tests are required and cycle ergometry will be of only limited value. The results of such specific tests will not only be influenced by the capacity of the cardiovascular system but also by local endurance and the specific motor skills of the subject. This is clearly demonstrated by the results of the present series 1 where the subjects not familiar with alpine skiing reduced their energy turnover over three consecutive days of slider testing whereas the skiers showed a uniform individual response pattern. This does not mean that the results of the experienced skiers are independent of the specific exercise conditions during the slider tests. Replacing the light sport shoes by ski boots (series 2) sufficed to markedly increase the energy consumption in all subjects. Heart rates, [lac] and VO_2 at submaximal exercise intensities were significantly higher than in series 1. This can hardly be due to a lower endurance capacity in the D-kader athletes since their VO_{2max} was also higher. The most attractive explanation is that fewer muscle groups were involved in the change of movement direction. Due to the ski boots worn in series 2 both the contraction of calf muscles and the storage of energy within the Achilles tendon could not contribute to the stretch-shortening cycle. Since this better simulates the situation in the field, ski boots should be preferred to other shoeware in slider tests for alpine skiing.

Table 2. Comparison of characteristic parameters during three different types of ergometry. Shaded areas indicate typical demands of slalom.

Characteristics	Cycling	Running	Sliding
direction of movement	frontal	frontal	lateral
type of contraction	concentric	eccentric / concentric	eccentric / concentric
load	< body mass	> body mass	> body mass
duty cycle	0.5s (at 1 Hz)	0.3 s (at 12 - 15 km/h)	1s (at 1 Hz)
relation between loading and unloading intervals of one leg	1 : 1	1 : 3	1 : 1

Alpine skiing involves lateral and eccentric movements that are not used during cycle or treadmill ergometry. Moreover, the time pattern of muscular action and relaxation during cycling and running is different from alpine skiing. This may be the reason why it was stated that for alpine skiing "laboratory evaluation is unreliable, and proper ergometers cannot be constructed. Therefore, only the actual activity in the field can be used for physiological studies" (Veicsteinas et al. 1984, p. 1187). This statement appears questionable for two reasons: the field conditions change from race to race and even within one race so that there is no reliable bases for inter-and intraindividual comparison. Secondly, a look at Tab. 2 shows that the requirements of the slider ergometry are close to those of slalom and even similar to giant slalom and super G events.

Haymes and Dickinson (1978) reported a decrease in maximal oxygen uptake from the beginning to the end of a season. Their results refer to top skiers (United States women's alpine ski team) and cycle ergometer tests. If the muscular endurance capacity rather than the cardio-respiratory system is the limiting factor, an alternative explanation becomes attractive: during the preseason period the athletes trained on a bicycle and, therefore, increased the aerobic capacity of the respective muscle groups. During the competitive season there was no cycle training so that the muscle groups specifically involved in that motor pattern may have lost some of their aerobic power. This assumption is supported by the present findings that there is only a weak, if any, correlation between parameters of endurance capacity obtained from cycling and sliding tests.

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THE METABOLIC LOAD IN ALPINE SKIING—AN ATTEMPT AT A PRESENTATION USING COMPUTER-SUPPORTED MODELLING

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1 Introduction

Apart from the aspect of optimizing the sport-event-specific performance ability, the aspect of increased safety has lately attracted more and more attention.

When looking through the available literature dealing with this topic, it is conspicuous that, from the point of view of energy utilization, there is no exact knowledge of the stress profile and the energy provision in the various disciplines of alpine skiing.

The measurement of anaerobic capacity using the Wingate Test [4,9] and of the maximally attainable "lactate acidosis" [16,31] is only suitable to analyse general aspects of the metabolic performance ability. Using the criterion of the "maximally attainable lactate acidosis" [1,3,28] with comparable exercise duration in the laboratory and during competition, and working from the assumption that the total energy turnover is approximately of the same height with equal post-exercise blood lactate concentration (PEBLC), the determination of the equivalent mechanical performance is possible only with limitations.

However, the results of these studies cannot be used for a detailed analysis of the time duration and the distribution load of energy provision for each component during alpine ski races. Thus the following questions are still open:

- Are there limiting conditions caused by the exhaustion of metabolic resources?

- In what way are the components of metabolic performance, which can be measured by laboratory methods, significant for the identification of performance limits during competition?

Neither the results nor the energy provision have been interpreted. Consequently, the physiological conditions and interactions of the metabolism have not been explained.

This is exactly why the question of how the beginning of muscular metabolic exhaustion in alpine skiing can be quantified and correspondingly modelled is of great interest. In individual cases the post-simulation in a corresponding model developed for the clarification of the three energy-providing processes in the working muscles could provide a corresponding approach.

2 Findings of the literature

Alpine skiing is influenced to a very high degree by the course profile and the resulting demand profile. For this reason, there is no standardized load or stress profile.

The assumption of an average-load profile is therefore necessary to examine general aspects of energy provision by way of a model.

To this end, a typical, hypothetical load situation was developed on the basis of the stress resulting from ground-reaction forces and the force distributions during individual swings [25] measured over several years during giant-slalom competitions:

- run through 41 gates,
- duration of the load approx. 82 s,
- it is assumed that approx. every 2 s there is an active muscle action leading to a change of direction.

The load organisation is therefore characterized by a sine-wave-like duration; the occurring ground-reaction forces are between 2500–3000 N on average. In this context, the basic measurements were conducted in the form of both individual and multiple investigations [25].

Both in the laboratory test [1, 2, 3, 10, 12, 13,16, 26, 28, 30, 31; Tab. 1] and in the field test, maximal PEBLC values between 10–17 mmol/1 blood were measured. As far as the maximal oxygen uptake (VO_2max) is concerned, which was measured only in the laboratory, values of 4020–5230 ml/min were obtained for the men; the men's relative oxygen uptake (relVO_2max) was 60–65 ml/kg body weight (BW); the corresponding values of the women were about 50–55 ml/kg BW.

The estimations of the proportions of energy provision from the available metabolic resources during a giant-slalom race are considerably less exact. The aerobic proportion is estimated to be between 20 and 46 % while the anaerobic lactacide proportion is between 54 and 80% [5,26,29]. According to other estimations, the anaerobic lactacid share is about 40% and the anaerobic alactacid proportion about 25–30 % of the total metabolism [30].

Table 1. Mean values to be found in the literature for body weight (kg), the absolute and relative oxygen uptake (VO_2 (1/min), relVO_2 (ml/min*kg)) and the post-exercise blood lactate concentration (PEBLC (mmol/l)). For further information see text.

Findings in literature concerning metabolic parameters during alpine skiing:

Author and year	number of athletes	weight (kg)	rel.VO2 (ml/min/kg)	abs.VO2 (ml/min)	blood lactate (mmol/l)
AGNEVIK et al. 1966	---	---	---	---	7-15
ANDERSEN et al. 1988	---	---	59-67	---	---
ASTRAND et al. 1986	---	---	---	---	7-15
ERIKSSON et al. 1977	---	---	---	---	6-13
HAYMES et al. 1980	---	---	66.6	---	---
KARLSSON, 1984	---	---	---	5120	---
SAIBENE et al. 1985	8	67.0	58.9	4018	9 (netto)
TESCH et al. 1978	---	---	---	---	6-13
VEICSTEINAS et al. 1984	8	78.0	52.4	4110	8-10
WHITE et al. 1991	12	78.8	53.1	4215	---

By way of the post-simulation of the metabolic dynamics using a load profile which is similar to the giant slalom as far as the metabolic performances or parameters are concerned, a more exact estimation of both the sum total and the duration of the proportions of energy provision is possible.

3 Theoretical foundations of the metabolic model

As far as the ground-reaction forces (see above) are concerned, the loads are clearly higher than those of a recreational skiier [25].

For this reason, the corresponding factors of converting the ground-reactions to the muscular load were chosen in such a way that a normal, average metabolic-performance ability would not suffice for the realisation of the load assumed in this context.

The most simple analysis of the shares of energy provision in a given performance and time (41 giant-slalom gates, 82 s duration) is the distribution of the three ATP-forming reactions to the work done (performance * time) [11, 19] represents t. This is possible by converting the metabolic parameters measured (VO_2, PEBLC) to work contributions over constant energy equivalents for VO_2, PEBLC and PCr.

As in the slalom, the ground-reaction forces, which are the equivalents of the mechanical load, vary considerably depending on time, the calculation of the energy shares is only possible using an optimization process. In this context, however, the relation of the shares of energy provision, which have been calculated this way, to the available or estimated metabolic capacities remains unclear.

The examples of the simulation of the dynamics of energy metabolism in the giant slalom presented in the following (ch. 4) are based on a differential equation model which is based on the following assumptions:

1. The mitochondrial respiration and the glycolysis are adjusted through the decrease of the phosphorylation state of the total cellular phosphate energy system (GP=ATP+PCr). For this, so-called “characteristic steady state activation lines” can be given [22,23,24].
2. The ATP/PCr balance expressed through creatine kinase in the muscle cell is calculated using algebraic equations [22].
3. The influence of contraction-induced ATP consumption and the new formation of ATP (which is caused through the activation of mitochondrial respiration and glycolysis) on the amount of GP, including the delay of O_2 transport, is calculated using a system of two non-linear differential equations, as related to one kilogram (kg) of muscle mass [21].
4. The pH value is an important modulator. Depending on the height of this value, the balance within the Lohmann reaction is shifted to higher or lower ATP values, or phosphofructokinase and thus glycolytic flow rate is activated or inhibited [7].
5. The lactate accumulation in the active muscle compartment (approx. one

third of body mass (BM), and the distribution of lactate in the passive compartment (about two thirds of BM), as well as the elimination of lactate in both compartments are calculated using two additional differential equations. The whole distribution space of lactate (active and passive compartment) represents about 47% of the body volume (BV). The total fluid volume is about 68% of BV. Thus, the distribution of lactate as related to the measurable blood concentration can only take place in two thirds of the body fluid.

6. For simplification, the total O_2 uptake as related to the active volume (32% of BV) is calculated, so that the conversion factor of body-weight-related VO_2 (VO_2 (ml/min*kg KG)) to muscle-related VO_2 (VO_2 (ml/ min*kg Muscle)) 1.0/0.32 equals 3.125. These assumptions correspond with those of Hoppeler, who also estimates the muscle mass which can be used during running loads as about one third of the body mass [15].

The energy equivalents used in the following simulation can be verified as follows [8,20]:

1. As far as the maximal oxidative metabolic performance is concerned, it is assumed that for the formation of 1.0 mmol ATP about 3.95 ml O_2 are necessary [6,8]

   —> PCr-O_2 equivalent = 3.95 ml O_2/mmol ATP.

2. 1mmol/l muscle lactate correspond to about 1.35 mmol ATP; correspondingly, 1 mmol/l muscle lactate requires 5.33 ml O_2 (1.35 * 3.95=5.33)

   —> PCr-LA equivalent = 5.33 ml O_2/mmol ATP.

3. Per Watt and minute the O_2 demand is 11.7 ml [20]

   —> Watt-VO_2 equivalent = 11.7 ml O_2/min/Watt.

4. On the basis of the difference of PEBLC prior to and after exercise, the equivalent of 1 mmol/l higher blood lactate is about 2.6–2.7 ml O_2 [20].

   —> Lactate-O_2 equivalent = 2.7 ml O_2/mmol/l.

For 1 ml of mitochondrial mass of the skeletal muscle the maximal O_2 uptake is about 3.5 up to 3.9 ml/min [15]. With a mean mitochondrial volume (MV) of the skeletal muscle of 3% (=30 ml MV/kg muscle; 14) this leads to a VO_2max between 105 and 120 ml/min*kg muscle. With a body weight of 80 kg and an active muscle mass of 32%, this results in a VO_2max of

$$3.0 * 39 * 80 / 3.125 = 2995 \text{ ml/min}$$ for the active muscle mass,

plus about 600 ml for the energy demand of the rest of the organism. Related to a bicycle ergometer load, this results in a net performance of about 256 Watt if an O_2 uptake of 11.7 ml per 1 Watt (see above) is assumed.

Assuming a corresponding MV (%), there are the following absolute O_2 uptakes (gross/net (ml/min)), relative O_2 uptakes (ml/min*kg) as well as percentage deviations (related to the assumed mean value of persons who are not specifically endurance-trained):

MV (%)	=	3.0/3.5/4,./4.5/5.0
VO_2max of MV (ml/min*kg)	=	117/137/156/176/195
Net VO_2max (ml/min)	=	2995/3495/3994/4493/4992
Gross VO_2max (ml/min)	=	3595/4094/4594/5093/5592
Gross relVO_2max (ml/min*kg)	=	44.9/51.2/57.4/63.7/69.9
Gross mean VO_2max(%)	=	100/114/128/142/156

If the durations of the ground-reaction forces measured can be transferred to the contracted state of the muscle, there is hardly a reduction of the blood flow during the race. Therefore, the assumption of a reduction of the muscular O_2 uptake does not seem to be necessary. This also applies to the post-simulation.

The estimation of VLAmax is much more difficult. Based on the increase of PEBLC after a 100 m sprint the VLAmax of sprinters is about 1.9 mmol/ s*1 (13 mmol/1 net PEBLC/(10s exercise time—3s lactate-free interval)). If, as based on the maximal PEBLC, one assumes the upper limit of 17 mmol/ 1 for a giant slalom, this would only correspond to a net lactate formation of 0.19 mmol/l*s (15 mmol/l net PEBLC/(82–3 s)=0.19 mmol/l*s). From this a VLAmax can be calculated for a 100m sprinter, which can be higher by the factor of 10 as compared to a giant-slalom skier. The difference between the VLAmax estimated for the maximal 100m sprint and the share of the VLAmax that must really be used during a giant-slalom race is therefore considerable.

From this, one can conclude that the maximal glycolytic performance, as based on the VLAmax during a ski slalom race, cannot be used directly. This leads to the question why, in spite of a relatively low average use of VLA, a high glycolytic performance ability is necessary.

The post-simulation of the dynamics of the energy provision, taking the parameters determined by way of experiment into consideration, could also contribute to finding an answer to the latter question.

A further advantage of the simulation of the metabolic dynamics is that the influence of the available or variable VLA on the result of the downhill ski run, taking into consideration real conditions, also becomes estimatable with regard to quantity.

For the post-simulation, the average values determined from muscle biopsy investigations during rest [17,27] are assumed for the concentration of energy-rich phosphates. These values are:

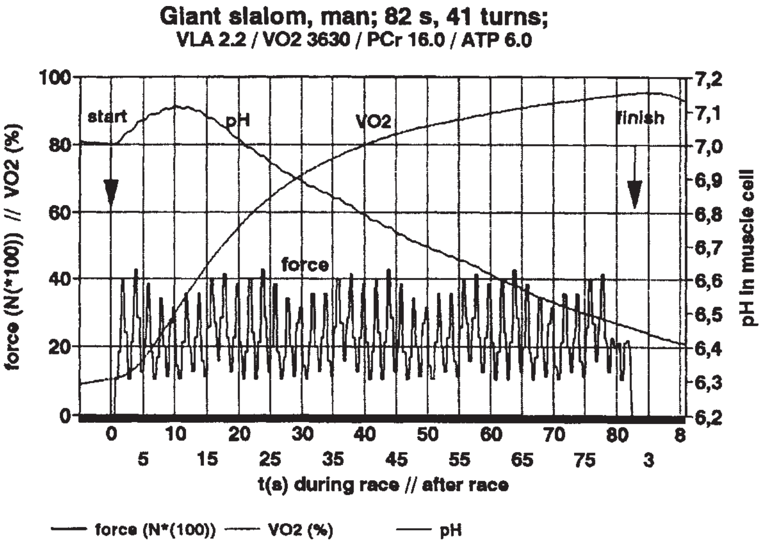
ATP	=	6.0 mmol/kg
PCr	=	16.0 mmol/kg (as related to ch. 4.1.) or 26.0 mmol/kg (as related to ch. 4.2.)
CR	=	5.0 mmol/kg (creatine=CR)
pH	=	7.0.

4 Results and discussion

4.1 Results of the simulation taking into consideration normally low metabolic starting conditions

Fig. 1 shows the simulation of a giant-slalom run.

On the basis of the performance parameters to be taken from the literature (Table 1), the simulation assumes an elite athlete with an average physiological performance ability. Based on the findings in the literature, a normally low VO_2max of about 3600 ml/min or average-to-high VLAmax of 2.2 mmol/kg*s, which is characteristic of an elite athlete, is taken as a basis.



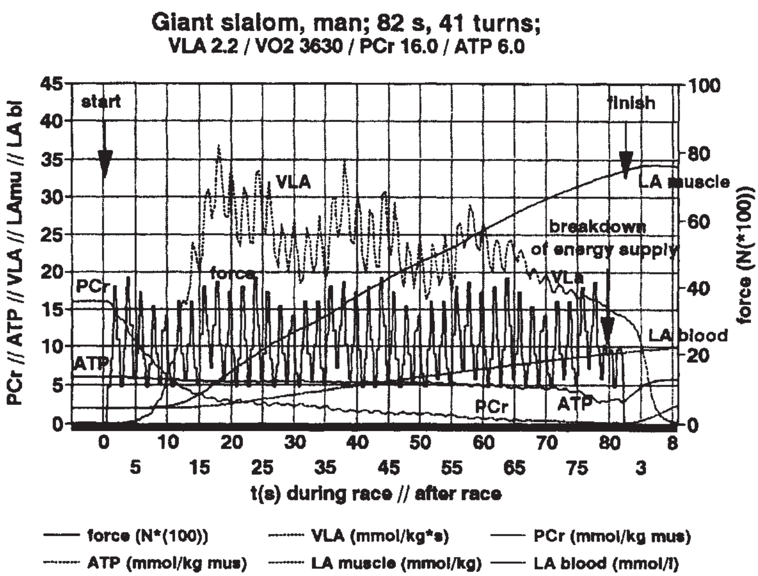


Fig. 1a/b. Post-simulation of the dynamics of the metabolic conditions during given ground-reactions (force (N)) of a giant-slalom run. In the top figure, the dynamics of VO_2 and the pH value are presented, while the bottom figure shows the dynamics of VLA, PCr, ATP, as well as muscle and blood lactate. The corresponding starting conditions can be taken from the title. For further information see text.

Fig. 1a/b shows that after about 45 s, the athlete's VO_2 is about 80% of his or her VO_2max. At the end of the exercise, i.e. after 82 s, VO_2 is around 95% of VO_2max. This is also in agreement with the measuring results during dynamic work; therefore, there is initially a relatively steep increase, and after about 70 s there is an almost stable O_2 uptake, which covers the greatest part of the energy demand (about 40%).

Even during the first 10s of the exercise, the PCr concentration decreases by about 30% of its initial value; this means that the anaerobic alactacid energy provision is generally restricted to the first 10 to 15 s of the exercise. Until the end of the exercise there is a further slow, although continuous decrease of the PCr concentration. However, the ATP concentration remains almost constant. There is only a significant decrease when the PCr concentration is almost nil.

As there is an initial decrease of PCr during the first 10 s, there is a steep increase of VLA to about 30–35 % of VLAmax. In this context it is remarkable that there is a simultaneous activation of VLA which is in each case dependent on the ground-reaction forces (Fig. 1b). This leads to the conclusion that the greatest part of the energy needed for the peak forces occurring during the respective ground-reactions has its origin in a short-term activation of VLA.

In this context, the O_2 uptake or aerobic energy provision has the function of providing a basic covering of the energy demand; it is not possible that the energy demand is covered solely via the O_2 uptake (one reason for this is the slowness of the aerobic system).

The significant activation of VLA is reflected in the continuous increase of muscle lactate and later the increase of blood lactate. Taking into consideration the available simulation, muscle values of about 34 mmol/kg and blood values of 9 mmol/l have been reached by the end of the exercise.

If the exercise is continued, the increase of muscle lactate is accompanied by a continuously decreasing pH value. Although the activity of the glycolysis first remains relatively constant over a large area there is a levelling out which becomes more and more obvious. This levelling out is solely caused by the pH-induced inhibition of glycolysis [7].

In Fig. 1b this behaviour is expressed in a steady decrease of VLA during the last 15 s of the exercise. On the basis of the assumptions underlying this study, the simulation at the same time leads to pH values in the area of 6, 45 at the end of the exercise; this is in agreement with the findings from the avialable literature [18].

At the beginning of the exercise, there is an increase of the pH value which is caused by the decrease of PCr and thus the increase of CR [7]. This alkalosis leads to a shift of balance in favour of ADP, which results in the activation of glycolysis.

The simulation shows that, from a specific point on, even the short-term activation of PCr alone cannot compensate for the contraction-induced variations of PCr. Neither is a further increase of VO_2 possible, because it has already reached a maximal value. As a last consequence, the pool of remaining ATP is used or reduced. The result is a deficiency of energetic balance which becomes higher and higher and which leads to a restriction of muscle contraction, and lastly has a negative effect on the execution of performance.

The direct relationship between the decrease in the ATP system and the contraction force could be verified by way of experiment [27].

Based on the assumptions mentioned, Fig. 2 shows the behaviour of the individual metabolic parameters during the phase immediately following the exercise. While the ATP pool has reached its initial level as early as about 5 to 10 s after the exercise, the fast replenishment of the PCr store, up to 90%, takes about 60 s. The slow replenishment of the remaining 10% is accompanied by the normalisation of the pH value and takes a correspondingly long time. Within about 2 min, the VO_2 adjusts itself to a post-exercise value whereas the adjustment of the maximal PEBLC (about 20 mmol/l) is achieved only after about 8 min. By this time, the pH value has reached 6, 7 again. The real findings obtained in practice are in agreement with the assumptions from the simulation.

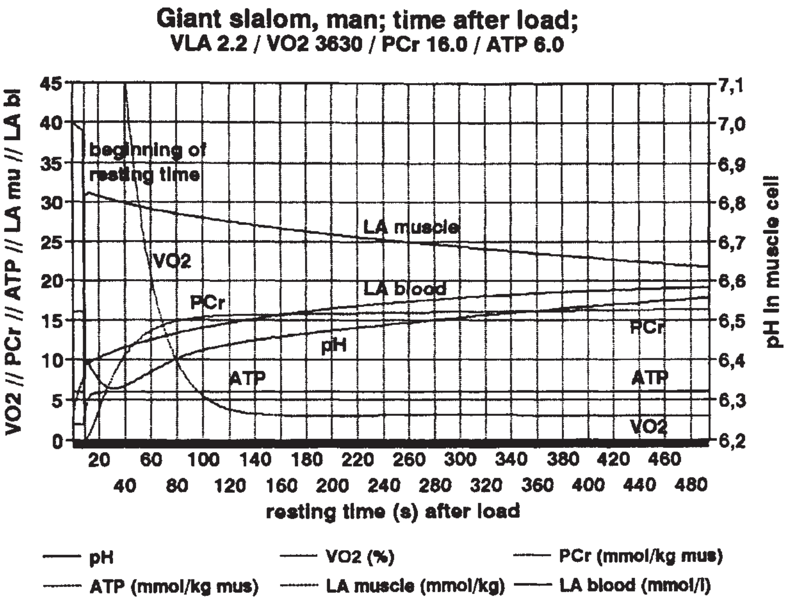


Fig. 2. Post-simulation of the dynamics of the metabolic conditions immediately after a giant-slalom run. The assumptions with regard to the concentration of VO_2max, VLAmax, PCr content and ATP can be taken from the title. For further information see text.

As the figures above and Tables 2 and 3 show, there are metabolic limitations with a normal, average performance ability which become manifest especially during the last third of the load situation. It remains to be concluded that the metabolic conditions presented here represent the lower limits of the performance ability of an elite giant-slalom skier.

4.2 Variability of the metabolic performance ability assuming different metabolic starting conditions

From Table 2 it can be seen the the performance during the giant-slalom run, which is assumed on the basis of the ground-reaction forces, can be realised with considerably different PEBLC and pH values depending on the height of VO_2.

Table 2. Summary of the simulation results based on a VO_2 which is low (3630 ml/min), medium (4230 ml/min) and high (4830 ml/min) for a male giant-slalom skier, or based on a high (1.80 mmol/kg*s), very high (2.20 mmol/kg*s) and extremely high (2.60 mmol/kg*s) VLAmax. At the same time, the calculated shares of energy provision (%), as well as the cellular pH or blood lactate values (mmol/l), are presented. The assumed ground-reaction forces are in the area of 2500–3500 N, the initial values of the cellular pH values are about 7.0 for the ATP concentration around 6.0 mmol/ kg and for the concentration of PCr around 16 mmol/kg, which is very low.

Table of different possible uses of energy resources in giant slalom for identical use of force, depending on different glycolytic (VLA) and oxidative (VO_2) metabolic conditions; PCr content 16mmol/kg, ATP content 6mmol/kg:

Metabolic conditions		**Share of energy production**			**Remarks**		
VO2max (ml/min)	VLAmax (mmol/kg*s)	aerob. (%)	anaer.lact. (%)	anaer.alact. (%)	VO2(%)/ph/LA(mmol/l)		
3630	1.80	35.7	58.2	6.2	96.1	6.35	18.6
					ATP depleted, breakdown		
3630	2.20	35.3	59.5	5.2	95.5	6.33	19.1
					ATP depleted, breakdown		
3630	2.60	35.1	60.2	4.7	95.0	6.31	19.5
					ATP depleted, breakdown		
4230	1.80	42.2	54.3	3.5	94.7	6.36	18.0
4230	2.20	41.9	55.2	2.9	93.8	6.34	18.4
4230	2.60	41.6	55.9	2.5	93.1	6.33	18.6
4830	1.80	48.7	49.6	1.7	92.8	6.39	16.8
4830	2.20	48.3	50.2	1.5	92.0	6.38	17.0
4830	2.60	48.0	50.7	1.3	91.4	6.38	17.2

Based on the high PEBLC, the load can be estimated as almost maximal; even in the case of a high motivation and complete use of all mechanisms involved in the energy metabolism, a longer or higher total performance in the form of still higher ground-reaction forces is not to be expected.

As shown in Table 2, there is at least theoretically a more favourable metabolic situation if a higher VO_2max (>=4230 resp. 4830 ml/min) is existent; by a higher exploitation of the available VO_2max, there would be a reduction of the use of VLA or the anaerobic lactacid energy provision. However, under the present assumptions, this is not a very possible event, because the PCr concentration is almost exhausted even after 60 s in the course of the starting situation. The question as to what extent this can be realised with individual athletes must also remain open.

A considerable advantage with regard to the distribution of the energy provision would be achieved if there were a higher PCr concentration (about 26.0 mmol/kg) at the start (Table 3). Besides a lower metabolic stress, as based on the PEBLC and the pH value, a significant shift in favour of the anaerobic-alactacid energy provision would then be identifiable.

Based on a relatively high VO_2max of 4830 ml/min and the starting conditions to be seen in Table 3 with regard to the PCr pool or the different rates of glycolysis for the execution of the performance demanded, therefore, the partial or complete exploitation of individual proportions of the energy metabolism is not necessary.

Table 3 shows the simulation results assuming the different starting conditions with regard to PCr concentration as well as a VO_2max or VLAmax of different height or the correspondingly calculated percentage shares for the energy provision.

Table 3. Summary of the simulation results corresponding to the assumptions of Table 2. Deviating from this, the PCr concentration is assumed here as 26 mmol/kg. For further information see text.

Table of different possible uses of energy resources in giant slalom for identical use of force, depending on different glycolytic (VLA) and oxidative (VO_2) metabolic conditions; PCr content 26.0 mmol/kg, ATP content 6.0 mmol/kg.

Metabolic conditions		**Share of energy production**			**Remarks**		
VO2max	VLAmax	aerob.	anaer.lact.	anaer.alact.			
(ml/min)	(mmol/kg*s)	(%)	(%)	(%)	VO2(%)/ph/LA(mmol/l)		
3630	1.80	33.3	55.0	11.7	92.4	6.46	18.6
3630	2.20	33.0	55.5	11.5	91.6	6.45	18.7
3630	2.60	32.8	55.9	11.3	91.0	6.45	18.8
4230	1.80	39.6	49.6	10.8	91.3	6.50	16.9
4230	2.20	39.3	50.2	10.5	91.0	6.49	17.1
4230	2.60	39.1	50.6	10.3	90.9	6.49	17.2
4830	1.80	45.8	44.3	9.8	91.0	6.54	15.2
4830	2.20	45.5	45.9	9.6	91.0	6.53	15.4
4830	2.60	45.2	45.4	9.4	91.0	6.53	15.5

Assuming that there is a close relation between the contraction force and the ATP concentration of the muscle cell [27], the reduction of the muscle mass would change the possibilities of force realisation during contractions in such a way that the continuation of the exercise at the given intensity or height would be impossible (Fig. 1b).

In this context, it must also be pointed out that the post-simulation does not show how and to what extent an increase of the active muscle mass influences the behaviour of the individual metabolic parameters.

In general, it can be assumed that a variation of the muscle mass also leads to a change of the corresponding gross values for the simulation and that, apart from an increase of VO_2max, there is also an increase of PCr or ATP. Consequently, this would also lead to a higher working performance.

From a subjective point of view, there has been a significant increase of the athletic component or the muscle mass of individual athletes in the alpine downhill and slalom events. This could be interpreted as a logically consistent development towards higher performance ability.

5 Conclusion

The possibilities presented here by way of example show to what extent the post-simulation of given metabolic conditions allows far-reaching findings and interpretation possibilities. The information, which can only be obtained in this way, goes far beyond the information gained from primarily descriptive performance diagnosis in the laboratory.

Additionally, there is the possibility to simulate the metabolic changes and their effects which otherwise can only be clarified by training experiments without the correspondingly lasting (mostly negative) effects on the athlete. Interpretations of this kind are also to be preferred for reasons of the objectifiability of the performance-diagnostic findings.

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FITNESS, CARDIOVASCULAR STRESS, AND SCD-RISK IN DOWNHILL SKIING

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Keywords: sudden cardiac death, fitness, cardiovascular stress, alpine skiing, mountain hiking, exercise.

1 Introduction

The Alps comprise the largest and most popular sports region in Europe. Of the 180,000 km^2 of mountainous area, Austria accounts for almost one third. In Austria alone each year more than 10 million persons from practically every country in the world are involved in one of the many alpine sports (downhill skiing, mountain hiking, ski touring, rock climbing, ice climbing, snow boarding, mountain biking, paragliding, etc.). About 85 percent of these persons are downhill skiers and/or mountain hikers. However, mountain sports are also combined with a relatively high risk of death [1]. In Austria there are annually about 300 fatalities during mountain sports. Based on accumulating reports on fatal cardiac events of skiers and mountaineers during the peak vacation periods, one is left with the impression arouses that downhill skiing, like hiking in summer, is associated with a particularly high risk of sudden cardiac death (SCD). Numerous studies have estimated the frequency of SCDs in general and during vigorous exercise [2–7]. However, little data is available on SCDs incurred during downhill skiing or mountaineering [8–9]. Therefore, the main goals of the study were the estimation of the SCD risk during downhill skiing compared with other types of (mountain) sports and the identification of main risk groups.

2 Methods

Recording of fatalities during mountain sports activities

A uniform set of forms was used to record the fatalities occurring during mountain sports activities in Austria in the period from 1985 through 1993. Data were compiled regarding the person (age, sex, nationality, membership in mountaineering associations, the type of mountain sport practised, etc.), the circumstances of the fatality, the doctor's diagnosis and further details (where, when, terrain, altitude, weather). Data were recorded by members of the Alpine Gendarmerie (Federal Ministry of the Interior), who are qualified alpinists and have para-medical training. All SCDs incurred during downhill skiing and mountain hiking in Austria from 1985 through 1993 were included. The diagnosis of "sudden cardiac death" was made by the emergency physician, by the doctor in the hospital, or on the basis of the results of an autopsy. The electronic processing of the data and their analysis took place in the Health Section of the Austrian Alpine Club.

Definition of "sudden cardiac death"

Sudden cardiac death was defined as unexpected, non-traumatic death in persons with or without pre-existing disease who died within one hour of the onset of symptoms [10–11]. Rare cases in which cardiovascular processes such as intracerebral hemorrhage, pulmonary embolism, and dissecting aortic aneurysm were demonstrated have been excluded.

Determination of the total number of persons involved in mountain sports and frequency of such involvement

An Austrian market research institute carried out a representative Austrian-wide survey under the auspices of the Austrian Alpine Club. Alongside other questions, the survey principally sought to determine the number of persons involved in individual mountain sports, their membership in alpine associations, differentiation according to age and sex, and the frequency of involvement in alpine sports [13]. An estimate of the total yearly number of hikers and downhill skiers in the Austrian mountains was made on the basis of available data on accidents and the yearly figures on the number of persons transported on ski lifts. A check of the total numbers of Austrian mountain hikers as determined in the survey was carried out on the basis of a microcensus in 1989 [14].

Short definition of mountain sports

In downhill skiing, lifts and cable cars are used for the ascent, and prepared and/or marked runs for the descent, whereas in ski touring the ascent is achieved with climbing skins on the skis outside of secured downhill ski runs. Mountain hiking encompasses tours in which the hands are not normally used as a direct means of locomotion. In comparison, for rock and ice climbing, the hands are necessary.

3 Results

The total numbers of SCDs during downhill skiing and mountain hiking in Austria from 1985 through 1993 are shown in Table 1.

Table 1. Numbers of sudden cardiac deaths (SCDs) during skiing and hiking in Austria from 1985 through 1993.

	M/F <35	M/F >34
SKIERS		
No. of SCDs	5/6	142/4
HIKERS		
No. of SCDs	4/0	335/22

M/F <35 (>34) are males/females under the age of 35 (over the age of 34)

About 30 percent of the total number of fatalities during downhill skiing and mountain hiking are SCDs [8]. In downhill skiers and hikers, about 90 percent of all SCDs are allotted to males over the age of 34. SCDs are rare in females and young males. However, young females seem to have relatively frequent SCDs during skiing as compared with females over 34 years of age. Figure 1 demonstrates the age-dependent numbers of SCDs during downhill skiing. A steep increase of the age-specific proportion is shown for males over the age of 50 years. The influence on SCDs by more regularly skiing or hiking is presented in Table 2.

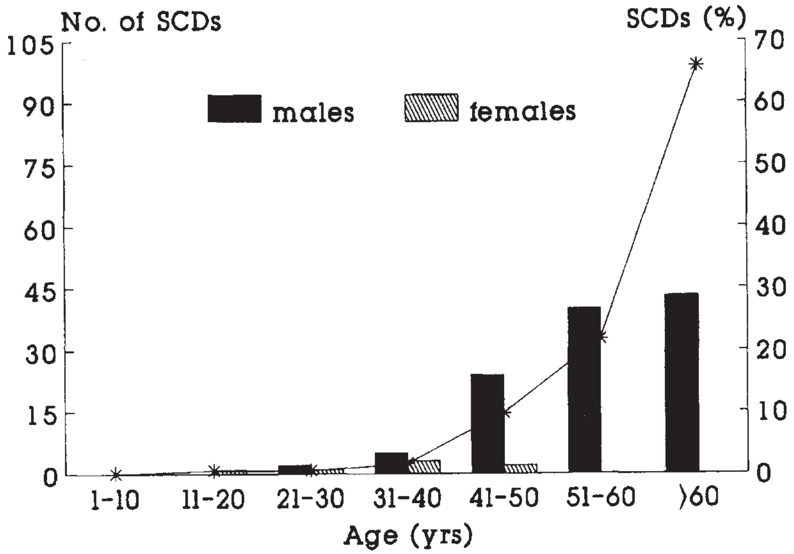

Fig. 1. The bars show the numbers of sudden cardiac deaths (SCDs) for men and women during downhill skiing in Austria from 1985 through 1991. Each asterix indicates the age-specific proportion of SCDs.

Table 2. Crude relative risks of sudden cardiac death (SCD) for Austrian male members and non-members (>34 years of age) of mountaineering associations.

	Austrian non-members of MAs	Austrian members of MAs	
	No. of SCDs per exposure days within 9 years		RR(95%CI)
Hikers	104/13,900,500	19/11,667,600	4.6(2.8-7.5)
Skiers	44/16,501,500	2/11,804,400	15.7(3.8-64.9)
RR (95%CI)	2.8(2.0-4.0)	9.6(2.2-41.3)	

RR means relative risk
CI means Confidence Interval
MAs means Mountaineering Associations

Austrian members of mountaineering associations have a 2 to 4-fold annual exposure time compared with non-members. Crude relative risk calculations indicate an increased risk for hikers as compared with skiers and a markedly enhanced risk for persons less engaging in mountain sports than those more regularly skiing and/or hiking. A comparison of the age-dependent crude relative risks of SCDs for skiers and hikers reveal a decreasing difference of the risk with increasing age (Table 3).

Table 3. Comparison of the relative risks of SCD among male skiers and hikers for different age groups

	Relative SCD risk (95%CI)*	
Age group	Skiers	Hikers
16-29	1	no SCDs
30-44	1	4.1 (0.83-20.45)
45-59	1	2.6 (1.30- 5.32)
>59	1	1.4 (0.85- 2.17)

* Relative risk adjusted for hiking and skiing frequencies
CI means 95% Confidence Interval
Test for linear association of the relative risks: P=0.06

4 Discussion

Whereas the vast majority of sudden cardiac death in subjects 35 years of age and younger are due to structural cardiovascular disease, coronary artery disease is mainly responsible for those over the age of 35 [15]. The Framingham study, carried out over a 28-yr observation period, indicates an annual overall SCD risk for persons between 35 and 70 years of age of 2.6 per 1000 men [10]. This corresponds to 1 SCD per 3,370,000 hours. In comparison, the SCD risk for men above the age of 34 when downhill skiing increases 2.2-fold (1 SCD per 1,500,000 hours) and when mountain hiking 4.2-fold (1 SCD per 802,000 hours) (Figure 2).

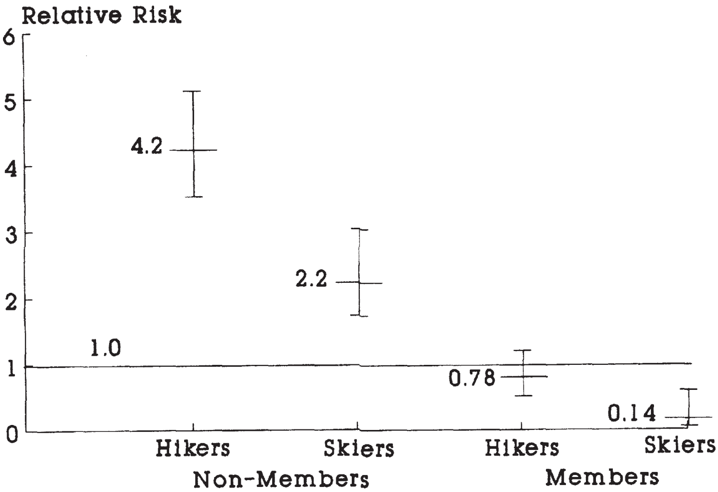

Fig. 2. Crude relative risks (with 95% confidence intervals) of sudden cardiac death during skiing and hiking for male members and non-members of mountaineering associations aged over 34 years as compared with the respective entire population (relative risk: 1.0). The calculations are based on the observed deaths in Austria from 1985 through 1993 and the corresponding hours of exposure (estimated from the numbers of exposure days—see Table 2).

Compared with cross-country skiing (1 SCD per 600,000 hours[16]) and jogging (1 SCD per ca. 400,000 hours [17]), the SCD-frequency when mountain hiking is similar and, when downhill skiing, markedly lower. The lower SCD risk in downhill skiing compared with mountain hiking may be caused by the different type of exertion in both sports and by the presumably different level of fitness of skiers and mountain hikers. Mountain hiking is characterized by a long lasting (up to several hours) dynamic work load of moderate intensity and alpine skiing by repeated static-dynamic short-term (1–3 minutes) work loads with interposed recovery phases. An increased incidence of SCDs during vigorous exercise has been demonstrated a number of times. However, it was also shown that the risk for persons with a high degree of regular physical activity is clearly lower in relation to inactive persons [2–7]. This may be a possible explanation why the SCD risk for male members (>34 years of age) of MAs amounts only 0.14 for downhill skiing and 0.78 for mountain hiking in comparison with that of the respective entire male population. Only little data exists concerning the frequency of SCDs in women during physical activity. In the surveys carried out by Siscovick et al. 21% of the SCDs during vigorous exercise are alloted to women [2]. During mountain hiking and especially during skiing, the figure seems to be somewhat lower. Altitude must be discussed as an additional risk factor alongside physical exertion [3]. Halhuber et al. found that the heart rates under ergometric exertion at moderate altitudes, as the expression of sympathetic activation, were clearly higher than at the valley level (men between 60 and 83 years of age). As well, at moderate altitude, extrasystoles occurred more frequently during recovery after ergometric exertion [18]. It is also known that sympathetic activation can trigger malignant arrhythmias [19]. Furthermore, arrhythmogenic factors, like enhanced fatty acid levels, electrolyte abnormalities, and changes in fibrinolytic activity and platetlet aggregation, which are more predominant during hiking, may also contribute to the SCD risk [20,21].

We are aware of the limitations of the methods. Some well known problems may arise from the routine collection of data. Possible sources of error may also be due to inexact survey results and lack of information regarding further characteristics of skiers and hikers. Nevertheless, some findings are worth considering for basic prevention strategies.

Summarizing, the SCD risk during skiing and hiking for men over the age of 34 not practising alpine sports regularly is greater as compared with the entire population. The SCD risk for hikers is more enhanced than for skiers; however, a steep increase in risk is observable in male skiers above the age of 50. No increased risk could be found for persons practicing alpine sports regularly. Altitude is discussed as an additional factor of provocation alongside the generally known risk factors and physical exertion. Exertion tests and an individually dosed preparatory form of endurance training prior to practising mountain sports must be recommended for symptomatic individuals and sedentary men>34 years of age [cf. 3,22].

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ELITE SKIERS AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION: EARLY FUNCTIONAL SPORT-SPECIFIC REHABILITATION IN WATER

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Keywords: alpine skiing, ACL-injuries, rehabilitation.

For elite competitive athletes injury is associated with enormous economic pressures, as well as with pressure from the public. This is particularly true for major competitive events. In such cases, the athlete's foremost desire is to return to competition or training as soon as possible. His desire is countered by the medical expert, who is forced to place time restraints, depending on the type of injury and the specific problems associated with it.

The medical expert's foremost principle should be not to permit an athlete to re-enter a competition unless he is fairly healthy and able to sustain stress.

Injured tissue does not repair faster in cases of top competitive athletes than in average human beings. Hence, it has become necessary to improve the quality of rehabilitation by developing and applying rehabilitation techniques specifically designed to treat the injury sustained by the athlete. In spite of the injury, the athlete should be able to train as intensively as possible.

The following three aspects should be in optimum harmony with each other:

1. The injured structure of the body should be given specific treatment.
2. Attention should be given to the position of the injured anatomic structure in the chain of motion pertaining to the specific type of sport. Moreover, regulation of motion and the sensomotor system should be given attention.
3. It should be ensured that the athlete's stamina is not overly impaired, especially in terms of strength, speed and endurance. A training program specifically designed to maintain the athlete's stamina should be pursued, as far as possible, even while the athlete is affected by the injury.

It should be remembered that the athlete is injured, but still in training.

In modern rehabilitation centers, an important aspect of treatment is the personality of the injured athlete. This specifically concerns the patient's ability to learn (Pöhlmann, 1986). The treatment should include conscious visualization of the motion pertaining to the specific type of sport. Ski-specific technical motions can be recalled in the present time and made directly available to the patient at the therapeutic swimming pool (with the help of modern videotaping techniques). This is one of several aspects of so-called mental training.

The major prerequisites for treatment of this type are high motivation, a good mental state of the patient and a clearly specified goal.

Notwithstanding his injury, the skier remains in close contact with his colleagues who are in regular training.

Although the incidence of injury to the anterior cruciate ligament has markedly increased among alpine skiers and has become a controversial issue in modern skiing, there are diverse opinions regarding post-operative rehabilitation measures following injury of this type. All specialists agree that functional treatment should be started as early as possible. However, opinions diverge widely with regard to the type of functional treatment, the steps of treatment, and, last but not least, the temporal sequence of treatment in terms of how much stress is permissible.

The goal of treatment after surgical reconstruction of the cruciate ligament may be summarized as follows: swift and painless stress-bearing capacity, passive as well as active stability, passive and active mobility, and a feeling of confidence with regard to the knee joint. Confidence in the strength of the knee joint is known to be an absolute prerequisite for optimum skiing performance.

Once these results are achieved, it may be assumed that the injury has probably healed. From a medical (ethical) point of view, there should will be no objection to subjecting the joint to normal stress.

The treatment of complex mobility disorders, such as those encountered after knee operation, necessitates the application of educational and scientific training principles to a much greater extent than has been done so far, especially if the injured person is an elite athlete (Harre, 1983).

A rehabilitation program for a ski racer should be based on the principles of training and motion. The program should include exercises, training instructions and corrective measures specially adapted to the sport and the specific injury.

Water is an excellent therapeutic medium for this purpose, because underwater therapy takes the reduced stress bearing capacity of the injured knee into account and yet permits the patient to drill motion patterns that are characteristic for skiing.

Specificity of Water in Therapy

Water is an essential therapeutic medium in modern rehabilitation programs. The concept of underwater therapy offers hitherto unknown possibilities of rehabilitation. Several metabolic and kinetic factors can be influenced by utilizing various effective elements of water such as buoyancy, temperature, resistance, hydrostatic pressure and electrolyte content.

It is the reduced weight of the human body in water that makes it possible to mimic skiing motions, even though the knee joint cannot be subjected to normal stress.

The various kinetic factors affected by the injury and by surgical trauma undergo a phase of repair during which certain reactions are set in motion. These reactions have major effects on the mobility, the loading capacity and the strength of the knee joint. An additional cumulative effect of the above mentioned factors is that the central regulation of motion is altered. The patient loses confidence and starts to feel afraid. Fear essentially influences the course of motion, in particular the timing of motion (Hotz, 1992). The consequences of fear can be immediately observed at a clinical level. The dynamic-motor stereotype of motion, including that of automatized patterns of motion such as ordinary walking, undergoes marked changes.

Reducing stress on the body helps to reduce fear. Fear disturbs the rhythm of motion and rhythm is the primary criterion for the evaluation of motion (Meinel, 1987).

Additional criteria are flow, precision, stability, force, speed and extent of motion. A summation of these factors causes what is known as the harmony of motion.

Reducing fear and training coordination of motion

Owing to mechanical and nociceptive stimulation of sensory nerve endings (Pacini's, Ruffini's and Golgi's organs, free nerve endings and muscle spindles) from the injury as well as from surgical trauma, the activity of motor neurons and the strength of the extensor (muscle) of the knee joint are down regulated such that these factors adjust to and protect the weakened tissue (Freiwald 1993).

Disturbances of this magnitude cause the patient to alter his gait. In order to relieve the leg of stress, he assumes a limp. This so-called “stereotyped limp” may become automatic in the presence of prolonged irritation. Subsequently, “learning to forget” such stereotyped habits will prove difficult and will require a lot of time, a fact that has been known to significantly prolong the time required for complete rehabilitation (i.e. complete fitness) in several cases (Wicker, 1992).

In the first place, water reduces stress and consequently reduces pain to a great extent. Moreover, it reduces the inhibitory factors in those sections of the central nervous system that are responsible for the regulation of motor functions. Hence, the development of a “stereotyped limp” can be effectively counteracted by this concept of treatment.

This is the reason why walking and coordination of motion are given particular attention during the three weeks of hospitalized rehabilitation.

Owing to the limited mobility of the operated knee joint, the patient’s pace is not as long as it would be at normal walking speed. Hence, he is compelled to reduce his walking speed. This reduces the length of pace and causes less stress on the elasticity of the capsular ligaments of the knee joint.

Therefore, in the beginning the patient is trained to walk by using shorter steps than he would use if his gait were normal. Each step is about as long as the length of one foot or one-and-a-half times the length of a foot. The arms are moved actively on both sides (no ambling). The execution of the movement should result in symmetrical gait.

Since stress is reduced, the muscles as well as the psyche relax. And, what is more, the patient experiences less pain. Consequently, normal gait without significant limping is achieved early in water, a fact that counteracts the development of stereotyped patterns of motion.

If the patient who has sustained injury of the knee joint and has undergone surgery of the cruciate ligament consistently trains to walk in water during the first four weeks following surgery, the following results will be achieved:

1. Training of symmetry and a less pronounced tendency to develop stereotyped patterns of motion.
2. Supports the coordination of the trunk, arms and legs, and thus makes it possible to drill the entire chain of motion.
3. The buoyancy of the human body in water and the resistance of water permit safe enhancement of kinesthetic perception.
4. Permits early commencement of proprioceptive training (position, extension, direction, speed, acceleration and position of body parts in space) and favourably influences the sense of equilibrium.

5. Permits rhythm training and has a favourable effect on the timing of motion.
6. Improves the elasticity and the sensitivity of the entire musculature of the leg and the trunk.
7. Massage and hydrostatic significantly enhance the flexibility of the lower extremity.

Inner Training

Water is an entirely new world of experience for the patient. Underwater therapy may be regarded as a step towards so-called "inner training".

The method of inner training originates from ancient Asian religions. It is based on a practical philosophy whose aim is to arouse and enhance spiritual and creative abilities by meditation and by perfecting the execution of physical exercises (Willimczik, 1991).

An important aspect of inner training is trust in the human body. The human body is an intricate, computer-like organism that regulates itself in a predetermined rhythm. In the final analysis, trust in the body is synonymous with trust in oneself. Accepting a situation for what it is may prove to be a practical way of approaching it and may be of great psychological help. The patient who goads himself to make maximum use of the rehabilitation will not achieve maximum benefit from the program. Rather, the patient who consistently pursues the program but also realizes that the injury is an integral aspect of his being will be happy and will rapidly achieve success. Awareness of this fact will help the athlete to accept the injury and will make it easier for him to develop a positive attitude towards it.

So-called inner training is a valuable adjunct to conventional training and treatment, because it takes not only external aspects, but also the athlete's subjective world of experience into account. Inner training enhances the ability to relax and regenerate, and reduces the subjective stress associated with training and treatment.

Ski-specific imitative training

In the treatment of sports injury, a lot of attention has been given and continues to be given to the injured part of the body. The fact that every aspect of the body is an integral part of a kinematic chain that is indispensable for the execution of any sport or, for that matter, any motion, is not given enough attention. If it were possible for the athlete to execute the complete sequence of a complex motion even with a knee joint that is, in fact, not capable of sustaining normal stress levels, it would mean less loss of coordination during the rehabilitation period.

The neurologist, Jackson, came to the conclusion that the brain does not know anything about the existence of muscles. Rather, the brain is only aware of motion patterns. Hence, the major goal of rehabilitation should be purposeful application of water in a manner that would enable the athlete to execute motion patterns pertaining to his daily life as well as specific motions associated with his kind of sport.

The buoyancy of the human body in water makes it possible to perform natural motions which are executed in three-dimensional fashion, in a spiral pattern and via several joints, in spite of the fact that the knee joint is too weak to sustain ordinary stress levels (Knott, 1970).

As far as the execution of movements is concerned, the same neuromuscular principles that apply to motion outside water apply to motion in water. However, the stress level is highly reduced because water relaxes both the body and the psyche.

While the athlete drills skiing movements in water, he is surrounded by a sum of spatial and temporal motion-related stimuli. In our rehabilitation program, many of these stimuli are specifically related to the sport. Drilling this type of motion makes the athlete aware of his potential abilities, which, owing to the injury, are temporarily passive. Functionally significant patterns of motion can be drilled in this environment.

When we use the term spatial summation, we refer to the sum of stimuli that may be released by various factors such as extension, physical contact and resistance.

Thus, performing specific skiing movements in water permits early commencement of a training program designed on the basis of motion techniques that are specifically adapted to the injury. Moreover, the program is designed such that it favourably influences neuromuscular patterns of motion.

Timing

Successful motor execution of motions related to any type of sport consists of the following aspects: application of the right measure of strength, a high degree of coordination and exact timing.

The motion of elite skiers is characterized by a certain uniformity in terms of specific accentuated muscular contraction. The rehabilitation program proposed here is designed such that this uniformity is preserved to a great extent. This is achieved by a high level of task-oriented and target-oriented coordination while mimicking specific skiing motions.

The structure of a motion may be defined as a unit of spatial-temporal as well as temporal-dynamic impulse elements.

In other words, the structure of the program of a motion is the rhythm of the motion and the rhythm of the program of motion, which may also be interpreted as the personality or the character of a motion (Hotz, 1992).

For execution of imitative exercises whose purpose is optimum rehabilitation, it is not the activity of a specific muscle that is of prime importance but the structural program of a motion. This structure should be preserved. The structure of the program is determined by and is the expression of the interaction of various impulses.

The inter-relationship between the following aspects is of decisive importance:

- Time interval (beginning of the impulse),
- duration (length of the impulse) and
- muscular intensity (extent or intensity of the impulse).

These temporal and dynamic aspects determine the structure of the program. Owing to these factors, the program acquires form-related elements and spatial implications.

Moreover, these factors determine the quality of an observable motion pattern. The quality of coordination of the three factors mentioned above (the beginning, duration and extent of the impulse) within the structure of a motion is known as the impulse timing of a motion (Roth, 1990).

The unity of temporal-spatial and temporal-dynamic impulse elements may also be summarized as the rhythm of motion. A characteristic aspect of rhythm is that it retains its individual structure and nature even if it is performed at a different (fluctuating) speed, i.e. at a speed that denotes a deviation from normal.

A thorough understanding of these aspects is highly significant for preserving consolidated motion programs during rehabilitation. These aspects may be summarized as follows:

a) The essence of a motion pattern is expressed by its rhythm, i.e. by its temporal and dynamic determinants.

b) If the preservation of a program is defined as the preservation of motion and technique, it may be argued that the preservation of motion and technique is, in fact, synonymous with the preservation of rhythm (because the essence of motion is rhythm).

c) A basic guideline for learning motion is that initially the motion should be precisely acquired in the phase of learning. After it has been learned, it may be performed swiftly. This principle could be applied in a converse manner for rehabilitation. In this context, it may be interpreted as follows: motion patterns that cannot be performed swiftly and under full stress (because of injury) can be repeated slowly and precisely by maintaining a rhythm that may be modified to suit the specific conditions, and can be conserved by being performed in water.

Several skiing techniques can be drilled in water at various degrees of skill, in a highly realistic fashion, without subjecting the knee to high levels of stress. The movements related to a specific kind of sport are stored in the athlete's motor memory. These programs of motion can be recalled at various degrees of proficiency, with the help of interpretation systems and decoding systems, and the programs can be used for specific training. These systems of interpretation and decoding may be presented in verbal (words, sentences) and/or visual (videos, diagrams, pictures, demonstrations) form.

The Use of Imagination (in water)

An athlete's imagination permanently influences his performance, both consciously and unconsciously. If the athlete's idea of a situation matches with the challenge the situation actually poses, the idea will help him to preserve the stored structure of a motion in his motor memory. The more precisely the steps of the motion are processed in the athlete's imagination, the more effectively can the proposed rehabilitation plan (whose major goals are minimum loss of the skiing feeling and maximum preservation of the skiing technique) be realized.

Owing to the fact that elite athletes undergo several years of intensive training, they are highly proficient in their kind of sport. Hence, during rehabilitation, they are much superior to persons who do not practice sports and even to those who pursue sports in terms of a hobby.

We apply the athlete's imagination in a consciously regular, controlled and targeted manner. He is made to train motion patterns with full concentration by performing imitative exercises whose basic pattern is similar to that of skiing techniques performed on snow.

This specific imitative training for skiers may be regarded as a special type of training.

Specific aspects of so-called mental training are combined with certain technical elements of so-called “regular training on the skiing piste”. The chain of motion, although executed under less pressure, is carried out in the correct rhythm and, what is more, in three-dimensional fashion.

With regard to mental training, this training program offers the following possibilities:

a) Subvocal training
The athlete is trained to repeat the training sequence in the form of a monologue.
b) Concealed perception training
This involves looking at a film on the execution of a motion (that the athlete is accustomed to perform) through the “mental eye.” To put it more simply, one imagines one’s movement with the help of video recordings. In our setting the athlete takes on the role of an observer, i.e. he looks at himself from an exterior viewpoint.
c) Ideomotor training
In contrast to concealed perception training, ideomotor training is an interior process. From an interior perspective the athlete vividly recalls the motion and re-experiences it in the present. He imagines himself performing the motion and tries to experience the mental processes that usually take place when he performs the motion (for instance, he may recall a cut swinging motion in the under-surface of his foot).

Various techniques of regular training are transferred to water and mimicked in this setting:

a) The following motions can be drilled well in chest-high water without putting too much stress on the injured knee joint: parallel swinging motion, transferring weight by a swinging motion, stress reduction in height, reducing stress in depth.
b) In order to train motion in an even more realistic fashion, the athlete is asked to wear his skiing shoes while performing some of the underwater raining techniques in the therapeutic swimming pool.

The two above mentioned aspects of training are combined such that they form a harmonious unit, whose application in rehabilitation has proved to be of great value for ace skiers. There are two reasons why this training program succeeds. Firstly, athletes are familiar with mental training and secondly, water is a convenient medium that does not pose any major problems for drilling ski-specific motion patterns.

It is fascinating to see how swiftly top competitive athletes adapt to motion conditions that are initially unusual for them.

When the athlete drills skiing techniques in chest-high water in a pool with a flat ground, it is obvious that external factors such as speed, the inclination of the slope, the texture of snow and centrifugal forces do not exist. Hence, the steering phase of a swinging motion cannot be mimicked at all.

Balancing and turning skills can be drilled to an extent that certain aspects of the kinematic chain of skiing may be reproduced on a neuromuscular level. Consequently, these skills are not jeopardized as much as they would be if the athlete did not train at all.

Once the knee joint is trained such that it is capable of sustaining more stress, and once the athlete feels fit to advance from skill drills to full participation (training on actual skis), he will be able to start at a higher level than he would have done without this training. Thus, the program shortens the total time needed for rehabilitation, i.e. from the time of injury or surgery until complete fitness for participating in a competition.

Use of videotapes to train motion in the pool

Sport-motor video training is defined as video-based learning of motor skills in the context of sports training (Olivier, 1994). It is a process regulated by information and its aim is to achieve maximum approximation of a realistically performed motion to a pre-given, kinematically defined ideal technique (Daugs, 1990). Sport-motor video training is based on the fact that one of the basic prerequisites for the acquisition of specific motor skills (Müller, 1994) is the creation of an internal representation of a motion, which, in this context, is based on the characteristic echokinetic conditions of perception and execution of motion in video training (Prinz, 1992).

The creation and preservation of this representation of motion are based on the processing of information.

The information obtained by video documentation has two aspects:

a) The ideal technique is presented and is intended to communicate what exactly should be done (video instruction).
b) The presentation informs the observer about what he has actually done (video feedback).

We do not use video training to learn sport-motor skills. Rather, we use it as a means to transfer actual skiing conditions to this specially designed rehabilitation training. In the pool, we try to create an environment that is similar to the environment on the skiing piste.

A major goal of video training is the conservation of training and motion patterns during rehabilitation. A further goal is to ensure that the injured athlete is in close contact with the remaining team members who are in training or are participating in the competition.

Evidently, when the athlete is able to mentally participate in the regular training program of his team, his motivation is significantly enhanced. These factors increase the efficiency of the training and rehabilitation.

One of the essential principles of modern rehabilitation, which is "INJURED BUT STILL IN TRAINING" is expressed in this program in an excellent manner. Almost all elite athletes have been filmed in action at some time or other. Video tapes of excellent quality are available from regular training as well as from television broadcasts of major competitions. These films can be intensively used for the program.

In any kind of training, but particularly in rehabilitation training, there should be a great deal of emphasis on attention. During video training, the tasks should be demonstrated and reproduced accurately. And this is possible only if the athlete applies full concentration.

Mentally, the rehabilitation training program should be carried out as if the techniques were being performed during regular training on snow. In other words, the athlete should carry out the training program with total concentration and with his entire attention directed towards the motion patterns and the training conditions.

Possibilities of video training

While using video-taped documentation, the following three types of video recordings can be used in the training setting:

a) Video recordings of the training runs performed by the athlete himself. The athlete can analyse his own runs and train these motions in the therapeutic swimming pool by mimicking the skiing motions in a slower rhythm, without subjecting the injured knee joint to high stress. This will make it possible for him to consciously examine his own technique. He may discover technical errors that may have become automatic, could discuss these with his trainer and could learn to conceal or rectify these errors by mentally rehearsing the correct pattern of motion.

b) Videotaped recordings of training with one's own team or with opposing teams
In spite of being in rehabilitation, the injured athlete will be able to able to actively participate in the regular training program of his team by watching these video films. Provided all members of the team cooperate, it will be quite easy to make the most recent training videotapes available to the athlete. This, in turn, will enable him to be in close contact with this team. This will also enhance his motivation and will help him to better accept the treatment and the training program. Moreover, it will favourably influence the outcome of the therapeutic measures.
c) Videotaped recordings of alpine ski slopes
Videotaped recordings could also provide the athlete valuable information about alpine ski slopes and racing pistes. The athlete will be able to carefully observe the downhill run of well known slopes such as the "Hahnenkamm" ("cockscomb") slope in Kitzbühel (in the Austrian Alps).

While mimicking skiing motions in the pool, the skier could mentally run the downhill slope such that his motor memory is trained and the information is stored.

When the athlete is capable of sustaining full stress, he will have the racing piste well stored in his motor memory and will be able to adjust better and more swiftly to the competition.

Training (Mimicking) ski-specific motion in deep water

It has been proven that the aqua jogger is very useful for mimicking ski-specific motions in deep water. This accessory ensures buoyancy and enables the athlete to move freely, with a slight forward inclination of 10 degrees when he is neck-high in water.

The skier has to stabilize his body by using the muscles of his trunk. In this position and using the aqua jogger, he will be able to mimic all the ski-specific exercises that he practised in chest-thigh water, with the additional advantage of having no contact with the ground.

The same applies to video training. The only difference is that in video training there is absolutely no ground contact, a fact that further reduces stress on the injured joint. However, the neuromuscular aspects of motion can be practised several times and the rhythm of ski-specific imitative exercises can be preserved. This is highly valuable when the athlete transfers the skills acquired during rehabilitation to the actual training environment in the piste.

Training stamina

In addition to being suitable for training coordination of motion, water is eminently suitable for training stamina. By training in this medium the athlete will be able to minimize loss of stamina during rehabilitation.

The major focus of underwater training during phase II of the rehabilitation program is to preserve the athlete's basic stamina. The movements designed for this purpose can be performed in water for a long period without experiencing pain and without subjecting the injured joint or the injured structures of the body to stress or tensile load.

Basic stamina training improves and/or preserves the capacity and the performance of the cardiovascular, respiratory and metabolic systems. Simultaneously, it supports local adjustment processes in the musculature such as capillarity, and increases the number and size of mitochondria.

Moreover, it activates the enzymes involved in aerobic metabolism and increases the intramuscular glycogen store.

While carrying out basic stamina training in water, we use various aids. One such aid is a life jacket provided with rubber bands. The rubber bands are fixed to the edge of the pool such that the athlete is forced to swim against insurmountable resistance. The patient floats on his back and perform backstrokes, primarily using his arms.

The legs are not stressed much during the first weeks. Later, once the symptoms have subsided, the athlete may practise kicking his legs upwards and downwards. This movement may be performed more intensively, in various rhythms of coordination.

Rubber fins may also be used as an additional aid.

The arms may be moved in terms of a synchronous, symmetrical stroke (similar to a double-arm stroke). This motion is followed by moving the arms above the water and returning to the original position.

Alternatively, the arms can be moved in terms of alternate upward strokes above the water (similar to swimming the crawl).

The patient should not have much pain. Depending on his individual performance, his heart rate may vary from 130 to 150 beats per minute. One training unit should range from 40 to 60 minutes and should be performed once daily. This prolonged training unit entails continuous cyclic motion of the arms in water. Its intensity will be determined by the patient's heart rate. Although this information regarding intensity is rather imprecise, it is adequate for rehabilitation, because the only purpose of the first postoperative weeks is to preserve the athlete's endurance. A carefully regulated training program involving measurement of lactate, urea and ammonia levels and the application of tests (such as the Conconi test) is not needed during the first three phases of our rehabilitation program. By increasing intensity, the training units can also be performed in the interval method (extensive and intensive interval training).

We found that the training unit fitted best with the total daily treatment and training program when it was carried out in the early hours of the evening. The reason is that a lymphatic drainage of the injured leg can be performed immediately thereafter, and the resulting vagus impulse and hypotonus of the musculature allow for general relaxation and create favourable conditions for regeneration.

Conclusions/Summary

Our experience has shown that applying various possibilities of modern underwater therapy and combining these techniques with a rehabilitation concept specifically designed to suit the type of injury and the injured athlete improves the quality of rehabilitation and helps the skier to return early to competitive training after operation of the cruciate ligament.

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TROPONIN I—A NEW MARKER OF MUSCLE DAMAGE IN ALPINE SKIING

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1 Introduction

The large emphasis on the eccentric actions needed to perform turns in Alpine skiing explains why the poorly conditioned competitor can experience muscle soreness when beginning a serious training program. This is the same soreness experienced by the recreational skier at the beginning of a skiing season. Most, if not all, of this delayed onset muscle soreness (which begins approximately 8–12 h after such exercise) is assumed to come from the microscopic injuries which occur to muscle cells not conditioned for eccentric activity [1]. Obviously, such microscopic injuries can result in lowered performance and also seem to be a risk factor in ski accidents. The most important muscle group to be targeted is the quadriceps. This is the major muscle group that maintains the skier's position in space, defining the delicate balance required for executing a turn. As the quadriceps becomes damaged, it loses power. This loss of power could create an inability to recover from injury-producing falls. Clearly there is a need for rapid diagnosis of ultrastructural damage to avoid overtraining as well as skiing out of control. By means of immuno-histochemical and electron microscopic techniques, Lieber et al. [2] investigated the time course of cytoskeletal and contractile protein changes which occur after eccentric exercise in rabbit tibialis anterior (TA), and extensor digitorum longus (EDL) muscles. The earliest change noted was significant loss of the 55,000 dalton (Da) intermediate filament protein desmin labeling of the EDL muscle fibers five minutes after the initiation of eccentric exercise. Over 30% of the EDL fibers had lost desmin staining, three days after 30 minutes of eccentric exercise, while only about 15% of the TA fibers were desmin negative. Loss of desmin staining occured in the absence of contractile or metabolic protein disruption. Increased staining intensity of the intrasarcomeric cytoskeletal protein titin, was also observed in fibers which had lost desmin staining. Desmin dissolution thus represents the earliest structural manifestation of muscle injury during eccenric contraction [2]. Cytoskeletal disruption may predispose the contractile apparatus to the structural damage which has previously been reported [3]. The article by Lieber et al. [2] provides significant and promising new information with regard to very early morphological changes (the loss of antibody staining for the desmin cytoskeletal protein) during eccentric contraction, and has heightened interest in early serum markers to diagnose cytoskeletal and/or contractile apparatus disruption, which occurs in muscle cells not conditioned for eccentric activity.

Plasma creatine kinase activity is not a reliable index of ultrastructural damage [4]. It may, in fact, be a reflection of the metabolic adaptation to exercise-induced muscle damage [4]. Therefore, our approaches are aimed at eventually identifying a new (early) serum marker to diagnose contractile apparatus disruption.

2 Methods

The procedures followed were in accordance with the Helsinki Declaration of 1975, as revised in 1983. The risks and benefits of the study were carefully explained and written informed consent was obtained from each participant before entering the study.

2.1 Exercise regimens

Eccentric-biased and concentric-biased exercise: 23 healthy male volunteers, ranging in age from 21 to 25 years, were recruited from the Department of Sports (University of Innsbruck). Before inclusion into the study, each subject had a complete physical examination and successfully performed a test of his maximum oxygen uptake (VO_{2max}) on a treadmill. The exercise session consisted of either 20 min of downhill treadmill running on a negative 16% incline (N=13), or 20 min of level treadmill running (N=10). The exercise intensity was set at 70 % of each subject's maximum heart rate determined by the VO2max test. During treadmill running we controlled lactic acid in 5 min intervals. Plasma concentrations of total troponin I (TnI), cardiac specific troponin I (cTnI), myosin heavy chains (MHC), and creatine kinase (CK) were measured before exercise, immediately after exercise, and 2, 6, 24, 72, 144, and 216 hours after exercise.

High-force anaerobic exercise: 12 healthy young men (mean age: 23 years) were recruited for this study. Only concentric actions were performed with one leg on an isokinetic dynamometer. The active muscle groups involved were the quadriceps and the hamstrings. The exercise session consisted of 40 repetitions at 180°/s. We determined lactic acid immediately post-exercise, and 1, 3, and 5 minutes after finishing. Plasma concentrations of TnI, cTnI, MHC, and CK were measured before exercise, 5 min, 30 min, and 1, 2, 4, 6, 10 and 24 hours post-exercise.

High-altitude Alpine touring race (Geierlauf): the study was performed at the Geierlauf 1995. Ten healthy subjects (mean age: 25 years) participated in this study. The Geierlauf is an Alpine touring competition of 25 km distance with an altitude difference of 1780 m, and a vertical drop of 970 m; the highest point is the “Geier”, 2857 m. Outdoor temperature at 9 a.m. was -9°C. At 1 p.m. outdoor temperature was -6°C. The snow temperature was -4°C and -3°C at 9 a.m. and 1 p.m., respectively. Plasma concentrations of TnI, cTnI, and MHC were determined before exercise, and 6 and 20 hours post-exercise.

2.2 Laboratory analysis

Blood samples were collected in ethylenediaminetetraacetate (EDTA) coated tubes (Sarstedt, Nymbrecht, Germany) and were withdrawn by venipuncture from an antecubital vein. Samples were immediately centrifuged at 2000g for 15 min. CK activities were measured without delay, and plasma for measurement of the other variables was frozen and stored at -20°C until analysis (performed within 4 weeks after collection).

Creatine kinase (CK) activities: CK (88kDa) is a key enzyme of muscular metabolism that exists predominantly as a soluble cytosolic protein in muscle fibers. It is found in all types of skeletal muscle fibers in similar concentrations [5]. CK activities were measured at 25°C by means of N-acetylcystein-activated, optimized ultraviolet test from Merck (Darmstadt, Germany) The upper reference limit (URL) of CK is 80 U/L for men.

Myosin heavy chain (MHC): Myosin is a structurally bound protein (540 kDa) made of six polypeptide chains: two identical heavy chains (230 kDa each) and four light chains. MHC is split by trypsin and papain into active fragments, light and heavy meromyosin, and subfragments, S1 and S2. Subfragment 2 (51 kDa) is the rod-shaped part of the heavy meromyosin fragment. Concentrations of MHC fragments were mesured by an immunoradiometric assay (Sanofi Diagnostics Pasteur, Marnes la Coqujette, France). This sandwitch assay uses a pair of monoclonal antibodies primarily raised against two different epitopes on subfragment 2 in the rod of human ventricular ß-type meromyosin. Cardiac ß-type MHC is coexpressed in slow-twitch skeletal muscle fibers [6, 7]. Both antibodies used in the assay react strongly with both human slow-twitch skeletal MHC which owes a strong structural similarity to ß-type cardiac MHC. The affinities of the antibodies to slow-twitch skeletal muscle myosin and ß-type cardiac MHC were identical [8]. By contrast, the antibodies do not significantly react with a-type cardiac MHC or with MHC of fast-twitch skeletal muscle fibers or any human smooth muscles. The URL is 300 U/L.

Cardiac and skeletal troponin I: Troponin I is the inhibitory protein of the troponin-tropomyosin regulatory complex that regulates the interaction of actin and myosin in striated muscles. The skeletal isoform of troponin I (sTnI) has a molecular weight (MW) of 18.5 kDa; the cardiac isoform of troponin I (cTnI) has an extra 30 residues on the N-terminus resulting in a MW of 22.5 kDa. By lymphocyte hybridization, we obtained high affinity monoclonal antibodies (MAbs) directed against the non cardiac specific part of Troponin I (TnI) and other high affinity MAbs directed against the cardiac specific part of Troponin I (22,5 kDa). Twenty-five of these MAbs were specifically directed against the cardiac form, while 15 MAbs recognized also the skeletal form (sTnI) (MW of 18,5 kDa). Screening of all MAbs by pairs (one coated MAb on NUNC Maxisorp immunotube, the other as peroxidase conjugate) was used to construct the antigenic map.This epitopic map has permitted the identification of some interesting pairs of MAbs capable of measuring troponin I concentrations. Two optimal pairs of MAbs were selected to determine both total troponin I (TnI) and the cardiac isoform of Troponin I (cTnI), (Sanofi Diagnostics Pasteur, Marnes la Coquette, France) concentrations by using two independant immunoenzymometric assays (IEMA). These assays were used to study the different circulating forms of TnI after exercise. By exclusion of cTnI release TnI concentrations allowed the assessment of skeletal-muscle injury. The URL for cTnI is 0.1 g/L [9], which has been confirmed previously [10]. The URL for TnI is 2.2 g/L (unpublished data).

Lactate: During intense muscle activity, the body is not capable of providing sufficient oxygen to the fibers to regenerate sufficient adenosine triphosphate and the muscle fibers employ the anaerobic process of glycolysis, which results in the production of lactic acid [1]. Capillary blood samples were withdrawn from a hyperemized ear lobe. Blood lactate was analysed with the Accusport (Boehringer Mannheim, Mannheim, Germany).

2.3 Statistical Analysis.

Means and standard errors (SE) were calculated to describe continuous variables. Differences between groups were assessed by one-way ANOVA with a Neumann-Keuls post hoc analysis. The paired Student t-test was used for intra-group comparison. A p-value<0.05 was considered significant.

3 Results

Cardiac specific troponin I could not be detected in any sample taken (<0.1 g/L), thus excluding a protein release from the heart.

3.1 Responses to eccentric-biased and concentric-biased exercise

During exercise lactic acid levels rose to approximately 4 mmol/L in both downhill and level runners, respectively.

Serum CK was significantly elevated after exercise in both downhill and level runners, with peak values 24 h after finishing. Interestingly, peak values did not differ between both groups (mean: 374 vs. 275 U/L; P=0.1, t-test) (Fig. 1).

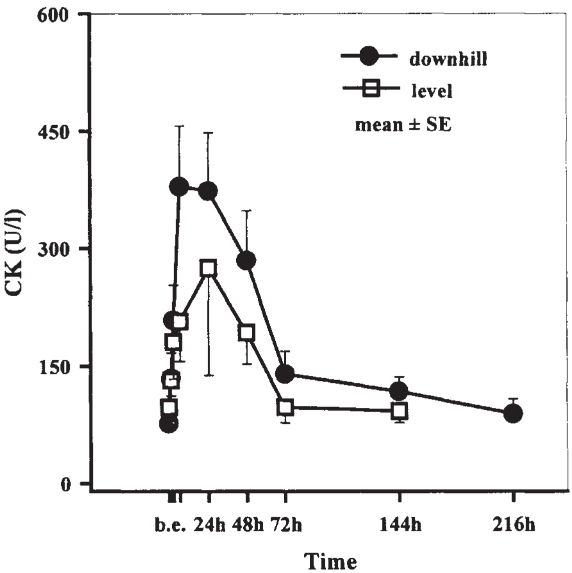

Fig. 1. Circulating creatine kinase (CK) after eccentric-biased and concentric-biased exercise. Data given as mean and standard error (SE). Abbreviations: b.e.=before exercise.

MHC increased after exercise with peak values 48 h after finishing. Peak values were significantly higher in downhill vs. level runners (mean: 1467 vs. 522 U/L; P=0.048, t-test) (Fig. 2).

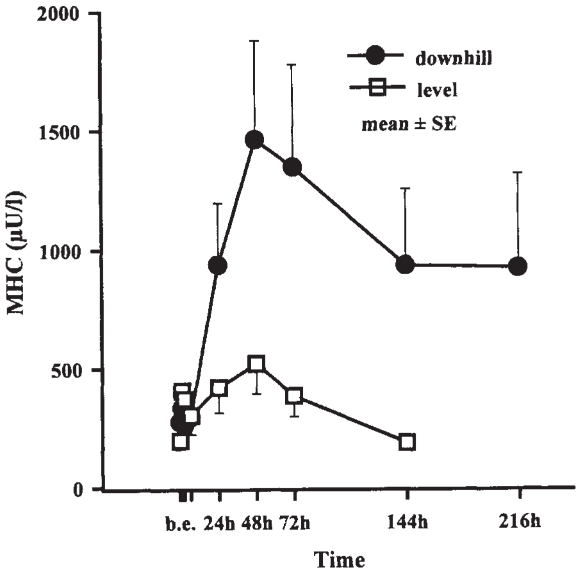

Fig. 2. Circulating myosin heavy chains (MHC) after eccentric-biased and concentric-biased exercise. Data given as mean and standard error (SE), Abbreviations: b.e.=before exercise.

Tn I increased rapidly after exercise with peak values 6 h after finishing. Peak values were significantly higher in downhill vs. level runners (mean: 30.6 vs. 6.4 g/L; P=0.003, t-test). The time courses, however, were identical (P=0.12; ANOVA) (Fig. 3).

3.2 Responses to anaerobic exercise

The most prominent change observed after 40 repetitions at 180°/s on an isokinetic dynamometer was an increase of lactate (Fig. 4) even though the muscle fibers maintained their contractile proteins and enzymes (Fig. 5).

3.3 Responses to a high-altidude Alpine touring race (Geierlauf)

TnI increased rapidly after this Alpine skiing event (mean peak value: 3.7 g/L) (Fig. 6) while the muscle fibers retained their contractile protein MHC within the first 20 h after finishing (mean peak value: 229.6 U/L; URL is 300 U/L) (Fig. 6).

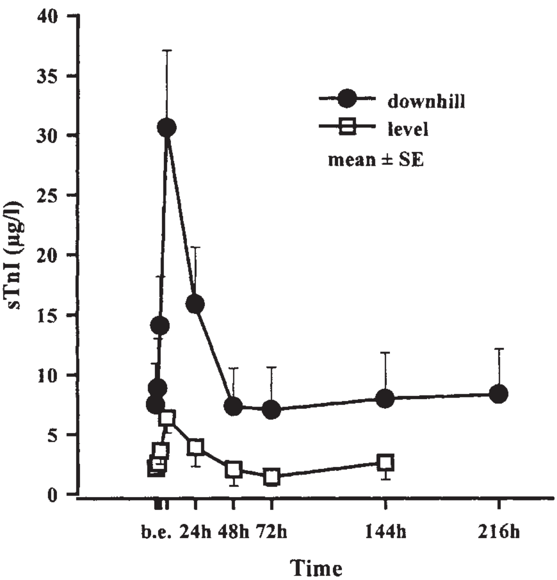

Fig. 3. Circulating skeletal isoform of troponin I (sTnI) after eccentric-biased and concentric-biased exercise. Data given as mean and standard error (SE). Abbreviations: b.e.=before exercise.

4 Discussion

The specific requirements for Alpine skiing include muscle endurance, strength, power, plus both aerobic and anaerobic conditioning [1]. Another requirement for skiing which is not necessary to the same extent in other sports is the need for repetetive concentric and eccentric quadriceps contractions without a rest period [1]. In a ski turn, the muscles oppose both gravity and centrifugal force by means of eccentric actions. It is widely agreed that skeletal muscle injury (e.g. cytoskeletal and contractile apparatus disruption) and muscle soreness are associated with forced lengthening of an activated skeletal muscle, i.e., eccentric contraction. A most significant finding is the loss of the desmin protein after cyclic eccentric exercise, which is associated with prolonged loss in the contractile function [2]. Thus eccentric exercise initiates a series of events that result in disruption of the cytoskeletal network and contractile apparatus that could be the mechanism for deterioration of the contractile response. This prolonged loss in contractile force can result in lowered performance during skiing and create an inability to recover from injury-producing falls.The fact that the muscle fiber cytoskeleton reveals complete disruption within 1 day of cyclic eccentric exercise has heightened our interest in early serum markers to diagnose cytoskeletal and/or contractile apparatus derangement.

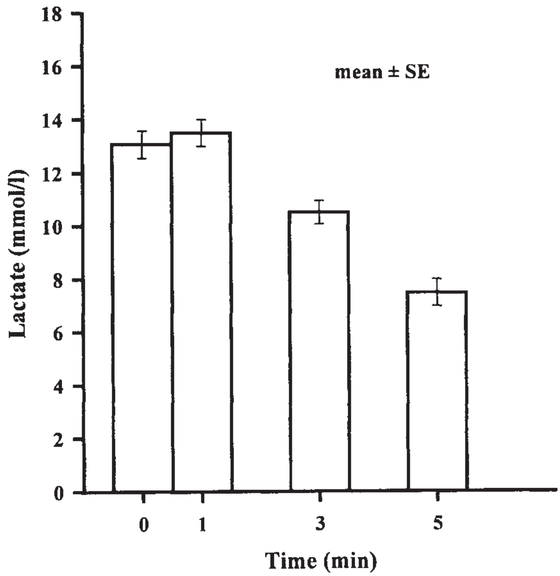

Fig. 4. Blood lactate after anaerobic exercise (concentric actions). Data given as mean and standard error (SE).

In the present study we were unable to show any difference in peak CK values between eccentric-biased (damaging) and concentric-biased (non-damaging) exercise (Fig. 1). These results agree with previous observations suggesting that plasma creatine kinase activity is not a reliable index of microscopic injuries which occur to muscle cells not conditioned for eccentric activity [4].

Recently, we used monoclonal antibodies to measure plasma MHC concentrations that permitted determination of the muscle fiber's response to eccentric contraction-induced muscle injury [11]. MHC peaked 48h after eccentric-biased exercise. Therefore, from the results of this data set (Fig. 2), it can be concluded that MHC dissolution represents a late structural manifestation of muscle injury during eccentric activity.

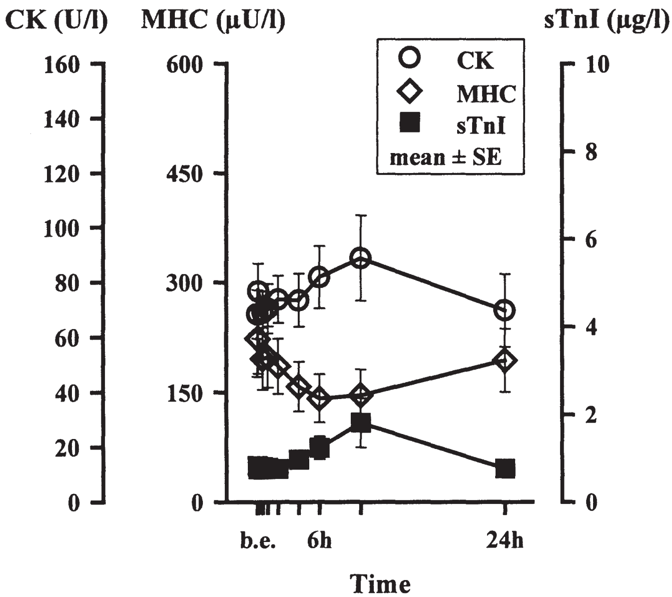

Fig. 5. Plasma creatine kinase (CK), myosin heavy chains (MHC), and skeletal troponin I (sTnI) after anaerobic exercise (concentric actions). Data given as mean and standard error (SE). Abbreviations: b.e.=before exercise.

The major objective of our research was the identification of an early serum marker of exercise-induced muscle damage. As shown in Fig. 3, we may have succeeded in the identification of such a marker. The profile of circulating sTnI values is suggested as a new marker of microscopic injuries (contractile apparatus disruption), which occur to muscle cells not conditioned for eccentric activity. Interestingly, the same TnI pattern could be detected after myocardial infarction [10].

During Alpine racing or intense recreational skiing, the demands on the glycolytic system are high and cause muscle lactic acid levels to rise from resting values of approximately 1 mmol/kg to over 25 mmol/kg of muscle [1]. The accompanying accumulation of hydrogen ions which are derived from lactic acid dissotiation results in lowering of the pH (or acidosis) in the muscle. Such a high acid content in the muscle fibers inhibits further breakdown of glykogen and may also interfere with the muscle's contractile processess. We tested the hypothesis that acidosis is associated with the degradation and/or removal of skeletal muscle myofibrillar proteins and enzymes. A prominent increase of lactic acid was observed (Fig. 4) even though the muscle fibers retained their contractile proteins and enzymes after high-force concentric loading (Fig. 5). Thus a high lactic acid level and/or the accompanying accumulation of hydrogen ions cannot be accountable for a major provision of the loss of contractile proteins and enzymes.

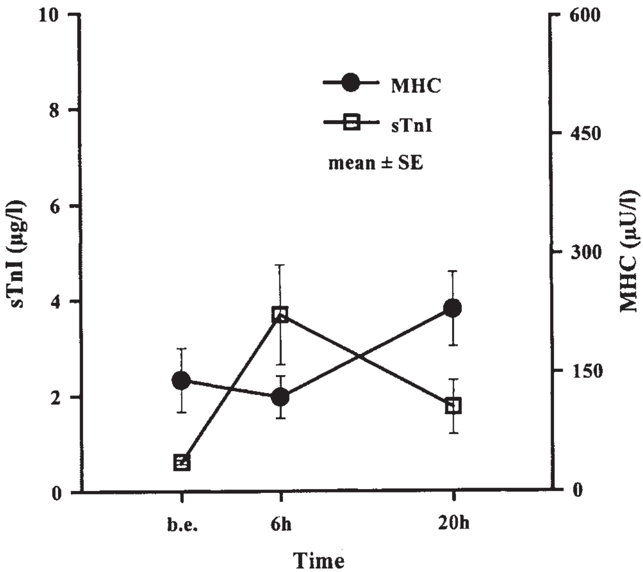

Fig. 6. Circulating myosin heavy chains (MHC), and skeletal troponin I (sTnI) after a high-altitude Alpine touring race. Data given as mean and standard error (SE). Abbreviations: b.e.=before exercise.

Important differences between running and Alpine skiing involve the fact that the runners' leg muscles are contracting for shorter intervals in order to maintain 110–120 double strides/min [1]. Additionally, the runner elevates body mass with each stride which emphasize concentric muscle actions. The skier's muscle actions, especially in the super G and downhill, are much longer and slower and, as in all Alpine disciplines, the emphasis is on eccentric muscle actions, as the skier opposes the downward pull of gravity. The runner's muscles are engaged in very brief eccentric actions with the foot strike of the lead leg while the Alpine skiers muscles are involved in somewhat slower eccentric actions of longer duration during each turn, particularly in the downhill and super G [1]. Therefore, we have broadened our studies to include Alpine skiing events. The physical requirements for Alpine skiing differ when a comparison is made between the recreational skier and the ski racer. Although these differences are relatively small, they can influence the choice of pre- and in-season conditioning programms [1]. Preliminary data (not shown), however, indicate that skiing causes sTnI levels to rise in the poorly conditioned competitor and recreational skier. Moreover, we were able to show a rapid increase in plasma sTnI concentrations after a high-mountain Alpine touring competition (Fig. 6). sTnI release thus represents an early structural manifestation of muscle injury during Alpine skiing.

Our results provide evidence that the high muscle force associated with the eccentric contraction or the length change occuring during the eccentric contraction causes a rapid degradation and/or removal of skeletal muscle myofibrillar complexed troponin I. By contrast, a high lactic acid level and/ or the accompanying accumulation of hydrogen ions (acidosis) is not required for this rapid degradation and/or removal. Obviously, a low pH (or acidosis) in muscle can result in lowered performance associated with the feeling of fatigue [1], but cytoskeletal and/or contractile apparatus derangement during eccentric eccercise may also contribute to a loss in contractile function [2]. The precise mechanism underlying this rapid degradation and/or removal of skeletal muscle myofibrillar complexed troponin I is not fully understood but may involve activation of the non-lysosomal Ca 2+-activated neutral protease, calpain [12]. Clearly, future studies are needed to define the very early events responsible for the loss of troponin I during eccentric activity.

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PHYSIOLOGICAL CHARACTERISTICS OF TOP YOUNG CZECH CROSS-COUNTRY SKIERS OF BOTH SEXES

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Keywords: exercise testing, treadmill ergometry, maximal oxygen uptake, ventilatory threshold, cross-country skiing.

1 Introduction

Maximal oxygen uptake related to kg body mass ($VO_{2max}.kg^{-1}$) is generally accepted as an important determinant of aerobic endurance capacity, and it is probably the most commonly used physiological parameter in assessing performance capability in such endurance-trained athletes as cross-country skiers [1] [3] [7] [10] [11]. Thus, there is a strong correlation between running performance and maximal oxygen uptake when the groups investigated are heterogeneous in terms of performance capacity [1] [4] [6]. On the other hand, in subjects with more homogeneously trained athletes, the correlation between running performance and maximal oxygen uptake is often reported to be relatively weak [1] [5] [9]. It should be kept in mind that maximal oxygen uptake is only one of several factors that affect performance level in cross-country skiing [1] [7], In running, the performance level of the competitors is usually judged from one or a few running events. In cross-country skiing the performance is more affected by such factors as snow conditions, equipment and ski-preparation procedures. Results from single cross-country races may therefore not always reflect the real difference in endurance performance between the competitors. To better describe the physiological prerequisities of cross-country skiing performance beside maximal oxygen uptake, the other functional variables must be assessed. Some of most frequently used variables are anaerobic threshold and coefficient of energy cost of moving [1] [3] [4].

Successful performance by cross-country skiers has been shown to be significantly influenced by moving economy [1] [4]. Moving economy may be described by the coefficient of energy cost of moving which indicates how much energy is required to transfer the body mass of 1 kg over a horizontal path of 1 m [4].

The aim of this study was to evaluate the top young Czech cross-country skiers (CCS) of both sexes in laboratory on a treadmill and according to our data and data presented in literature to determine the same physiological standards for top young CCS.

2 Methods

Forty of the best young female and fifty-three of the top young male CCS have been evaluated by an incremental exercise on a treadmill with 5% inclination. The initial speed of running was 11 $km.h^{-1}$ in female athletes and 13 $km.h^{-1}$ in males. The running speed was increased each minute by 1 $km.h^{-1}$.

All athletes were the best young CCS. The best of them regularly participated in international competitions and were successful in Junior European or World Championships. All subjects trained at least 6 days a week and had been engaged in high-intensity training for at least 5 years, and the mean time spent in intensive sports training unit was 2 $h.unit^{-1}$.

The measurements were made towards the end of the preparatory period (November). To classify the skiers according to their relative performance level, their ranking on the Czech Junior Cup list (classical style) after a followed winter season was used.

The body-fat determinations were realised with help of skinfold measurements which were taken by an investigator who had previously shown test-retest reliability of $r>0.90$ on the right side on the body using Harpenden calipers at the ten sites as described by Parizkova [8]. Body fat was calculated using the generalized equation of Parizkova [8].

The respiratory variables and gas exchange were measured using an open system. The athletes breathed through a two-way valve with a small dead space (Jaeger). Pulmonary ventilation was measured using a pneumotachograph (Jaeger) calibrated before and after each test by a mechanical pump. The oxygen concentration was measured using a paramagnetic analyser and the CO_2 concentration using an infrared analyser (both Jaeger). Both analysers were calibrated throughout the physiological range of measurement using gases of known concentration. Heart rate was monitored by means of short-range radio telemetry (Sporttester, Polar). The computer printed out these values every 30s. The maximal values were defined as the mean of the two highest consecutive values.

The coefficients of energy cost of moving were calculated from the maximal intensity of exercise where a reliable relationship between the intensity of exercise and the energy expenditure was still observed, i.e., at the “anaerobic threshold—AT”, in our case at the “ventilatory threshold—VT” [3].

Although many non-invasive methods may be used, a nonlinear increase in pulmonary ventilation with respect to VO_2 or VCO_2 is at present the simplest, and probably the most accurate method for determining the VT. The criterion for VT determination was a non-linear increase in pulmonary ventilation versus VO_2 or VCO_2 [3].

The VT was assessed by means of a two-compartment linear model using these relationships. This was done with a computer algorithm to establish a two-line regression intersection point [3].

Blood lactate concentration was measured in the third minute after the end of the exercise from blood samples which were collected from arterialized blood from a finger and the enzymatic method with help of Boehringer sets was used to analyse the blood sample.

The results are presented as means and standard deviations. Student’s t-test for non-paired values and analysis of variance (ANOVA) were used to test the significance between appropriate data.

3 Results

Tables 1 and 2 present a profile of the scores on some of the anthropometric and maximal functional variables for both groups of young CCS. The same tables list the selected maximal functional variables which were collected in top Czech young triathletes long-distance runners, middle-distance runner, cyclists, and swimmers of both sexes using of the same protocol and diagnostic apparatus as in CCS.

We have not found any significant differences between these data in athletes where the running is a basic moving activity, i.e. CCS, triathletes and runners. The difference in maximal oxygen uptake per kg body mass was significant only between CCS and swimmers ($p<0.05$).

Maximal speed of running was significantly higher in CCS, triathletes and runners than in cyclists and swimmers ($p<0.05$ in all cases).

The average $VO_{2max}.kg^{-1}$ of CCS of both sexes of higher sport performance was significantly higher than for the CCS of lower performance ($p<0.05$).

Table 1. Mean (±SD) values of selected antropometrical variables which were determined in the best young Czech cross-country skiers (CCS), triathletes (TR), Long-distance runners (LDR), middle-distance runners (MDR), cyclists (C) and swimmers (S) of both sexes (boys—B, girls—G).

	Age (years)		Mass (kg)		Height (cm)		%Fat (%)	
	B	G	B	G	B	G	B	G
CCS	17.2	17.1	66.7	58.8	176.5	168.4	8.2	10.4
(n=53-40)	2.2	1.4	7.1	4.7	5.1	2.0	2.3	2.6
TR	17.7	17.3	68.5	59.2	177.4	168.7	8.7	10.2
(n=23-18)	2.0	1.7	6.7	4.3	5.7	2.4	2.7	3.1
LDR	17.6	17.2	63.6	53.1	177.3	166.8	6.2	9.0
(n=39-21)	1.9	2.1	6.2	3.6	4.2	3.8	1.9	2.5
MDR	17.8	17.3	64.7	54.1	178.1	168.3	7.9	9.8
(n=17-12)	1.9	2.4	4.1	3.8	4.3	4.5	2.1	2.2
C	17.7	17.0	65.7	56.3	176.5	167.3	8.7	10.9
(n=17-12)	1.8	1.7	3.6	4.1	3.4	1.8	2.4	2.8
S	17.5	17.2	70.3	61.3	178.6	169.6	9.8	11.2
(n=12-10)	2.0	1.9	3.7	3.2	3.9	4.9	3.0	3.8

Table 2. Mean (±SD) values of selected maximal functional variables which were determined on the treadmill with 5% inclination in top young Czech cross-country skiers (CCS), triathletes (TR), Long-distance runners (LDR), middle-distance runners (MDR), cyclists (C) and swimmers (S) of both sexes.

	VO2max (1.min^{-1})	VO2max.kg^{-1} (ml.kg^{-1}.min^{-1})	Vmax (1.min^{-1})	Vmax (km.h^{-1})	LAmax (mmol.1^{-1})
			Boys		
CCS	4.80	71.9	152.7	18.6	12.9
(n=53)	0.33	5.9	13.7	1.2	2.3
TR	4.53	67.9	136.6	18.4	12.5
(n=23)	0.39	5.4	15.6	1.0	2.3
LDR	4.47	70.3	134.6	18.7	12.2
(n=39)	0.41	6.3	12.8	1.7	2.3
MDR	4.45	66.8	138.7	19.1	13.1
(n=29)	0.43	4.7	18.7	0.9	2.6

	VO2max (1.min-1)	VO2max.kg-1 (ml.kg-1.min-1)	Vmax (1.min-1)	Vmax (km.h-1)	LAmax (mmol.1-1)
			Boys		
C (n=17)	4.27 0.32	65.4 5.1	132.3 19.6	18.0 0.7	13.3 3.5
S (n=12)	4.58 0.38	61.6 3.6	148.4 19.3	17.2 0.8	11.1 3.2
			Girls		
CCS (n=53)	3.71 0.28	63.1 2.4	137.3 14.1	15.4 0.6	12.4 1.2
TR (n=23)	3.30 0.21	56.1 2.4	124.8 13.2	15.4 0.9	12.6 1.4
LDR (n=39)	3.14 0.24	59.2 2.9	121.2 12.9	15.8 1.2	12.7 1.9
MDR (n=29)	2.92 0.34	57.3 2.6	117.3 15.1	16.2 0.9	13.7 3.0
C (n=17)	2.81 0.29	55.1 2.4	113.4 14.7	15.1 0.8	12.9 3.7
S (n=12)	3.23 0.40	52.1 3.6	128.3 16.2	14.9 0.9	11.8 3.3

The mean values for selected functional variables at VT level in all tested groups of young athletes of both sexes are given in Table 3. The same table presents the data for the coefficient of energy cost of running c. The overall average values of c are consistent with numerous previous observations [2] [4]. The values of c were not significantly lower in girls than in boys.

These values of selected functional variables at VT level are practically the same in groups of CCS, triathletes, long- and middle-distance runners and cyclists except the coefficient c which is in CCS, triathletes and runner specialists significantly lower than in cyclist and swimmers.

The highest speed of running at VT level was found again in runners where the technique of running is highest and lowest in "non-runners"—cyclists and swimmers.

Table 4 presents the functional standards for young CCS (age from 17 to 18 years) at an international level (predispositions for success in international competitions), which were carried out with regard to data from internationally successful Czech and foreign young and adult cross-country skiers.

The correlation analyses in CCS showed a non-significant association between relative sport performance and pulmonary ventilation and blood lactate when estimated jointly in both sexes. In contrast, significant relationship was found between field performance and maximal oxygen uptake in $ml.kg^{-1}.min^{-1}$ (in boys r=-0.601, in girls r=-0.723), maximal speed of treadmill (5% of inclination) running (-0.578, -0.712), oxygen uptake on the VT level (-0.611, -0.623), and speed of running at the same level (-0.593, -0.745) (all p<0.01).

Table 3. Mean (±SD) values of selected functional variables at ventilatory threshold and coefficient of energy cost of running c in top young Czech cross-country skiers (CCS), triathletes (TR), long-distance runners (LDR), middle-distance runners (MDR), cyclists (C), swimmers (S) of both sexes.

	$VO2.kg^{-1}$ ($ml.kg^{-1}.min^{-1}$)	$\%VO2max.kg^{-1}$ (%)	v ($km.h^{-1}$)	%vmax (%)	c ($J.kg^{-1}.m^{-1}$)
			Boys		
CCS	59.2 5.4	82.4 2.6	15.2 1.4	81.8 2.8	3.75 0.42
TR	56.0 5.4	82.4 2.1	15.3 1.6	82.0 2.6	3.74 0.49
LDR	59.1 5.1	84.1 3.0	15.8 2.1	84.5 3.4	3.73 0.19
MDR	55.3 4.7	82.8 2.6	16.0 1.9	83.8 4.2	3.72 0.10
C	54.5 3.7	83.4 2.9	14.6 1.8	81.3 4.0	3.81 0.12
S	48.6 3.9	78.9 3.2	13.5 1.7	79.3 3.7	3.85 0.09
			Girls		
CCS	52.4 2.6	83.1 1.7	12.7 0.7	82.3 1.6	3.72 0.39
TR	46.6 2.6	83.4 1.9	12.6 0.9	82.1 1.8	3.73 0.41
LDR	49.5 3.5	83.6 3.8	13.1 2.0	83.7 2.2	3.72 0.29
MDR	47.4 3.2	82.7 3.7	13.4 1.6	83.1 3.6	3.71 0.29
C	45.2 3.4	82.1 3.4	12.2 1.4	80.9 3.9	3.80 0.12
S	42.0 4.1	80.6 4.0	12.1 1.8	81.4 4.1	3.83 0.13

Table 4. Physiological standards for young cross-country skiers (age from 17 to 18 years) of an international level (treadmill ergometry).

	Boys	Girls
VO2mx.kg^{-1} (ml.kg^{-1}.min^{-1})	> 74	> 65
vmax (km.h^{-1}) (5%)	> 18	> 16
LAmax (mmol.1^{-1})	> 12	> 11
at VT level		
%VO2max (%)	> 82.5	> 82.5
v (km.h^{-1}) (5%)	> 15.5	> 13.0
c (J.kg^{-1}.m^{-1})	< 3.75	< 3.73

4 Discussion

When comparing the basic anthropometrical data of young cross-country skiers to that of elite triathletes, endurance runners, swimmers, and cyclists of the same age, the CCS were found to be similar in height to the other athletes. The body mass of CCS was slightly lower than the swimmers but higher than the cyclists and/or long- or middle-distance runners.

Values of $VO_{2max}.kg^{-1}$ are consistent with numerous previous observations in endurance athletes [1] [2] [3] [9] [11] [12]. Both specific muscle mass and oxidative capacity of working muscles may be increased by specific training and thus the $VO_{2max}.kg^{-1}$ reflects an actual spécifie predisposition for endurance exercise. Maximal oxygen uptake in trained athletes is generally higher in work situations that allow optimal use of specifically trained muscle fibres [2]. This may be one of decisive causes of differences in „running“ $VO_{2max}.kg^{-1}$ when we compare results of running specialists with cyclists and swimmers.

The values of maximal functional variables (mainly $VO_{2max}.kg^{-1}$) were similar to that of top young Czech endurance athletes and slightly higher than elite top swimmers of the same age, which were evaluated by the same protocol.

Maximal oxygen uptake has routinely been used to assess endurance-running performance. In fact, successful performance in competitive distance running has been primarily attributed to $VO_{2max}.kg^{-1}$. A number of investigators have found highly significant correlations between $VO_{2max}.kg^{-1}$ and distance running success in cross sectional studies [2] [6] [7].

The range of $VO_{2max}.kg^{-1}$ was relatively large in both groups of CCS. The higher values in $VO_{2max}.kg^{-1}$ in subjects with higher performance level suggest that an high maximal oxygen uptake is necessary to become a world-class skier. Thus, only limited possibilities appear to exist to compensate for a low $VO_{2max}.kg^{-1}$ with other factors influencing the physical performance capacity of top-level young CCS. A high level of maximal oxygen uptake does not guarantee good physical performance, since technique of motion and psychological factors may have an influence either positively or negatively. In practice this means that if we wish to characterize the state of aerobic training, we must evaluate $VO_{2max}.kg^{-1}$ and physical performance (speed of running) at the same time.

The literature regarding the physiological characteristics of elite young endurance athletes reveals that nearly all competitors have $VO_{2max}.kg^{-1}$ values in males higher than 67 and in females than 62 $ml.kg^{-1}.min^{-1}$ [1]. Thus, a high $VO_{2max}.kg^{-1}$ is considered a prerequisite for success in distance running and sets the limits of a runner's endurance potential.

Coefficient c can be used for the evaluation of the adaptation to the moving. The higher the level of adaptation to a given type of exercise, the lower the amount of energy necessary to transfer 1 kg of body mass along a distance 1 m. It is for this reason that the lowest values of c were recorded in runners of both sexes. The lowest values of c in middle-distance runners were obviously the result of a high level of adaptation to running of these athletes who were forced to exercise at very high speed.

The better predispositions for endurance exercise in girls than in boys [2] [4] [10] may be confirmed by slightly lower values of coefficient c and higher values of percentage of maximal functional variables at VT in girls than in boys.

These data and results from other groups of endurance oriented athletes suggest that perhaps there is some critical level of maximal functional variables (mainly maximal oxygen uptake) below which a CCS will not be successful, but above which other factors play a more important role in performance.

These functional variables were compared to other examinations carried out by our laboratory in adult CCS and data from our top young and adult long- and middle-distance runners. According to these results and according to the data from literature [1] [2] [6] [7] [9] [10] [11] [12] we can determine the physiological standards (see Table 4).

As in other sporting events of endurance character, the physiological data are not the sole predictor of racing success. On the other hand, we must note that these standards are necassary, but not sufficient conditions for success in cross-country skiing. These data play an important role in the selection of talents for CCS.

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Part Five
Sociology of Skiing

45
PLEASURE FIRST, MORALE LAST—ON THE JUSTIFICATION OF MODERN WINTER SPORTS

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Keywords: sociology, alpine skiing, sport ethics, nature.

Introductory Remarks: Sport ethics as the focus of sport sociological thinking

Besides those different motortheoretical approaches which were extensively dealt with in other work groups, we should now turn to the fact that skiing has developed into one of the most important factors of regional and economic policies as well as having become an explosive topic in ecological discussions.

Being well aware of the complexity of the problems which arise from this matter and under consideration of the limited time, I was forced to make a selection. Contrary to what most of you might have expected, I did not opt for giving a sportsociological overview which would explicitly demonstrate the social linkage of the phenomenon "skiing" under model-theoretical aspects.

I rather concentrated my lecture on a particular question of both sociological and philosophical character, i.e. the *sport ethical question:* "Does skiing allow us to do all those things that we are able to do?" After having looked into skiing under motor-analytical aspects during the past few days, I would now like to turn the focus of attention to the question: "Which are the *conditions for possible action* of individual and social-political sport management"—on a higher, a *meta*-level, so to speak, instead of dealing with those economic, political, ecological and other preconditions of skiing on an *object* level. Thus, such a ,,sport ethics of skiing" represents a meta-theoretical attempt to rejoin the manifold sport-sociological questions of modern sports and this under the aspect of responsibility. Consequently, the following sport-ethical lecture is, on one hand, a contributrion towards the special field of sport philosophy, on the other it attempts to develop a general, overall perspective for sport-sociological problems under sport-philosophical aspects.

In accordance with this prior decision, the following contribution is divided into 4 steps which—figuratively speaking—are arranged on two levels:

I A descriptive-classifying level of object,
1.Phase of confrontation
2.Phase of cooperation
II. An analytical-systematic meta-level
3.Phase of reflection
4.Five theses on ethics of the aesthetic appeal of skiing.

This differentiation should help to make evident that a modern discussion on the subject of "sport and environment" can no longer be reduced to a mere question of knowledge to be solved on the object level by closing existing gaps of knowledge with new "subject knowledge" (e.g. life habits of reindeers or how of high-pressure snow canons function), but that it becomes increasingly important to take a closer look at this nearly 25-year-old discussion from a general, self-critical perspective. This implies finding out at a level of analytical-systematic thinking on what kind of basic understanding of nature, winter sports and environmental morale the conflicts between the positions of sport fans and environmental activists are based upon and which consequences would subsequently arise for a "second round" of environmental discussion in sports if the respective preconditions, the conditions for possibilities of actions in winter sports were analyzed properly.

I Phase of Confrontation

1.1 The different stages of winter sports' development

Under touristic aspects, the development of winter sport activities in the Alpine region can be divided into four different stages. Considering the fact that these stages significantly determined the relation of sports and environment and its increasingly growing confrontation, this division is assumed as a general measure for classification.

First stage: "Activist-Tourists"

The first stage of winter sport is best described by that type of sport which first developed in the Alpine Region and which can be regarded as a subsequent reaction to the experience before the World War II. A characteristic feature of this stage is the "Actively-involved Tourist". Provided with contacts via alpine or ski associations and together with his family, this tourist went skiing with expertise and eager to learn and mainly headed for those fields preferred by the local inhabitants. Whenever he found a skiing site which corrsponded to his individual interests or to those of his small group, he was proud of his so-called discovery and hoped that his holiday resort would continue to exist as long as possible in its present form, determined by the daily life of the local people.

Second Phase: "The Recovery Tourist"

The second phase always started at a time when a skiing resort consciously adapted its infra structure to tourists' needs, which mostly meant an improvement of access roads, increase in parking lots, restaurants and hotel facilities. Apart from the activist tourists who regarded this development with a rather sceptical attitude, these innovations also attracted a different type of tourist, best described by the attribute "Recovery Tourist". They did not only come for skiing, what they were looking for during their holidays was relaxation and recovery.

> "Until 1950, 39 cable railways were built in Switzerland.
> Until 1983, 570 cable railways were built in Switzerland
> Until 1983, 1200 lifts were built in Switzerland.
> In 1948, 17.9000 nights were booked in Swiss hotels,
> In 1983, 33.600.000 nights were booked in Swiss hotels."
> (DIGEL, 1989, 88)

Third Phase: The "Adventure Tourist"

In the following period, many skiing resorts made an effort to extend their alternative supply of relaxation and recovery, in order to be able to remain attractive for the adventure tourist, also during periods of bad snow and weather conditions and long winter evenings. Indoor swimming pools, saunas, ice-skating rinks, discos, etc. did not only complement the offer of skiing, but developed into an entertainment culture of its own. As a consequence, the skiing resort became more and more a centre of attraction for the "adventure tourist" who, contrary to the activist or recovery tourist, merely regarded skiing as an incentive for holiday planning. For him, a diversified, attractive supply of entertainment in a winter land was a major factor for choosing his holiday resort. Simultaneously with the increase in demands for après-ski possibilities, this also implied greater demands on the infra structure of the region. Not only the number of lift facilities, but also their regional linkage, their accessibility, the quality of ski runs, density of ski huts etc. were considered as quality standards for a winter sport resort.

> "The arch-shaped bridge of the Alps is 1 200 km long. The Alpine Arch is 250 km broad. Each year, 40000 friends of the Alpine region book their winter holidays: 250 000 000 bookings of overnight stays.
> Due to holiday seasons, 10 000 tourists meet with 7 000 000 local inhabitants of the Alpine region.
> In addition to this, they are joined by 60 000 day-trippers: altogether they use 12 000 lifts and mountain railways, 40 000 ski runs with 1 000 run rollers—and thus 40 000 km of down hill lengths. This is equivalent to three times of the earth's girth. Each day, 1 000 000 skiers are transported up to the mountain."
> (ROOS 1988, 44).

Fourth Phase: "The Mass Tourist"
As any improvement of infra structure (from the lift to the disco) is only worthwhile if an utmost level of utility is achieved, the owners of such facilities generally also favoured an increase in number of guests. In order to make full use of the increased accommodation supply, a targeted direct marketing was required, also in regions far away from the Alps, such as northern Germany, Holland, Denmark, etc. The major number of tourists gained from these countries travelled on package tours on a weekly commuting scale. As a consequence, the skiing resort of the fourth phase was only able to survive under economic aspects, if it left the mass tourist as satisfied as possible so that he would wish to come back the following year. Consequently, the skiing resorts saw themselves forced to fulfill at least some of those dreams which the traveller, lured into high expectations by advertisements, had hoped for when he had decided on where to spend his most precious time of the year.

Summarizing all these facts, the following remains: the skiing sport from the post-war period with its mostly privately planned actions has been turned into a modern skiing business during which the tourist's life no longer forms part of that of the local inhabitants of region, but is determined by his desire for adventure and relaxation. Skiing as a productive power with its specific economic conditions aimed at value creation and increase thus becomes a dominating economic factor in many locations of the Alpine region. There is only one weak, yet decisive spot involved in this different way of dealing with skiing: *nature*. The most important capital of a skiing resort is, amongst other objective conditions such as the height of the location, accessibility of the ski region, the length of downhill runs, etc., in particular, the amount of snow within one season. As all other factors within the "winter sport" business are predictable, it is not surprising that attempts are made to keep this central point of insecurity as small as possible by using most modern technological aids. In other words: The factor "nature" must be made instrumental to the strongest possible degree so that it becomes a calculable factor in the sense of modern business economics.

1.2 Protection of Nature—buffer or steering gear of the development of winter sports

The instrumentalization of nature caused by the economization of all areas connected with winter sports met with resistance already at an early stage. Still, during the course of time, the type of criticism and its representatives changed substantially:

- the first critical remarks were made amongst the active tourists. Being travellers during the first developmental phase they witnessed the trend of sport expansion. Always looking for special conditions of winter sport, particularly unique for the individual person, they warned in good time against converting ski resorts into centres of relaxation and adventure. Nevertheless, as these warnings were due to personal experience and pronounced by an idealistic group of tourists, most skiing resorts, ready for expansion during the second and third phase of development, did not see any reason or show any interest in responding to their voices.

- The confrontation between economy and ecology in the field of winter sports did not develop into a serious one, also evident to outsiders, until environmental protection organisations, acting on both a supra-regional as well as an international level, such as Greenpeace, BUND or the World Association for Animal Protection, took up the subject and put the slogan "Save Nature" on their banner:

- "In summer, those measures which were planned for the wintry skiing pleasure,turned out to be serious violations to nature: artificial open wood strips, avalanche obstructions, lift poles, flat down-hill roads and hotel buildings turned the living space which once was in agreement with nature into a landscape for skiing, artificially created by man. Meadows, once colourful and flourishing, now appear grey and shaven. In summer, you will look in vain for flourishing meadows, sparkling springs and brightly green alpine pastures, at those places where in winter everything revolves around skiing tourism.... Everybody (who renounces skiing) can

> contribute to the conservation of beauty and excellence of the alpine mountains and help to avoid making a nightmare of technical mountain peaks, bare of any vegetation, filled with masses of people dulled by emotionless experience become a reality" (WWF-Journal, "Ski tracks". In: PRÖPSTEL, U. 1990, 9.)

Those slogans which on one hand led to a campaign in which the bogeyman "skiing" is painted in shrill colours are substantiated on the other hand by acribic geological and biological investigations. Detailed testings on climate and water retention in the region seem to confirm what protectors of nature assumed long ago: The mutation of the mere joy of leisure in the 50s and beginning of the 60s to the mass winter sport of the 80s and 90s leaves marks which seriously damaged the ecological balance of the sensitive alpine region.

Landslides, floodings, ground erosions and dying forests, decrease of animal species, their expulsion from their original habitats or their extinction, monoculture of woods and thinning out of flora and fauna have now been brought down to their precise origin: winter sports.

By demonstrating in an exemplatory manner samples of typical areas of ski runs, it seems to become undisputably evident what happens if steel edges destroy the earth crum, ski-run caterpillars dissolve the humus soil or avalanches can only be controlled by enormous, shapeless steel constructions.[1]

> "Those who tend to suspend or hush up the matter can no longer justify themselves by lack of information. After the catastrophies of landslides, winter sportsmen and non-skiiers are beginning to realize what is happening. The Alps are in a state of agony. (Nature 1–1988, 50)."

For many winter-sport resorts, these populist reproaches of the mid 80s were problematic in two ways:

- for one reason, the strong critisicm often coincided with the extension plans during phases 3 and 4,
- for another, the positive examples of nature and environmental organizations received strong, general significance after the catastrophy of Tschernobyl and the subsequently loud public sceptiscim towards modern technology and its instrumentalized understanding of nature.

Commercialized winter sport enterprises reacted differently in the various Alpine regions. Either one tried to hush up the massive environmental attacks of conservationists (particularly in France or Italy) or they were covered up with dream pictures of the sheer happiness of true winter sport. By means of linking the skiing regions, of inventing futuristic names, of beating the drum for unlimited skiing fun or huge advertising campaigns in regions far away from the Alps, oppositon was formed against those “killjoys” or “do-gooders”.

> “Super-Dolomiti” is the name of the skiing region which links up the fourhundred and fifty-seven (457) lift installations and 1500 km of ski runs of three provinces…(ROOS, P., 1988, 38)

2 The phase of cooperation and accumulation of interest

Quite amazingly, it was still during the phase of confrontation, mutual insults and ignorance between winter sport managers and nature conservationists that the following phase, which could be called the phase of cooperation, was initiated particularly by the varying institutions involved and respective associations specialized in this area.

In 1984, the German Skiers’ Association (DSV—Deutscher Skiverband) started an initial information campaign on environmental problems involved in ski sport and the correct behaviour in open nature. To avoid critical remarks about just having quoted justifications and not also precise instructions for action, ten rules for skiers’ good behaviour in nature were recommended.

Even before the DSV published its recommendations, a sensitive, so-called “soft” form of tourism had been proclaimed by the German General Association of University Sports (ADH—Allgemeine Deutsche Hochschulsportverband) which also tried to lay down some basic rules for its winter sport excursions (e.g. skiing only during conditions of a minimum snow level of 30 cms). And since the middle of the 80s, the German Sport Association (DSB—Deutsche Sportbund) has tried to give the impression that it is well aware of its responsibility for sport activities in nature[2] by environmental declarations, special commissions and its campaign ,,sport and environment“ (sponsored by Adidas).

Today, more than ten years after the associations first started their internal activities, hardly one month goes by during which no offer of further training or cooperative seminars on the subject “sport and environment” appears.

All these seminars are characterised by the joint attempt of achieving a "different way of thinking of all those involved"—at least on institutional level—and of promoting a development of sports which "is oriented along the given natural conditions of the region and according to its ecological limitations". (See also: Bodenheimer's Declaration of 10. October 1995, in: DSB-Presse 41/19, 10.October 1995).

Apart from these national activities, there are also examples which show that international sport associations, such as the IOC or FIS no longer regard environmental protection as a conflict of interest, but as a matter of cooperation for the future of sport. The most recent event typical for this shift in thinking, at least on an institutional level, is the Manifesto of Mainau on how to secure nature and environment which was unanimously agreed upon during the 39th Congress of the International Skiers' Association (FIS) in 1995. This manifest provides the precise implementation on a national level of those principles for saving the environment which were laid down during the UNO Conference in Rio de Janeiro. Besides the striking activities of sport associations, it also becomes evident that public authorities feel more and more inclined to embody environmental protection in regional and national legal prescriptions and laws and to secure cross-border measures by international agreements.

It would not be too difficult to fill this list with many more examples which then, no doubt, would become a unique best-seller on the relation of sport and environment over the past years. And if this list were furthermore complemented by those legal provisions which introduced the building freeze of new lift installations or new ski runs in most ski resorts, one might easily get the impression that the topic sport and nature had lost its explosive effect and controversy whilst entering into the phase of cooperation amongst the institutions involved: economy, ecology and sport seem to have found a mutual basis for responsible action!

Still, everybody who is acquainted with the reality of today's business of winter sports knows well enough that this is not at all true. Quite the contrary: more and more facts indicate that, beyond the borders of official agreements, winter sport continues to pursue its concept of productivity and expansion in analogue form to the slogan proclaimed by car industry managers: "With 12 cylinders—but with catalytic converter".

This implies that the general freezing of figures for lifts, overnight stays, etc. does not prevent an increase in ski-run loads. Although many ski resorts did not permit the construction of new ski location routes, the overall transition figures at the slope were often doubled by converting the drag lift which was built over 20 years ago into a four-chair lift by means of a "simple reconstruction measure".

Every enthusiastic skier knows that this practice of fiddling with prescriptions relevant to nature or with cooperation agreements is not only common practice amongst lift owners, but also is quite accepted by skiers. Who would like to climb into the lift which descends to the valley if the downhill run is not completely barred off in the slushy snow conditions over Easter and who would not be tempted to variation running if 30 cm of fresh snow fell overnight?

The precise problem which arises when considering the relation between individual skiing and nature (and my subsequent argumentation will be limited to this particular question) is the following: *We do know what we should do. But (often) we do not act this way.* Which brings us to the conclusion: the problem of sport and environment is not only a problem of knowledge, but one that refers to the person's attitude towards his\her own knowledge.

Decisions relevant to action are not only taken "according to one's best knowledge", but also as a popular saying tells us—"according to the best of one's conscience". Situations of action, therefore, do not only have a component of knowledge, but always include a component of sense and significance. Furthermore, they are judged upon according to the criteria to which extent they might be regarded as good or bad for the person his or herself or for others, i.e. they also include a moral relevance. With reference to the present environmental discourse in sport science, the following question appears: should this discourse be limited to knowledge, or should it not also take into consideration sense-meaning theoretical aspects and ethical aspects derived therefrom.

3 Phase of Reflection

During the following, third step of my lecture I would like to demonstrate that the lack of responsibility, with which the discussion on sport and environment is led,

- is less an expression of a simple information deficiency, as ecologists suppose when they start their information campaigns;
- is not simply a characteristic feature of conditions of function which are too complex, as insinuated by system theorists[3];
- is rather an indication of the little amount or even lack of attention which has been paid so far to the special sense-theoretical and moral component of skiing in the environmental discussion, or of the inadequate way it has been dealt with.

I would like to demonstrate this by referring to the following three aspects:

1. an inadequate use of the key terms “human—skiing—nature”
2 the mixing up of both terms “morale” and “ethics” as well as “norms” and “values”
3. the lack of a reflective (a so-called “meta-theoretical”) theory of respon sibility in skiing as an aesthetical-semiotic phenomenon.

3.1 The wrong semantic use of key terms

During my description of the relation between sports and environment, I referred to the second phase in a colloquial way as “phase of cooperation” and characterized it as progressive in comparison to the first phase. If one analyzes the structure of argumentation of the agreements, directives or expectations under a meta-theoretical perspective, the following pattern of thought emerges nearly unanimously:

Classial Interpretation model (on the basis of physio-centrism)

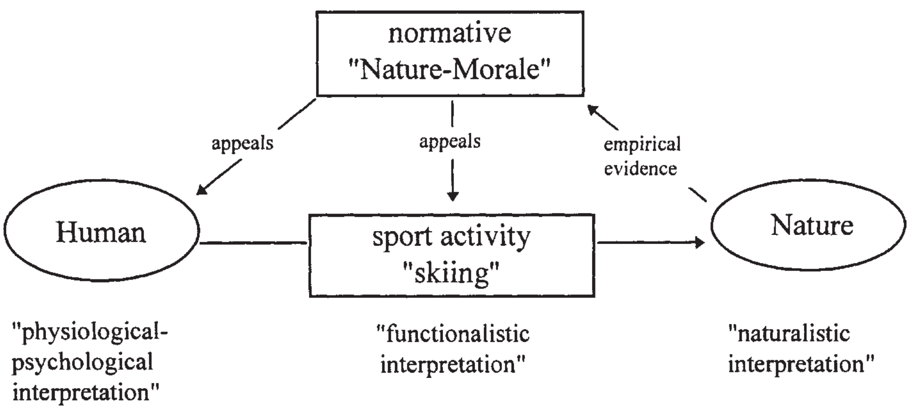

Fig. 1. Classical interpretation model (on the basis of physio-centrism).

This pattern starts off from the assumption that the skier as a sensible human being enters in a process of interaction with nature by the calculable motor action (skiing) during which nature can be described as an object phenomenon whose particularities with relevance to skiing may be described under *biological* and *geological* aspects. Analogous to other activities such as going to work by car in the mornings or the digging of a vegetable bed, skiing is also submitted to certain preconditions (physical, psychological processes, material, factual settings) and initiates various *consequences* in its environment.

Special problems arise due to the fact that these consequences might be of a different kind than what the initiator expected or might have supposed. This applies in the same way to the car ride as it does to skiing. By taking recourse to biological and geological knowledge, environmentalists then try to interpretate changes in the mountain region as consequences of modern winter sports and thus as deeper consequences of the action “skiing”. Moral appeals made to skiers that they should feel responsible for the consequences of their actions are thus reinforced in two ways:

- On one hand by pointing to the changes in nature unambiguously verifiable by empirical data;
- on the other by raising the claim that not only humans with their limited knowledge and partly selfish demands should be the measure of all things, but nature itself.

“We shall not act according to our own standards, but to those rules which nature itself indicates” (Groh, R., 1986, 88).

As I already hinted earlier on, I would like to assert that this structure of argumentation is inadequate to the subject and inappropriate for promoting a development of environmental ethics (in the sense of a reflective responsibility). In the following, I shall explain the reasons for my assertion by analyzing more exactly how the terms “nature”, “skiing” and “environmental morale” are used.

3.1.1 The term “nature”

Just as in many other sport-scientific discussions, the term nature is introduced into the sport-environmental discourse as a so-called “unmistakably teachable term” such as “table”, “window” or “car”, thus, a term, to which I can point to and which I can determine seemingly unambigously by applying empirical methods of natural science.

The destruction of nature which becomes evident in this way generally leads to the following radical ecological claim: not humanity, but nature, which presents itself clearly by showing off its wounds caused by civilisation, should pass on directives of action to humans as they themselves are no longer able to do so. Nature, in this context, appears as an opposite which presents itself to humans in its vulnerability and claims for rules of action. What is mostly overlooked by this opinion which, in philosophy, is classified as "physio-centrism" is the fact that the definition of nature can not be restricted to such a "naturalistic" form and that all definitions dealing with the meaning of nature rather imply a similar form as used with terms such as "democracy", "love" or "motherland", i.e. so-called "non-unmistakably teachable terms". Such a term does not necessarily imply a meaning which can be identified in an unbiased manner as such, but receives its particular meaning by being regarded under different perspectives derived from *theories* relevant to this respective meaning.

During recent discussions, particularly in the field of philosophy and sociology and to which BACHLEITNER (1994), amongst others, rightly drew particular attention, it became evident that the meaning of nature cannot be derived from nature itself, by putting together empirical, biological and geological facts, similar to mosaique pieces. This, however, is just what is mainly assumed in sport-environmental discussions. We should rather consider that our concepts of nature are always ideas of our own. "The standards for the way in which we deal with nature are our own standards". GROH/GROH 1996, 85). This implies that, although the fact of nature's material existence cannot be denied, be it animated or not, nature always becomes a *construct*[4] at that moment in which it receives a meaning by man, in other words: when man is developing a perspective of meaning towards nature.

For the problem of environmental responsibility in skiing which will be determined more precisely later on, this means: "Neither does nature talk, nor does it formulate values" (GROH/GROH 1996, 152). On the contrary: consideration of humans will also always include consideration of nature.

3.1.2 The term "skiing"

The term of "skiing" will now be regarded in a similiar, i.e. differentiating way. Due to the fact that sport activities take place in reality, they are submitted to conditions and imply consequences which can be recognized, it has become common practice in sport science to assume that we are here mainly dealing with a certain movement phenomenon which can be empirically identified. This statement is in no way less wrong than pointing out the geological structure of the ski slope or referring to the particular energy need of a freightened reindeer at different snow levels, carefully calculated by biologists.

A completely different perspective will open up, however, if one asks for the meaning a ski run implies for a skier. This meaning is not the result of the actor's additional, i.e. psychological motivation during the course of action, as assumed by action-research in sport with its orientation towards psychology, but skiing is—as the following text abstract from a daily newspaper shows—"an aesthetical concept of the world, structured according to various aspects, a construct which—as a phenomenon of action—cannot sufficiently be described by empirical, motor-theoretical or psychological analyses. It rather represents a subject area which can be investigated under semiotics, a sense-meaning theory of sports. This is also pointed out in the following simple report of a daily newspaper:

'We were dancing in a skiing trance beyond the limits. The landscape melts together into a total ideal-typical mountain. All that our "boards" feel is the level of harshness of the snow and the handle of the edges. A typical conversation during the break: "What a run!—Super—Like a dream—Just crazy"—Our bodies are steaming during these acts of total-body balance. Later on we feel tremendously successful—when we realize that even this skirmish of snow can be mastered…."

(AUTH, E.: "Beyond the limits in a skiing trance", Frankfurter Rundschau; 30.12.1995, 11)[5]

In the attempt to define meaning, the significance of skiing as an aesthetical phenomenon and not by its psychological-physiological function, it becomes evident that aspects which were rather neglected in the sport-environmental discourse receive a greater relevance. Skiing is thus turned into an experience of spacial-time moments, of dynamics and speed, of a perception of ones' own physical existence, a knowledge of authenticity, a field of tension of contrary feelings like fear and joy, cold and warm, fast and slow which are seldom to be found such a dense form in every-day life. Those who have become masters in coping with different forms of snow, various inclinations of slopes and conditions of sight in skiing, try to express their feelings and sensations by speaking metaphorically of "flying", "floating", "gliding", "swinging", etc. Often these stammering attempts are made in order to describe a special experience of the world, commonly and in a very sober way called "skiing", but which includes the opportunity to experience basic concepts of value such as individual freedom, social independence, personal self-determination, etc., values which—surely not incidentally—have received a strong value and high demand in our modern industrial society.

One might summarize this short out lay of facts as follows: the sport-specific action "skiing" always must be evaluated in two ways; on one hand, regarding the aspect of *form* of movement by taking recourse to motor sciences such as medicine, etc. (as has been done in various forms during the past few days of this congress), and on the other under the aspect of the *sense* of movement, the significance of action which is always expressed in the meaning which an invidual or a group of skiers attributes to this movement event. While it is possible to study the form of movement in an inter-personal manner under the empirical perspective of natural science, the question of which sense and meaning is included in the action belongs to the field of semiotics and, therefore, implies aesthetical research. And it would be relevant for this type of aesthetic to look into the kind of nature which the passionate skiier is trying to reconstruct. Generally, we are dealing with that kind of "nature" which has been crystallizing since the end of the 18th century as a romantic world opposite to the every-day world and which was discovered as a "space of nature" by the cultivated citizen through novels such as Goethe's "Journey to Italy" or Heine's "Journey to the Harz mountains" and which—in our times—is projected as a special world of its own within the normal world, and to which often references are made in a rather unreflected manner and within the context of the significance of actions in nature and whenever sense-meaning relations are being developed.[6]

3.1.3 The term of "environmental ethics"

If, finally, looking closer at the perspective of ethics which always resonates in an indirect manner whenever questions of environment in sports are discussed, again it becomes evident that we are dealing with an incorrect method of argumentation: the moralizing of nature as a holistic basis of human existence of higher value which is brought forward as an argument against the mechanical, dissecting concept of the world of modern times, can be derived from nature itself but represents under historic aspects the romantic extension of moral as described above and which since the period of the Enlightenment should be valid for humans. Consequently, it does not imply a special "moral of nature" but is in particular the expression of the *cultural* history of nature. The reference to "nature" as a normative authority, therefore, is inappropriate. If, however, such a reference is made under the demonstration of empirical evidence, as done in many environmental appeals in sports, then a so-called "naturalistic fallacy" was made, i.e. moral norms of the good and right dealing with nature are derived by referring to true-false statements obtained by empirics. Thus, the attempt is made to derive an "ought to" from the "being"—a so-called confusion of categories in argumentation which has been known since the antiques and which is regarded as untenable since Hume and Kant. With reference to the lack of responsibility in the environmental discourse of sports already mentioned above, this implies that this does not just incidentally happen, neither can it be regarded as an expression of insufficient knowledge or lack of involvement, but as a characteristic of a general failure of construction in the argumentation construct of the sport-environment architects and this in particular relation to the factual explanation of "nature", "sport action of "skiing" and "morale of action". Finally the question arises how appropriate preconditions for an adequate theory of responsibility can be suggested under the aspect of the catalogue of deficiencies as described above. In the following section, I would like to present my own suggestions, summarizing these in five theses.

4 Five theses on ethics of an aesthetical concept of skiing

1.THESIS: *Responsiblity in winter sports cannot be limited to moral appeals being derived from biological and geological assessments of damage from which they receive their ethical justification.*

This implies: "It is impossible to close the logical gap between (descriptive) statements which describe factual conditions and normative claims which express evaluations." (BIRNBACHER, D. 1980, 107).

As a precise consequence, it may be concluded: The seemingly indisputable proofs of natural science for the harmful consequences of skiing as presented by biologists and geologists may not be doubted as far as their scientific quality is concerned. What should be doubted, however, is the attempt to turn these results into a basis for a moral catalogue of actions. If this catalogue were to be developed according to the principles of environmental protection, other starting points than empirical facts would be required, i.e. concepts of value which would weigh different claims on the basis of a hierarchy of values, e.g. the "reindeer's right to live in its territory" and "the joyful life of a group of skiers". However, as we all know, these considerations are not made at all, or it is generally assumed that "the biological facts" speak for themselves.

2.THESIS: *Responsibility in winter sports can only be developed when conditions of the possibilities of skiing are laid open.*

This implies: Responsibility as a moral maxime can only be developed by reflecting on the aesthetical dimensions of the sense of skiing, i.e. from the basis of an aesthetical concept of ethics.

As a precise consequence, it may be concluded: only under the condition that a morally good action is due to the understanding of special circumstances, will it be more than merely correct behaviour complying with rules. And, as it happens, the special circumstances of skiing are rather of an aesthetical nature than of a functional character and the aesthetics of skiing always imply more than a new "concept of the world". During sports, (e.g. skiing), a new concept of the world under the aspect of time and space is experienced without any distance and in all its different shades, full of contrasts, contrary to the oeuvre of arts, which in itself produces a distant relation. Insight relevant to ethics on this basis implies the reflection on the circumstances required to produce this precise utopia combined with the wish to let this utopia continue to happen in future.

3.THESIS: *Responsibility in winter sports as a reflection of one's own knowledge and action is a challenge for humanity gifted with rationality.*

This implies: Ethics for ecology cannot be developed by referring to a non-rational holistic identity of nature (in the sense of the New Age) but presupposes the same anthropocentric rationality which is seemingly destroyed by nature.

As a precise consequence, it may be concluded: Human rational thinking may be held responsible for the instrumentalization of nature but it would be a complete illusion to answer the destruction of nature by referring to nature's proper right of its own which follows according to its own, holistic logic, i.e. to assume a dichotomy between "real nature" and "cultural humanity". Ethics of nature can only be developed on the basis of human rational thinking which turned, amongst other things, the natural space into a cultural property.

4.THESIS: *Responsibility in winter sports can only lead to precise reasoning if also the own action is recognized as one which has a changing effect on nature.*

This implies: In order to develop an ethics of ecology, the attempt must be made to lay open the *contradiction in logic* between a period of present time seemingly without history and, therefore, supposedly without future, during which the sense of skiing is determined under aesthecial criteria, and ethics of ecology which *bases its argumentation on the consequences of actions*.

As a precise consequence, it may be concluded: Moral discussions on responsibility have “to pick up” skiers from that place where they generally reside in their (euphorical) determination of sense, in their present, futureless time of joyful “now”. Only if it becomes evident that not only reindeers have to abandon their place of rest or that the inhabitants of local villages have to live with floods of tourists in summer, but that also those personal aesthetical dimensions of sense and meanings are affected, i.e. that those dreams which are constantly constructed in one’s own, personal utopia become increasingly unreal by the harmful treatment of nature, only then a state is reached, where we find a modest precondition for reflective thinking, for the precise development of an aesthetical concept of ethics.

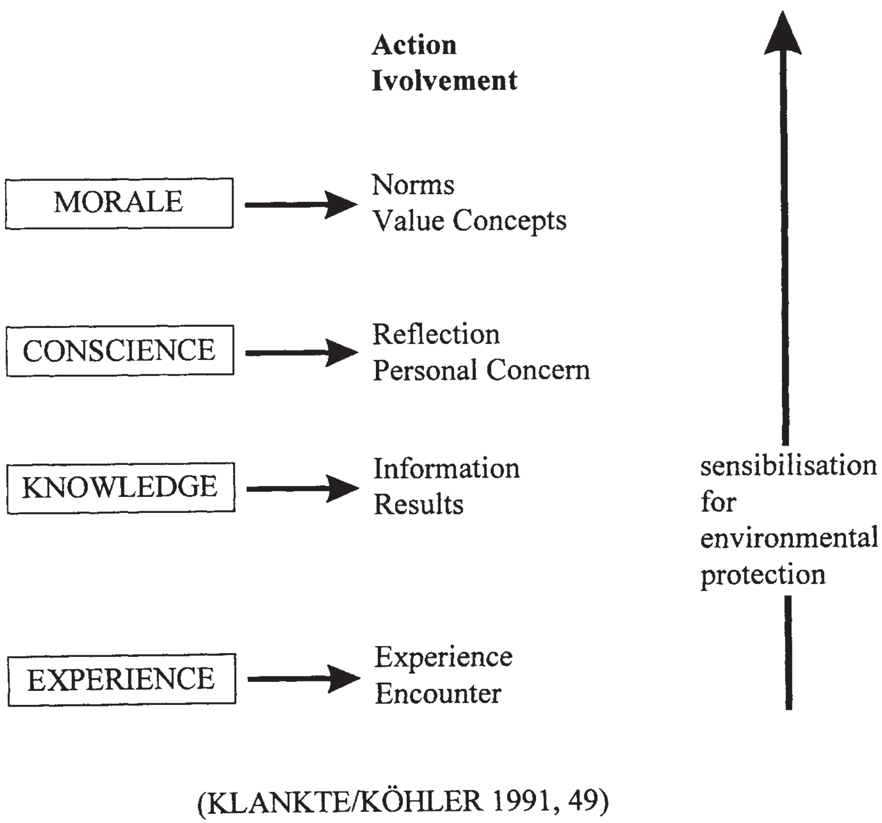

Fig. 2. Sensibilisation for environmental protection.

5.THESIS: *Individual responsibility in winter sports may be guided, limited and, under certain conditions, also be geared by means of collective directives for responsible action.*

This implies: Individual aesthetical reconstructions of nature always remain facets of that general space of nature which the cultural citizen has formed. This particular fact implies that they might be predominated by ecological directives of planning on a medium and long-term basis.

As a precise consequence, it may be concluded: In a case of conflict, laws, directives or action-restrictive measures which have become legitimate by the ecological discourse on ethics and received major agreement during the democratic process of decision-making will be superior to personal reasonings.

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[1] Cp. also, in particular, PRÖBSTEL, U. 1990 and LAUTERWASSER, E. 1985 or EGGERS; R., 1993

[2] See also DIGEL, 1989, 93–95 and others and the Association's Leaflet for Information on Skiing and water sports as well as the central information leaflet of the DSB on Sport and Environment. The figures which are published by the associations are partly significantly altered and are based on their own calculations. This is clearly demonstrated in the extract of text of Umrich:

"In the Alpine Region, there are 12 000 mechanical lifting aids with about 15000 ski runs, 18 000 ski runs at the most with about 18 000 km total length of ski runs, 25 000 kms at the most. Thus, these forgers indicated the number of ski runs three times higher and the number of total length of ski runs even six times higher (!)… Interpretating these figures for certain regions in a careful manner, it becomes evident that the average percentage of the ski-run area in the Alps in relation to the corresponding total area lies under 1%… Contrary to this, LERNUSCA states: "In some larger winter sport regions, the area of ski runs has already reached a percentage of 5%—10% of the total area. (ULMRICH, E. 2/1991, 61)

[3] For the field of sports, see: CACHAY, 1987, and others

[4] In the same context, see ZIMMERMANN, J. 1982, EDER, K. 1988, SCHÄFER; L. 1993 and others

[5] See also: FRANKE, E. (1978) amongst others

[6] See also the well-structured survey of GROßKLAUS, G. (1983), BACHLEITNER (1994) as well as ZIMMERMANN, J. (1982).

46
SKIING IN AUSTRIA: TRENDS, IMAGE AND IDENTITY

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Keywords: current trends, economic potential, identity-creating function, alpine skiing.

In Austria skiing is tremendously significant. Over the last fifty years numerous regions have been developed for tourism, following comprehensive technical and economic planning and using huge amounts of capital. Ski-lift and cable car companies developed ski-slope after ski-slope, connecting skiing area to skiing area, valley to valley. A supply industry was added, and mass tourism resulted. The more an area was developed for mass use, as in the example of skiing, the more money for equipment and development was invested, giving rise to areas of extensively used ground.

Ecologists have been complaining for a long time about the ecological strain placed upon the Alps by mass tourism, and particularly by skiing. The technological infrastructure now needs to be minimized and dramatic limitations set for the land used for skiing.

However, as far as I can see, this is not going to happen. Because of the strong identity-creating function skiing has in Austria, the problems raised by mass tourism are ignored. I am going to attempt to show the mechanism of this process of repression, and the underlying, complex syndrome which is bound up with skiing in Austria.

In Austria skiing has meant that farming regions which were at one time extremely poor have, as tourist regions, been able to reach a reasonable standard of living. What was previously considered unproductive land, has become overnight, when used by tourists, highly profitable. High mountain regions, rocks, snow and glacial ice, lakes and rivers, woodland and Alpine meadows attract the tourists, so that tourism has brought life to many mountain regions where agriculture alone was not enough for survival. The emergence of sport-oriented activity areas, the sport milieus, created new economic and social foundations. There is no doubt that countries such as Austria would suffer economically without tourism; half of Austria's tourism is based on skiing. Figure 1 shows that the deficit of the balance of trade is reduced by revenue from tourism. It shows how the trade surplus is covered, and that the trade deficit is reduced by the income from tourism.

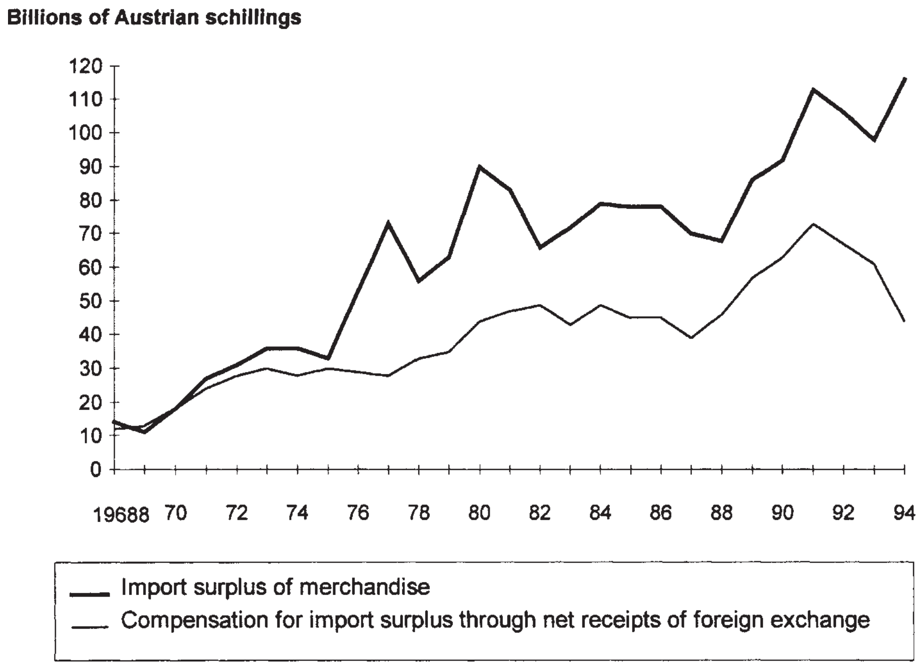

Fig. 1. Reduction of the balance-of-trade deficit by tourism from 1968–1994 [1].

Tourism, with all its branches, ranging from sport equipment manufacturers and ski producers to textile and shoe manufacturers, has developed to form a huge industry. In Austria, skiers come from almost all social groups and skiing has the characteristics of a national sport. The criterion for practice is mainly connected with a certain level of income and regional conditions. The continuous increase in income and amounts of vacations enable more and more people to engage in skiing, yet lower income groups are still significantly under-represented.

Opinion polls have gathered the following data: 13% of the population declare that they practise skiing on a regular basis while 30% ski at times. The absolute number of skiers in Austria is about 2.7 million people [2].

Table 1 shows that swimming is more popular, but that could well be a methodological problem: those questioned may well have meant sun-bathing.

Table 1. Ranking of sports activities in Austria [3].

Sports activities	
Swimming	37%
Skiing	34%
Cycling	34%
Mountain hiking	33%
Gymnastics	18%
Cross-country skiing	17%
Tennis	15%
Skating	13%
Soccer	10%
Athletics	7%
Sailing	4%
Horse-riding	3%
Motor racing	2%
Boxing	1%
Golf	1%
Ice-hockey	1%

The demographic structure shows the following characteristics: about two thirds of all active skiers are men, one third are women. A larger group of young people can be noticed as to the distribution in age, but still relatively high quotas of skiers who ski regularly and occasionally can be recognized in higher age groups.

Running parallel to the development of mass tourism is the development of Austria's ski clubs (Figure 2). From 1965 to 1980 the number of members rose sharply from 25,000 in 1965 to a peak of 161,017 in 1980. From 1980 to 1985 there was a decrease of 1.6 percent per year. Since 1985 it has stagnated. One of the main reasons for this drop or stagnation may well be in the lower birth rate. Since a large proportion of the downhill skiers are young, the statistics for club membership in the 80s emphasize the years with lower birth rates.

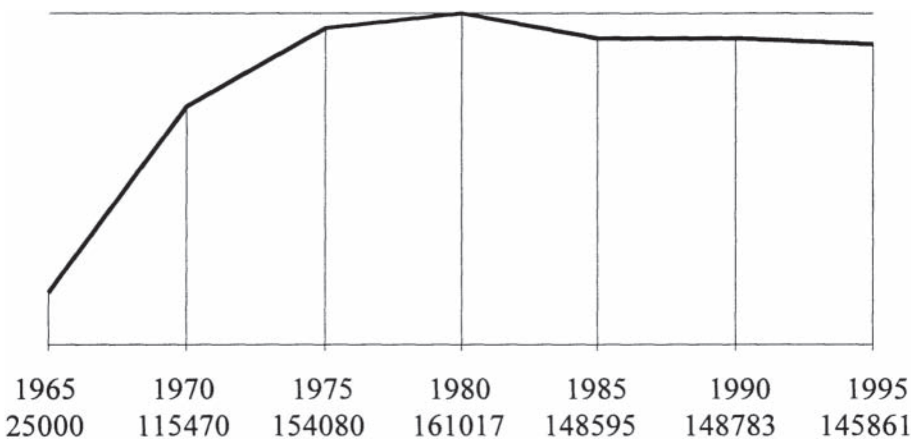

Fig. 2. Numbers of ski-club members in Austria [4].

Regional distribution: as can be seen in Figure 3, the ski centres (club membership) lie in the Alpine regions in Austria. Tyrol is far in the lead, with 38,188 members, Upper Austria has 26,923 and Styria 17,497. The eastern provinces have only a few members.

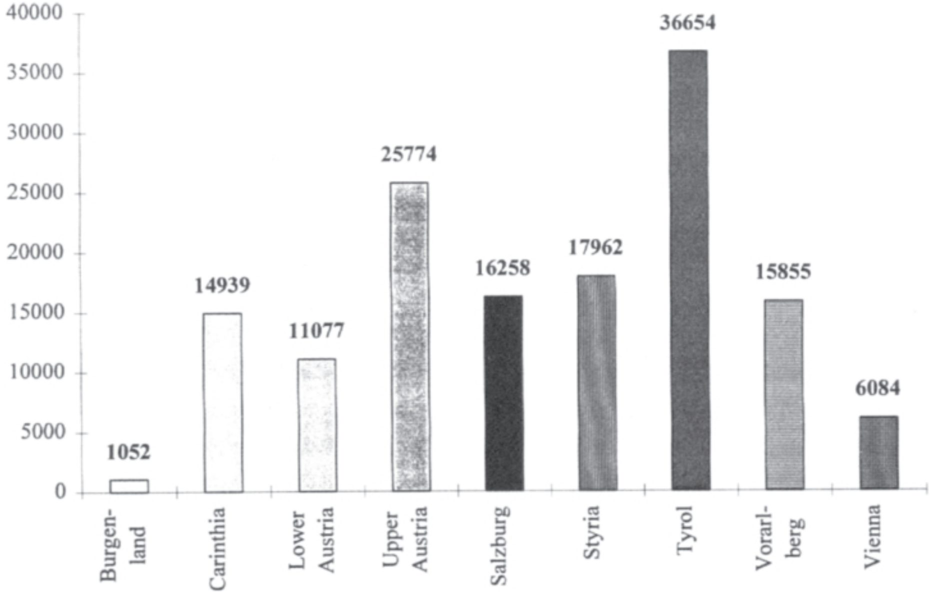

Fig. 3. Numbers of ski club members in the Austrian provinces (1995) [5].

This high degree of organization encourages top level skiing in Austria, and the success of Austria's competitive skiers are advertisements for Austrian tourism and the winter sports industry. In Austria, the ski champions are personifications of all the characteristics considered of any value in this country. These athletes usually come from simple backgrounds, train rigorously, never give up, accomplish great things, and are unassuming—but are, above all, successful. The media's portrayal of their career presents a multitude of social maxims: the legend of the success will make clear that social advancement is open to anyone if he or she wants it and is willing to try hard enough. The result is direct confirmation of social worth and significance, with which the Austrians can identify. Which is why television audiences want Austrians with whom they identify, to be successful in skiing competitions. Figure 4 shows that on television, skiing is the favourite sport for viewing.

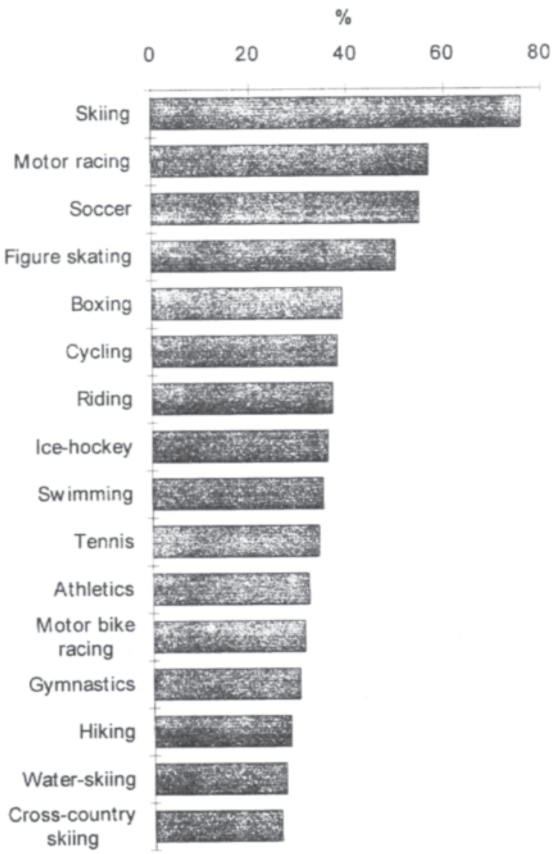

Fig. 4. Austrian television audience, sports preferences [6].

In Austria success in ski competition is seen as a type of presentation of the national-self, and is an extremely important symbol of Austria's identity. As a popular and national sport, skiing has taken on the function of a patriotic vehicle.

This is also shown by the results of a representative image analysis [7] of skiing in Austria that we carried out in 1988. In this survey, nineteen cards, with a quality written on each one, were given to those questioned who then chose the qualities they considered relevant to skiing. Alongside qualities such as being aesthetic, dynamic and pleasant, skiing was also seen as typically Austrian. This type of sport unites the various elements which make up the special character of Austrian skiing regions: the winter mountain world, the Alpine atmosphere of the ski villages, comfortable rustic houses, hospitality, food and drink, and conversation. Many visitors come to Austria to experience such things, and they in turn confirm that the country is indeed beautiful.

Evidence of this can be provided by referring to television again. Every day Austrian television provides information and pictures from Alpine regions in a program called Weather Panorama. From every skiing region in the nine provinces pictures of the mountains are transmitted into Austrian living rooms. The same can be said for the advertising 'spots'.

Photo 1. An example of the beauty of Austria's skiing regions: St. Christoph am Arlberg (where the 1st International Congress on Skiing and Science took place) [8].

To analyze the context of these pictures we can refer to Leon Festinger's theory of "Cognitive Dissonance". He maintains that people tend to reject information which would be dissonant with other already existing information, and they tend to seek information which would reduce an already existing dissonance, to achieve consonance.

Relating this to the effects of mass communication we can employ the reinforcement hypothesis. Communication research strongly indicates that persuasive mass communication is, in general, more likely to reinforce the existing opinions of its audience than it is to change such opinions.

Applied to our example, this would mean that these daily television pictures strengthen the already existing positive attitude to skiing and ideas about the beauty of Austria. Dissonances, for example ecological misgivings, are toned down.

In other words, modern communication technology ensures the omnipresence of the skiing regions in the minds of the Austrian population and shapes a collective ski ego. What is decisive is the high level of identification through which an identity-creating potential for skiing regions functions. And this in turn, is why in Austria skiing is tremendously important. It is more than just a sport, it is a part of the identity of the modern “Homo Austriacus”.

The enormous interest in skiing and its character as a national sport can be seen in Table 2.

Table 2. Interest in different types of sport [9].

Interest in the corresponding type of sport	strong interest in %	little interest in %	no interest in %
Skiing	52	31	17
Motor racing	33	34	33
Soccer	28	30	42
Tennis	25	37	38
Figure skating	19	34	47
Competitive dancing	14	23	63
Ice-hockey	14	26	60
Track and field	13	34	53
Gymnastics	12	31	57
Water sports (e.g. swimming/water-skiing)	11	33	56
Horse racing	11	23	66
Cycle races	9	31	60
Volleyball, Handball, Basketball	5	22	73
Golf	4	15	81

As for sports represented in the media, skiing is most popular; this is true for both TV and the printed media (Tables 3 and 4).

Table 3. Television habits towards sports [10].

TV broadcasts watched recently	number of people in %
Skiing	70
Tennis	37
Soccer	33
Ice-hockey	24
Motor racing	22
Figure skating	20
Water sports (e.g. swimming/water-skiing)	19
Volleyball, Handball, Basketball	11
Track and field	11
Competitive dancing	10
Horse racing	10
Gymnastics	9
Cycle races	9
Golf	9
None of the above	21

Table 4. Sport reports read in newspapers and magazines [11]

Reports read about	regularly in %	often in %	regularly or often in %
Ski races	29	17	47
Soccer	24	13	37
Formula One	23	13	36
Tennis	8	10	18
Cycle races	8	10	18

In the future, skiing will be dominated by quality. Cable cars with increased capacity and comfort will prevail. Individuality, paired with social exclusivity, will become more important. This corresponds with the results from an Austrian commercial survey, which has detected the following trends in winter tourism [12]:

- search for adventure
- increasing environmental sensitivity
- desire for communication and entertainment
- interest in new types of sports (especially by the young)

As a perfect combination of danger, muscular tension, creative ability and individual expression, skiing and even more, snowboarding, which is becoming increasingly more popular, seem to fulfill these motives. Within a group of people who share the same interests, a blend of freedom and a feeling of camaraderie and solidarity with the group may be present during ski tours or on ski vacations. Not just as a sport but also as a way of life skiing gives people an opportunity to use their physical and mental endowments in the way in which nature intended them to for survival. Skiing might be one of the best answers to urban ambience and the disintegrating aspects of modern life.

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ALPINE SKIING IN SOCIAL CHANGE—A PILOT STUDY

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Keywords: sociology, motivation, interviews, alpine skiing.

1 Are the quantitative changes in alpine skiing leading to a change in signification and motivation?

Has the boom in alpine skiing which took place between 1960 and 1980 in Austria [1] [2] been replaced by a marked decrease in the 90s? The German sociologist and leisure researcher Opaschowsky diagnosed a momentous change in the interests of German youth [3]. A comparison between 1986 and 1994 indicated a significant loss of attraction to alpine skiing.

In 1995, the Austrian skiing industry suffered a sales drop of over 50% compared to the preceding years [4]. Snowboarding has become a new field of economic interest and a challenge for young people.

On the other hand, representative data do not directly show such changes. In fact, microcensus data comparisons between 1985 and 1992 [5] did not suggest any marked changes whatsoever (33.5% to 32.3% alpine skiers). Furthermore, a recently released eight-year comparison of leisure activities among the Viennese population [6,7], pointed out a rather stable proportion of alpine skiers (44% in 1986, 42% in 1994) along with increasing proportions of snowboarders (2% in 1994). In order to understand such social change, we have investigated the variation in significance and the subjective meaning of alpine skiing, while it also seemed necessary to look into alterations in learning conditions and the economic background. A comparison between generations was expected to give a clearer image of the social change. There are reasons to believe that any quantitative change leads to processes of psychological obsolescence as generally, goods lose their value. Social differentiation may also have become more difficult. Individualization leads to product differentiation and behavioral change [8].

2 Methods and hypotheses

At first, twenty semi-structured interviews were conducted with skiers aged 20 to 25 and their respective parent (skiing father or mother). On the basis of this data, hypotheses were elaborated which required cross-checking by means of a fully structured questionnaire and written answers.

Thirty-four parent-child dyads from the student milieu were interviewed (Fig. 1). Among the young generation, the answers concerning signification and motivation referred to “today’s situation”, while their parents responded in retrospect (“back at the age of about 20”). The basic idea of choosing such a sample originated in experimental matched-pair technique. By comparing one parent with children, the influences of social milieux could be held constant, the representativeness of the sample being of no necessity. However, there were several limitations as well. Target persons had to be skiing students (or students having skied in the past) with a skiing parent (one parent who did skiing in the past). In other words, only one out of four possible combinations (skiing versus not skiing) were available. Two other combinations would also have been interesting: Skiing parents with children who refused to ski and skiing children whose parents did not ski. Nothing can be said about these groups, but it would be reasonable to assume that for children with non-skiing parents, skiing could bring about differences in motivation; perhaps this group would be more interested in skiing since they engaged in something their parents could not do or could not afford to do.

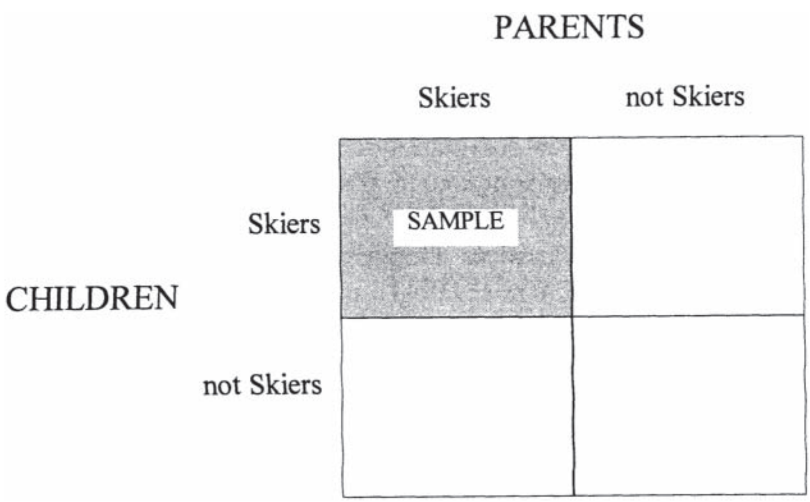

Fig. 1. Characteristic of the sample (n=68).

The experience acquired from our qualitative interviews resulted in the following hypotheses: Differences between the parent and younger generations should be interpreted as indicators of social change. A declining attractiveness of, and involvement in alpine skiing was expected (Hypothesis 1) and, as a result, reduced the importance of skiing as a status-gaining activity (Hypothesis 2). Higher living standards and consumer expectations should lead to a marked increase in the importance of consuming fashionable clothes, and other equipment connected with skiing among the younger generation. (Hypothesis 3).

Decreasing attractiveness and achievement orientation were considered probable, which on the other hand would indicate a distinctive interest in the sociability component in skiing among the younger generation (Hypothesis 4), and also increase the importance given to alcohol consumption and skiing as a means to make new acquaintances (Hypothesis 5). The lower level of interest in skiing should also lead to a significantly lower concern for skiing idols and watching competitions on TV (Hypothesis 6). As a further result of the changes in total, a decreasing interest in consuming high-quality skiing gear (together with the acceptance of higher prices) was expected (Hypothesis 7).

The interviews were conducted by students of the Institute of Sociology survey methods seminar, in the course of December 1995; the study was not supported either by an institution or a fund.

3 Results

3.1 Structure of the sample

The average age of our "younger generation" was 22, i.e. they were born around 1973. Ninety percent had started to ski before the age often. This means that they had already grown up in the well-established skiing world of the 1980s (Table 1).

The "parent generation" had an average age of 51, meaning they were born by the end of World War II (1944); most of them had started to ski between the ages of 10 and 14, i.e. between 1954 and 1958. This period of time was precisely the one marked by the beginning of the entire technical development. Polednik [1] reported an amount of approximately 410 cable railways, chairlifts and skitows in 1954, which is rather insignificant compared to the 3,532 funicular transportation facilities in 1980. The parent generation had started to ski at the initial stage of technological development. (Incidentally, compared to 1980, the absolute number of such facilities today does not show any remarkable increase, although indeed, improved transport capacity and comfort).

Table 1. Sample structure.

	parent generation (n = 34)		younger generation (n=34)	
male	50		50	
female	50		50	
age: mean	51,1	born	22,4	born
standard deviation	5,8	1944	2,8	1973
active skiers	85		94	
have been skiers	15		6	
lower than advanced education	47		15	
advanced education	32		82	
university and similar	21		3	
skiing: weeks per season				
mean	2,26		2,15	
standard deviation	1,4		1,2	
Vienna	77		74	
other provinces	23		26	
income (household/net/monthly):				
- 25 000 ATS	21			
- 35 000 ATS	36			
above	43			

The data concerning income and education indicated that the majority of our sample represented upper-middle and upper class, i.e. typical, “users” of alpine skiing. Both parents and children went skiing a little longer than two weeks per year on average, which is reasonable, considering 75% of our sample lived in Vienna.

The distribution of education reflected the social change in the educational system which has taken place during the past twenty years. Only 50% of the parents of our student generation had reached advanced or university-level education; however, they represented the post-war generation which had been the basis for the development of alpine skiing as a mass sport in Austria.

3.2 Differences between the parent and younger generations with regard to learning to ski, and differences in reported ability

Both parents and children were asked how important the variables of school, parents and friends had been for them while learning how to ski (Table 2).

The school influence, it seemed, had been important for both generations.

Table 2. Difference between the parents' and younger generation: Learning, ability, economic aspects (* tests for significance: Lamda, Goodman & Kruskal Tau, p<.05). Percentages.

		parents' generation (n = 34)	younger generation (n = 34)	
skiing was taught	mainly	15	0	
at school	partly	36	62	
	not at all			
skiing was taught	mainly	16	68	
by parents	partly	16	32	
	not at all	69	0	*
skiing was learned	mainly	39	3	
with friends	partly	46	56	
	not at all	15	42	*
self evaluation of	very good (1)	18	32	
skiing performance	good (2)	35	44	
(5-point scale)	lower (3-4)	47	24	*
preferred runs	blue-red	59	27	
	black	27	44	
	unprepared	15	29	*
starting to learn	before 10	32	97	
skiing	10 - 14	41	3	
	15+	27	0	*
age: reaching top	10 - 14	3	9	
performance	15 - 19	27	62	
	20 - 24	12	24	
	25 - 29	21	6	
	30 - 34	12	0	
	35 +	26	0	*
to afford skiing, I must				
reduce other expenses	agree			
(5 point-scale)	(point 1+2)	35	12	*

Although school tended to be more influential for the younger generation, it did not take a really prominent position. Our younger generation had been taught mainly by their parents, which had not been the case for the parent generation. Nearly 70% of the older generation reported that they had not been taught to ski by their parents. Peers and friends seemed to have been more important to them than to their children.

For the younger generation, learning and achieving one's level of performance had not been so integrated in social contacts with friends and peers. Rather, learning to ski was a family activity. This may be one reason why skiing has been losing its significance and status within a group. A marked change in the age at which skiing abilities had been acquired could also be observed. Only 32% of our parent generation had started to learn to ski before age 10. This is a low figure in regard to the younger generation: 97% had started before that age.

Learning to ski at an early age proved to have a lot of consequences. The younger generation evaluated their skiing performance much higher than their parents did. Only 24% of the younger generation estimated their skiing abilities as less than "good", while 47% of the parent generation thought their performance to be less than "good".

The degrees of difficulty in preferred runs also strongly reflected the differences in performance between the generations. In a much higher proportion, the younger generation gave preference to "black" and "unprepared" runs.

The parent generation reported that they had reached their optimal skiing abilities at a later age than the younger generation had. The median for the former fell in the age group of 20 to 24, and that for the younger generation in the age group of 15 to 19. We should also bear in mind that 26% of our parent generation reported that they had reached their optimal level of performance after age 35.

As expected, the economic restraints for the post-war generation also proved to be much more severe. Thirty-five percent of our parent generation reported that they had to reduce other expenses to be able to afford skiing. Only 12% of our younger generation had made this experience.

In the following discussion, the ways in which these marked differences in the socialization process of skiing have influenced subjective meaning shall be dealt with.

3.3 Differences in subjective meaning and motivation

As already mentioned, the respondents received a list of twenty items of signification, motive, or meaning. Among the children, the answers referred to "today's situation", while the parents responded retrospectively.

Factor analysis grouped the variables into seven factors. The differences between the parent and younger generations along the lines of the dimensions drawn from factor analysis shall be discussed.

The main factor can be described as "enthusiasm about skiing". Skiing was seen as something exceptional. For the skier, it was the most important sport when compared to other types of sport played, and when he/she could not ski for a long period of time, a deep yearning was felt. It could be clearly seen (Fig. 2) that the younger generation showed less enthusiasm and involvement in alpine skiing than their parents (Hypothesis 1).

Skiing as a means to gain status within a group is of lower importance for the younger generation (Hypothesis 2).

Striving for perfection seemed to be more important for the parents. Expectedly, consuming fashionable clothes or other equipment for interesting ski areas appeared to be more important to the younger generation (Hypothesis 3). For the sociability hypothesis (Hypothesis 4), we could not obtain a clear result. But one behavioral trait did seem to characterize the parent generation: skiing alone, unlike their children who were less interested in that.

Motivation from ski idols and an interest in TV competitions characterized the parents (Hypothesis 6), whereas entertainment involving alcohol (après-ski), and the opportunity to make new acquaintances were of greater interest to the younger generation (Hypothesis 5).

It was found that skiing equipment was considered more important by the parent generation (Hypothesis 7) and, although it was assumed that there would be a correlation between enthusiasm and involvement, this was not generally the case.

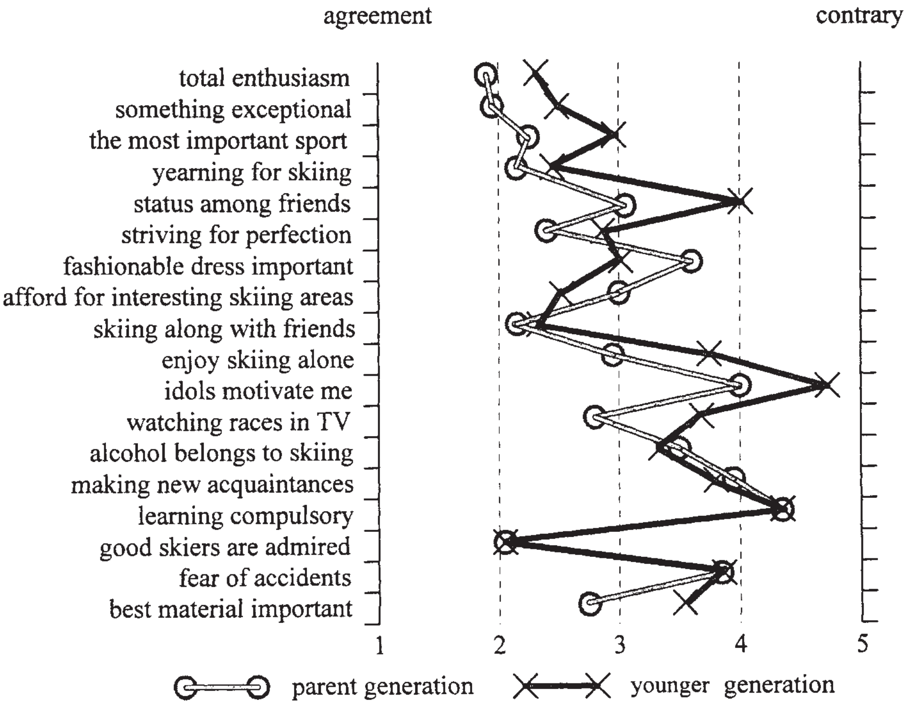

Fig. 2. Subjective meaning of alpine skiing by parent and younger generation (n=68).

Table 3 shows the result of a discriminant analysis between the parent and younger generations: motivating idols, status among friends, watching competitions on TV, the importance of good ski gear, and the perception that alpine skiing is a modern sport are the variables which best discriminate between the two groups. With the variables used in our analysis, we could arrive at a correct classification for 94% of all of our cases (Table 4).

Questions were also asked about attitudes towards the ecological situation today. The respondents had to decide between modern techniques for comfortable skiing (including cable cars, artificial snow) versus ecological arguments. No significant differences between the parent and younger generations could be established. Most of the respondents gave a plea for cable cars and prepared slopes. The fact that alpine skiing as a mass phenomenon in our country has lost some of its attractiveness could also be seen in respect to alternatives to skiing activities (Table 5).

Twenty-one percent of the parent generation and 21% of the younger generation practiced cross-country skiing (12% of the younger generation exclusively), 24% of the parents and 27% of the children used Big Foot or "Firngleiter" (firn gliders), and 38% of the younger generation enjoyed snowboarding (compared to only 6% of the parent generation). Nearly one third of the younger generation responded that they did more snowboarding than skiing. It appeared to be a greater challenge for the younger generation, perhaps the same challenge as skiing had been for the parent generation.

Table 3. Subjective meaning of alpine skiing.
Discriminant analysis between parent generation and younger generation (n=64).

	a	b	c	P%	C%
idols motivate me	.31	.18	**	12	3
status among friends	.31	.69	**	31	6
watching races on TV	.28	.44	**	47	24
best material important	.27	.67	**	35	18
modern sport	.25	.46	**	76	41
most important sport	.24	.21	*	68	35
enjoy skiing alone	.24	.54	*	41	21
something exceptional	.20	-.22	*	71	56

a: pooled within - groups correlations between discriminating variables and canonical discriminant function (variables ordered by size of correlation within function)
b: standardized canonical discriminant function coefficients
c: significance (Lamda U-statistic univariate, F-ratio, df=1/df=62), * = p<.05, ** = p<.01
P%, C%: percentages agreement (1+2) parent and younger generation.

Table 4. Classification results from discriminant analysis (percent of "grouped" cases correctly classified: 93,7%.

	actual group	No. of cases	predicted group membership 1	2
1	younger generation	32	30 (93,8%)	2 (6,3%)
2	parent generation	32	2 (6,3%)	30 (93,8%)

Table 5. Alternative activities
"What else do you do besides alpine skiing?"
(* significance p<.05)

	parent generation (n = 34)	younger generation (n=34)	
touring	21	21	n.s.
cross country	39	12	*
Big Foot, Firngleiter	24	27	n.s.
Telemarking	0	0	
Free-Style	6	6	
Snowboard	6	38	*

Who, then, snowboards, and who is changing over from skiing to snowboarding? A regression model (Fig. 3) shows rather clearly what is going on. Former skiers who had been taught to ski by their parents were snowboarding instead, and they also evaluated their skiing performance rather high. Those who had reached their optimal skiing abilities rather early also snowboarded. Two variables explain one third of the variance in the model.

Variables	Beta
skiing was taught by parents	.34
reaching top performance in skiing at an early age	.41
self evaluation of skiing performance high	n.s.
	$R^2 = .33$

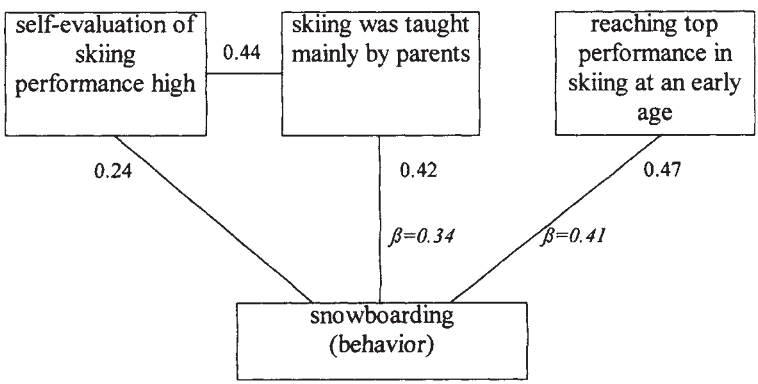

Fig. 3. Multiple regression model (sign. p<0.01).

Table 6. Perceived changes in skiing (parent generation only, n=34).

	Percentages
skiing became more interesting	32
neither/nor	35
skiing became less interesting	32
today fun has more importance	38
neither/nor	38
today fun is less important	24
today skiing is as much attractive as 20 years ago	44
neither/nor	21
today skiing is less attractive than 20 years ago	35
If I were 20 again and I would have to decide between skiing and snowboarding	
I would prefer skiing	35
both	59
snowboarding only	06

Finally, some answers of the parent generation concerning skiing today should be presented (Table 6). Ambivalent evaluations of modern developments could be observed.

The data strongly support the general assumption that individualization leads to product differentiation and behavioral change. Altogether, one can be certain that there will always be different types of snow-sporting activities, and alpine skiing cannot be expected to maintain a monopoly. Also, the so-called alternatives to alpine skiing will eventually need a corresponding infrastructure.

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THE SOCIAL INFLUENCES OF SKI-AREA DEVELOPMENT IN JAPAN

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Keywords: social influence, ski areas, tourism, international comparison, sociology, alpine skiing.

1 Introduction

From the 1960s, skiing has become one of the most popular sports in Japan. The number of skiers is increasing year by year. The number of people who skied in the 1994–95 season is estimated at about 20,000,000, about 16% of the population of Japan. About 26% of Japanese want to ski according to a 'leisure survey'. From the latter half of the 1980s, there have been many plans to develop ski areas in the name of community development. Today, there are more than 660 ski areas in Japan. Half of them are very small-scale ski areas, having only one or two ski lifts each. The other half of them are larger than before: there are more than 20 or 30 ski lifts at some of them. There are about 10,000 lodging facilities (hotels, Japanese style hotels, inns, pensions, *minshuku*) near or in the ski areas. Almost all ski areas have restaurants or eating houses and more than half of them have ski schools.

The ski areas and attached facilities are already developed as described above, while there are movements to oppose ski-area development. Typical of these are nature and environmental conservation movements, one of the social movements caused by the development of ski areas and other facilities. Another opposing group is sometimes organized by people who live near or in the region of a developing ski area. They insist on maintaining their way of life and their mountains. I think that it is necessary to take into consideration the movement as a social impact of ski-area development.

In winter, we have much snow in the northern districts on the Sea of Japan coast and in the mountain districts of our country. Also, these districts are the depopulated areas, because of few opoportunities to find a job and earn money. Compared with the Pacific coast, industrial development is smaller. The people in these districts can not make a living only by agriculture and forestry. Of course, there are some companies and factories in these regions, but the wage of workers is less than that of the workers in the large cities, because of the cost of the materials and product transportation, the upkeep and other expenditures. A farmer who lives in a mountain village once said in my interview research that, ‘We are treated as the people of a developing country by the government.’ Matsumural [1] called these social conditions the Domestic North-South Problem. As this study sought to assess the social significance of ski-slope development, it was important to know the socio-economic background of the country and ski-area regions.

Several problems should be taken into consideration to comprehend the social influences of ski-area development in Japan. It is useful to exploit some theories for thinking about these social phenomena. First, to explain the general relationships between ski activities and people, it is convenient to use the notion of ‘involvement’. It is suggested that there are several kinds of involvement in skiing, from the personal level to the national level of economic policy.

Second, in order to characterize skiing behaviour, we must consider both the skiers’ social character and the regional characteristics of the ski area. We must pay attention to those regions with developed ski areas especially, because the impacts of development directly change the way of life of the inhabitants in the district. In this research, two kinds of regional studies are reviewed: the human geographic perspectives of ski-area development and the rural sociological research of the regional changes after creating the ski slope. Valene L.Smith [2] described, from the anthropological point of view, that ‘the social impacts of tourism [skiing] are the most fundamental and of particular concern to anthropologists and other social scientists.’ From an anthropological perspective, the impacts are treated as the problem of cultural contact. From a human geographic point of view, the influences appear as rural changes in the form of house building for the pensions or the *minshuku*. From a rural sociological viewpoint, the impacts brought about changes in rural organization, occupation patterns, and daily routine.

This research had three major aims. The first was to clarify impacts on the region and its dwellers with developed or developing ski slopes. Any development would directly influence the people of the region, expecially the lifestyle of the inhabitants and their social organizations. In this study, it was found that there are four types of ski areas in Japan, according to ski-slope constructors. The first type of ski area was founded by many small companies. Each of them built some ski lifts in a ski area. Most of their owners are private corporate managers in the district of or near the ski area. The second type of ski slope was established by local, self-governing boldies. Most of them are small ski slopes. The third type of ski-area developer was the larger sightseeing or travel agent. The fourth type of ski-area constructor was what we call a 'third-sector company'. Those companies were founded by the joint investment of one or more corporations and the local self-governing body. Comparing these types, there were some differences in the relation between the management bodies of the ski areas and the regions.

The second aim of this study was to seek a settlement between the environmental and developmental issues in the ski areas. Most mountains in Japan are of low altitude, covered with trees, and few farms. Before the 1980s, there was no consideration for nature found on the ski slopes. Today, not only the Nagan Olympic downhill course, but many plans for ski areas are opposed by environmental protection groups. In this study, the possibility of 'sustainable development' within ski areas will be investigated.

The third aim of this study was to gather primary data for international comparative research into ski-area development and its social influences. It would be very important, even if social conditions are different, to look at the significance of ski-areas on a world-wide scale.

2 Involvement, tourism, and rural society

2.1 Involvement

It is a rather classical theory of sport sociology to use the notion of involvement to explain the reationships between sports and people. There has been little research explaining ski activities by using involvement. It is, I think, very useful in understanding ski behaviour itself and related activities. G.S.Kenyon [3] states that 'involvement means more than the participation', and that sport involvement has three dimensions. They are the behavioural, the cognitive, and the disposition levels of sport involvement.

At the behavioural level, sport involvement is divided into primary and secondary involvement. Primary sport involvement is almost equal to sport participation. In defining the actual sport scene, athletes and players of the sport are included in it. The secondary sport involvement is divided into the consumer and the producer. The patterns of consumption are direct and indirect involvement. The difference between direct and indirect is the difference between the spectator of the live sporting event, and the TV or radio audience or the sport-article reader. There are three types of sport producers: the leaders, the judges, and the entrepreneurs. The leaders include coaches, managers, team leaders, and instructors. The judges are supervising organization members of the sport, sport-committee members, referees, umpires, score keepers, and other official members of the sport. The entrepreneurs include producers of the sporting goods, promoters, wholesalers, and retailers.

It is a very interesting and significant division of sport involvement as a whole, but it is not so simply classified at the individual level, because, as Kenyon pointed out, one would take on different social roles under the different social conditions of sport. It is very interesting that secondary involvement is divided into consumers and producers. Perhaps, considering most sports as non-productive activities, he used the 'producers' to mean the producers of sporting activites. Today, the word should include the aspect of economic activities, because the economy has invaded the sporting world more powerfully than ever before. Some other types of entrepreneurs must be included for adapting ski behaviour. They are the ski-area constructors, the ski-lift companies, the ski-area managers, the owner of the lodging facilities, and the transportation or tourist companies [4].

Some amendments of the divisions by Kenyon are needed to suit present-day ski activities. First, primary involvement is also divided into consumers and producers. The division of sport participation is made for this purpose. Some people ski for fun or to improve their abilities, others earn money by skiing—for example, the professional ski racer or the championship skier. Even skiing for non-economic purposes is sometimes productive, such as the amateur ski race broadcast on TV. Second, regional scale should be added to sport involvement, because skiing itself can be done in the particular districts. It is already explained above that entrepreneurs play an important role in skiing. The popular skiing type in Japan is what we call *gelende* (slope) skiing, or, *pachinko* (Japanese pinball game) skiing. Skiers get on the ski lifts and slide down the step board of the lift repeatedly. It can be said that there is no ski area without snow and a lift in Japan.

There is no room to examine the details of the cognitive level of sport involvement or the dispositional involvement in this paper. However, at the dispositional level, it would be interesting to investigate the differences between skiing activities in different countries. The Japanese young men like to ski all day long, continuing on the lighted slope at night.

All the phases of involvement should be researched for understanding the whold impact of ski-area development. In this study, however, I describe mainly the social changes of districts with developed ski areas.

2.2 Tourism

Tourism or human geographic studies concerning ski areas have appeared since the 1960s in Japan. Some researchers in the geography of tourism focussed especially on ski-slope development and regional changes.

S.Shirasaka [5] [6], and H.Ishii [7] thought of the region as a 'complex structure' for understanding the changes. Shirasaka pointed out that the ski activities in Japan would be restricted by the natural conditions, the relative location, and the transportation facilities, and corresponded to the general tendency of the increase and diversification fo recreational needs. Shirisaka classified the Japanese ski areas into three types:

1. National. Total lift length is over 12 km. Open over 120 days. The skiers come from all over the nation. The national ski races are sometimes held here. They are Nozawa Onnsen, Shigakogen, Zao, Naeba, etc.
2. Regional. Total lift length is from 4 to 12 km. Open from 90 to 120 days. The skiers come from not far away—i.e., from near the ski area. They are Sugadaira, Kusatsu, Daisen, Togari, etc.
3. Local. Total lift length is under 4 km. Open under 90 days. The skiers come from the town near the ski area, and ski for a day. They are Iizuna, Takayu, Zaobodaira, etc.

He also described the historical development of ski areas in Japan.

1. First stage (from 1911 to the first half of the 1940s):
   Skiing was instructed by T.Lerch in Japan in the year 1911. He taught ski technique to soldiers, teachers of physical education and private citizens. From this year, skiing and ski areas have been diffused all over the country. At this stage, most ski areas were developed near the hot springs. The ski slopes had no lifts, the skiers climbed to the top of the slope on or with their skis. Most of the ski areas were constructed by the owners of inns. Ski clubs were founded in various places, and the ski association of Japan was established in 1925.
2. Second stage (from the latter half of the 1940s to the first half of the 1950s):
   Ski lifts were built on most of the ski slopes during this stage. The important condition for the development of new ski areas was the means of transportation. In this period, most ski areas were developed near a railway station.
3. Third stage (after the latter half of the 1950s):
   The large tourist companies began to develop ski areas during this stage. They made large-scale ski areas with lodging facilities in various regions. At the same time, many *mishukus* (private homes, providing meals and lodging for tourists) had begun to be run by the farmers near the ski areas.

Many settlements have changed from being agricultural mountain villages to host villages for skiers. Shirasaka named those villages ‘ski settlements’. He researched the national ski areas for seeking the reason for and the condition of the ski settlements. He reported case studies about the Nozawa Onsen, Shigakogen, and Tsugaikekogen ski areas and settlements. These included the history of the ski area, the conditions of location, the land-use patterns, the change of industrial structure, the management of the ski facilities and *minshuku* management. His desciptions were very simple and extensive, but were very significant and important suggestions for social scientists.

Ishii also focussed on the formation of the *minshuku* settlement. He insisted on the importance of the regional case study from the view point of historical geography. He explained the rationale for this importance in that human spatial conditions and patterns were defined by environmental circumstances and the cultural power of the human groups.

2.3 Rural Society

There have been a few sociological studies concerning the development of ski areas. O.Moon [8] researched a mountain village in Gunma prefecture which developed a ski slope in 1964. She investigated the village in detail, and reported the change in agriculture, supplementary occupation, in the household and the social organization of the village. She described the social and economical background of the time as follows:

> As with all the other village communities in Japan, Hanasaku is also part of a nation and of the world, and the course of its recent history has thus been inevitably affected by forces external to the community. The decline of traditional supplementary occupations such as the charcoal industry, timbering and animal husbandry, the shift of crops from subsistence food crops to rice and vegetables grown for cash, the spread of agricultural machinery and decrease in the labour needs of farming can all be considered as changes directly and indirectly derived from changes at the national and international level, which have affected many other villages in a similar way.

After she grasped the above conditions, she pointed out the divergence of Hanasaku from other villages. First, the ski-slope development was not disruptive to community organization, because there was a population superfluous to agriculture which could find non-farming jobs at the ski slope with ease. Second, ‘the greater involvement in wage-earning activities did not in itself undermine the traditional functioning of the household.' Third, the advent of tourism in this village did not disrupt the traditional organization or household, because 'the business provided the young with an occupation more stable and attractive than farming and other wage labour outside the household.' Fourth, the economic diversification in Hanasaku did not weaken the traditional solidarity of the village community, for the local government adopted a policy of local development that emphasized the tourism industry and agriculture equally. Fifth, the most remarkable aspect was the proliferation of social and religious activities, because the Hanasaku people earned more money through new jobs than before.

3 Other cases of development

3.1 Types of development

There are many methods of classification of ski areas. They are divided by historical period of development, width of slope, number of lifts, managing type of the ski area, etc. The changing standards of the historical-period division arose from technical innovation of construction and important social events. The width of slope and the number of lifts depend on land-ownership patterns and the capital of the developer. When Shirasaka researched the ski areas of Japan (1980), there were 534 ski areas. Now (1995), the number of them has reached 644. In fifteen years, 110 ski areas have been developed in Japan. I want to add a fourth stage to the developing pattern.

4. Fourth stage (during the latter half of the 1980s):

   A new pattern of development appeared in this period: the third-sector method. At the third stage, large tourist companies developed ski areas. During this stage, new companies were established by the joint investment of local government and private companies. Orfcourse, those companies included tourist companies. The new companies were established in various regions. This phenomenon was related to a law that promoted the development of general recreational facilities.

   This law, the so-called 'resort law', aimed to encourage the construction of large recreational facilities for long-stay visits. Through this law, 40 prefectures (47 in Japan) were approved for development into resorts in 1992. However, over 80% of planned facilities (1715 out of 2046), including ski areas, golf courses, and marine sporting facilities are not yet under construction. The reasons are the depression of the 1990s, the opposition of environmental protection groups, and the neighbourhood protest movements in the developing areas. The companies had no spare money to invest for the third sector. It was the year in which the 'Earth Summit' was held. People have become interested in the protection of nature on a world-wide scale. The dwellers were also the landowners in the developing areas. They did not want to sell the land that they inherited from their ancestors.

There are four types of ski-area developers in Japan.

1. Small companies near the ski area.
   Perhaps they were the oldest type of ski-area constructors in Japan. Most of them were also the owners of hotels of inns near the *onsen* (hot springs). They developed the old large ski areas near the hot springs. For example, seven ski-lift companies constructed the ski area in Akakura, Niigata prefecture. They sold their own lift tickets for each company till 1975. It was very inconvenient for the skiers. From 1976, they could sell uniform ticket by means of a computer-controlled system.
2. Local government.
   Except some early develped ski areas near the hot spring, like Nozawa Onsen, this type of constructor emered in the 1960s. Many local governments in snow-fall districts were bothered by the decreasing population and *dekasegi* (going a long way to find work during the winter). The local governments took measures against those conditions. They invited factories to their village and promoted other industries. The ski-area development and tourist industries were part of their measures. The local government bodies utilized subsidies for agricultural villages from the national government. The mangement structure of ski areas was different in each village. For example, there have been management sections of the ski area in village offices (like Nozawa Onsen), the local government has entrusted the hamlet near the ski area to manage it (Taranokidai) and the local government has extablished a non-profit organization for the ski-area management Daikura).
3. Tourist companies.
   There were some big, private railway companies that developed ski areas in the 1930s. Outstanding development by the private railway companies has occurred since the 1960s. One of the reasons is the prosperity of Japan, and another is the ski boom. The famous companies are Seibu, Tobu, Tokyu, Hankyu, etc. Large-scale development has been done by the big private railway companies.

4. Third-sector companies.
   This type of company has been established since the 1980s. Local governments and some companies, through joint investment, founded companies to develop and manage the ski areas.

Most ski areas in Japan have some companies which do business within the ski area. Some have expanded to connect with the neighbouring ski area.

3.2 Two Cases

3.2.1 Taranokidai

In the year 1984, Kusibiki town in Yamagata prefecture decided to develop a ski area near the hamlet of Taranokidai [9]. At that time, the hamlet inhabitants, especially the men, went a long way to find a job during the winter. The local government constructed a lift, and entrusted the management of the ski area to the hamlet. After the ski-area development, over ten persons could get jobs in winter for lift operating and the patrol of the ski area. Five women were employed in the eating house. The hamlet organized a management union for the ski area, and all houses have been a member of the union since its establishment.

This was the smallest type of development of a ski area, but there was great impact on the dwellers' way of life in the winter. First, the image and the atmosphere of the hamlet became cheerful and spirited. Before the development, the hamlet was a snow-fall mountain village and only a few guests visited there in the winter. Many skiers near the town have come there since the development. Second, the inhabitants found jobs in the ski area. They could earn more than 10,000 yen a day, if they went out to the *dekasegi*. They earned about 5000 yen a day for working in the ski area. Even though the amount of money was decreased, they were satisfied with the conditions, because they could live with their families during the winter. Third, the management union refreshed the rural traditional organization. For management, the hamlets hold the annual general meeting once a year. Fourth, a young employee of the ski area could marry one of the skiers. It has been a great social problem that the farmers in the depopulated districts could not get married in Japan.

3.2.2 Daikurayama

The local government of Tajima town in Fukushima prefecture developed ski areas in 1982. The town office utilized a subsidy for a forestry project for constructing the ski area. Until 1984, the town had built five lifts in the area.

The town office managed the area for the first two years, but it was very hard for them to work in the town office and manage the area at the some time. The local government established a non-profit corporation for managing the ski area. The corporation has managed tha ski area in the winter and administered other sport facilities in the other seasons since 1984. The over 50 town dwellers could get jobs operating the lift and working the restaurants. In the hamlet near the ski area, 55 houses have been rebuilt into *minushuku* for the skiers.

The town office decided to develop a third-sector company for expanding the ski area. The company was established with Tobu railway in 1986. The company built two high-speed lifts, a restaurant with a resting room, a ski rental and mending room and a hotel in the ski area. The company wanted to widen the ski area, but it could not yet enlarge because of the economic depression and the opposition of landowners.

From the time when the young skiers heard the plan of opening the ski area in their town they began to prepare a ski school. They made a ski club in their town and took the licenses as ski instructors. They began to manage the ski school in the same year the ski area was opened. The ski-school instructors also taught skiing in the elementary school.

There had already been the *minshuku* in the hamlet, Haryu, near the ski area for lodging in the summer since 1973. Haryu was a village of adolescent tourists for the summer. The hamlet organized the union of young adolescent tourist villages for managing the facilities. It was the entrusted work of the town similar to the Taranokidai ski area. The *minshuku* had no facilities for the skier, for example, a drying room for skis and boots. The owners had to rebuild their houses for the skiers. Not only their houses, but also the organization of the *minshuku* had changed for the skiers. The union bought a small bus for the transportation of skiers from the *minshuku* to the ski area. It is about a four kilometers distance. New lodging facilities and pensions have been built since the ski area opened. The owners were from the town of Tajima itself.

4 For the next step of development

Environmental problems are not only the problem of the natural sciences, but also that of the social sciences. As we all know, the construction of ski slopes disrupts forests, destroys the natural habitat of animals, birds and insects, and has caused mountains to lose their ability to retain water. Now it is necessary to consider both environmental protection and regional development. [10]

Miyamoto, K.[11] described ‘the spontaneous development’ theory that included both nature and development. In his theory, development should be considered within the realm of environmental conservation. It should have the purpose of enriching the inhabitants’ life by preserving nature, considering amenities and promoting welfare and culture. It is development not by the central government or large companies, but by the dwellers themselves. They should consider information about development, make plans and manage them based on the culture, industries, and technologies of the region. They should strengthen the quality of the regional economy by developing various types of related industries. To accomplish this type of development, it is necessary to increase the autonomy of the institution of resident participation.

The spontaneous-development theory is based on the standpoint of regionalism. There are some difficulties adopting this theory to ski-area development; for example, the ski areas need skiers from other regions, expecially from big cities, to be viable. It does, however, as a basic concept for development, address the treatment of nature and of region. Environmental protection should have priority over economic profits. The destruction of nature, caused by development, should be minimized. The dwellers of the ski area should consider the related industries for themselves and nature. It is time that ski activity itself be changed in Japan [12].

For international comparitive study, two major points should be researched: the relationship between environmental protection and development (a basic problem of sports which are performed in nature, such as skiing), and the relation of inhabitants to development. This point should be divided as follows: social and economic background of the nation; the characteristics of the ski-area district; the relations between the inhabitants, including the local organizations and the ski-area management bodies; and the substantial and mental impact on the dwellers.

5 Conclusion

The lifestyle of the inhabitants changed because of the ski-area development. Substantially, they found jobs in the ski area in winter. The atmosphere of the hamlet and the town became very spirited. The degree of these changes depended on the type of ski-area developer.

From an environmental perspective, the mountain-district dwellers were perplexed with the problem. They were caught in a dilemma between earning more money and protecting the environment. They sought a method consistent with both demands.

For cross-national study, it is suggested that one must understand the inhabitants' points of view to assess the direct influences changing their lives. In each nation, the following points should be clear: social and economic background of the nation; the characteristics of the ski-area district; the relation between the inhabitants and the ski-area management bodies; and the environmental and psychological impact on the dwellers.

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DOWNHILL AND TELEMARK SKIING AS PART OF YOUNG PEOPLE'S LIFESTYLE

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Keywords: identity, lifestyle, social/cultural reproduction, youth culture, alpine skiing, telemark skiing.

1 Introduction

Sport is a vital part of young people's lifestyles and youth culture. According to Giddens [1] the notion of lifestyle takes on a particular significance in modern life. "The more tradition loses its hold, and the more daily life is reconstructed in terms of the dialectical interplay of the local and the global, the more individuals are forced to negotiate lifestyle choices among a diversity of options." (lbid). This means that lifestyle choices are increasingly important in the constitution of self-identity. The German sociologist Thomas Ziehe, emphasizes with particular reference to the situation of young people, that identity development is becoming more complicated as traditional structures in society are being disrupted, but also more open as the individuals are, to a greater extent, able to create their own lifestyles and identitities [2].

As a function of the mentioned conditions in society, some scholars claim that social classes are dying, by changes in class relations combined with decreased class differences [3]. In such a perspective it is reasonable to question the relationship between sports participation and social class.

Empirical studies show that sports participation is most common among people in the middle and higher social classes [4] [5] [6] [7] [8] [9] [10], but also that social stratification is found within the sports system. Some sports are connected to the labour class, other sports to the higher social classes. Social stratification in sport has been explained as a function of perceptions of the body and body culture [11], and to lifestyle preferences [12].

The focus of this study is sports participation as part of young people's lifestyle, wher social and cultural reproduction is of particular interest. The sports which have been focussed upon are downhill skiing and Telemark skiing. Downhill skiing has traditionally been a middle and upper-class sport. Telemark skiing may be considered as a kind of an off-shoot sport, which may be unterstood as because downhill has developed less distinctive with regard to social class, that people from the higher classes create new styles of performing sports. I remind you that Telemark skiing is rooted in ancient Norwegian ski traditions, but was reinvented in the United States in the late 70s. Modern Telemark skiing has some similarities with downhill skiing but the technique, the rules in competition, and the equipment, are different. For example, competition in Telemark has a jump built into the course, and the turns are judged according to the criteria of Telemark turns, where a certain distance between the boots is required.

2 Methods

The study used an ethnographic approach, where both participant observation and qualitative interviews have been used. The sample consisted of one group of downhill skiers and one group of Telemark skiers, with 10–15 participants in each group, girls and boys together. The athletes were followed during practice through the winter season, once a week for three months. Observations were also made during competitions. Although my own age and level of performance differed from the athletes, I followed parts of the program and followed the skiers through the practice.

After the ski season the most acitve skiers were selected for interviews, seven skiers from each group. The interviews, which focused upon lifestyle and leisure activities in general, lasted for about an hour.

3 Results

The empirical data uncovered differences between the two groups as well as among the participants within the groups. I will point to some of the major patterns that emerge from the data. First, to the organizational structure of the groups and the ambitions and motivations for skiing, and second, to skiing as part of the participants' leisure and lifestyle.

The organizational structure of the groups was different in several ways. In the downhill group, the skiers had organized practice three times a week, and most of them took part in competitions during the weekends. The skiers also followed organized training during summer season and the fall, and the group used to visit a summer ski resort. The overall goal of the program is to encourage skiers to perform their best, and to advance on the ranking lists.

The program of the practice is mainly focused upon the courses, to train the skiers in competition-like situations.

On the other hand, the Telemark skiers met for practice once a week during winter season, and there was no program for summer and fall. Competition was less important. The ski-club arranged club championship, but other than that, the skiers normally didn't take part in competition. The overall goal of Telemark skiing was experiencing the joy of the body movement, and to teach the skiers to manage the Telemark technique, which includes running the courses, skiing in virgin snow and different kinds of jumping.

In analysing the motives for participation, the results show some similarities among the skiers in both groups. Skiing is regarded as a valuable leisure activity, which most of them had been introduced to in early childhood. The recreational aspect as well as physical fitness was also emphasized. The majority expressed that feeling joy and having fun were the basic motives for skiing. However, when the issue of fun and joy is further elaborated, it appears that among the downhill skiers, fun is more closely connected to goal-setting, ambitions, and the skiers' own perceptions of their abilities to succeed. Consequently, the question of dropping out is, for the skiers, a continious reflection in their development as a skier. For the seventeen and eighteen year olds, the issue of reaching a proper ranking at the national level, seems to be predominant in their decisions about whether to continue or not. One of the boys expressed himself this way about his future plans:

> *I go for another year, see how I'll do. I can't be bothered. Then I might quit and find another sport. It's too expencive and time consuming, to continue, if you don't really succeed.*

A major difference between the two groups, is their sports activities in general. With a few exceptions, the downhill skiers had skiing as their only activity, because they had to spend all their time and energy improving their skills. Skiing was a major part of their lifestyle and identity, as one of the girls expressed:

> *"I feel like I've invested quite a lot of myself in skiing, of course it has given me a lot back, it has, but I-would really like to feel the happiness, that I have succeeded, that I once will sometime do it really good."*

For the Telemark skiers, skiing was one of several sports activities. The girls' activities included tennis, dancing, and aerobics, the boys, playing tennis, basketball, and bandy. Skiing Telemark gave them a kind of social status, and ski equipment and designer sportswear were essential symbols in this regard. Besides the weekly organized practice, the ski resort was an arena to develop friendship and to feel they belonged in a group with others similarly disposed. This quotation illustrates:

> *I know almost everyone there, since I was nine I have spent most days in Winter season there, I just go there and meet people or wait for someone to show up.*

The results from the study indicate that cultural reproduction in sport still exists, both in relation to social class and gender. The Telemark skiers have in general higher social-class backgrounds than the downhill skiers. Their parents occupy higher positions, are higher educated, and to a certain degree, better off economically compared to the parents of the downhill skiers. The leisure style of the Telemark skiers was, in general, more sophisticated. So was their language and manners. These findings may be understood in accordance with the French sosiologist Pierre Bourdieu [12], whose contribution to class theory, lifestyle, and preferences, is of central importance. His concept of capital and its different dimensions (economic, symbolic and cultural capital) is useful in understanding the power of the social class variable. The results demonstrate that the symbolic and the cultural dimensions are probably more important than economic capital, for explaining different sports preferences.

Concerning gender, the downhill skiers seem to be less conservative and traditional than the Telemark skiers. Both the observations and the interviews show that girls and boys in downhill are participating more on equal terms compared to the Telemark skiers. They followed the same program, and the coach did not make any special arrangement in relation to gender. However, in many situations, the girls demonstrated classic female behavior. They more easily showed fear and weakness, and were more afraid of making fools of themselves. In the Telemark group, the girls withdrew from jumping and more strenuous activities, which the coach accepted, and made alternative activities for the girls. The interview data indicates a more traditional perception of females and males in sport, compared to the downhill skiers.

This finding may be explained in relation to gender as well as social class. It seemed that the Telemark skiers in general had more conservative attitudes than the downhill skiers. For the girls, this may have been reinforced in the

Telemark setting, which offered a variety of options to compose their own sport's role, while the girls in the downhill group more or less followed the same standard as the boys. Downhill was in "the fast line" in many conceptions, whether for girls or boys. The latter points to the genesis of the different sports disciplines. Downhill skiing is a highly competitive sport, which means that young athletes who aspire to a sports career, have to adjust their lifestyles to the requirements of that particular sport's discipline. Telemark skiing on the other hand, is more an arena for youth culture, where symbolic and cultural capital play an important role in communicating lifestyle preferences and further, social and cultural heritage, to the surroundings.

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ALPINE WINTER SPORT RESORTS: TRAVEL MOTIVES AND DIMENSIONS OF SERVICE QUALITY

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Keywords: winter holiday, travel motives, quality domains and dimensions, service quality.

Due to the tourism crisis in the western part of Europe, an urgent need for action has occurred. Because the decrease of overnight stays in Austria and Switzerland may be increased through structural, political and currency-system measures. Alpine winter tourism needs a change and/or restructuring of the supply to tourists, built on the basis of demand, which could be anticipated through professional market research. Based on these considerations, the Institute for Tourism and Service Economics (ITD) tried to analyze, and is still analyzing, the development of winter-sport resorts.

1 Travel Motives

This paper shows the main results of a study, carried out by the Institute of Tourism and Service Economics at the University of Innsbruck in Austria, concerning tourists' travel motives for alpine winter holidays. The entire research project analyzed various aspects of service quality in alpine winter resorts, but within this presentation only travel motives will be demonstrated.

Methodology
200 tourists were interviewed in one alpine winter resort in Austria, during the winter season of 1995. The survey was based on a semi-structured questionnaire. The tourists were asked to choose motives from a nine-statement battery, and to express their individual agreement or disagreement on a 5-point Likert scale. (1="I strongly agree" to 5="I strongly disagree").

Results
55.2% of the tourists interviewed were male, 44.8 % female. 54.2 % of the tourists were younger than 36 years, 45.8 % were older. For the most part the tourists

(76.7 %) spend more than one week in the winter resort. More than 70 % of the holiday makers in this survey were native German speakers. Concerning the frequency of holidays spent in the analyzed resort, 21.5 % of the tourists were first-time visitors, 78.5 % had already spent more than two holidays in the resort, and altogether, more than 50 % of the persons asked regularly came to this resort for winter holidays, (=regular tourists).

Travel Motives of Winter Tourists

Table 1. Mean value of each travel motive used in the survey.

Travel motives	Mean value
Meeting friends and acquaintances	2.5
Family Holiday	2.9
To get to know a new ski-resort	3.5
Satisfaction with the accomodation	2.4
Holidays at a favorable price	4.4
Cross-country skiing holiday	4.8
Relaxation and recuperation	3.0
Fun and entertainment	2.1
Doing active sports	1.7

The table above shows that *doing active sports* was the most important motive for a winter holiday in the Alps. Furthermore, tourists wanted to have *fun and entertainment* and wanted to *meet friends and acquaintances* on their holidays. Another favorable motive for spending a winter holiday in a certain resort was *satisfaction with the accomodation.*

Table 2. Comparison of travel motives between first time visitors and regular tourists.

First time visitors	Regular tourists
1. Doing active sports	1. Doing active sports
2. To get to know a new ski-resort	2. Satisfaction with the accomodation
3. Fun and entertainment	3. Fun and entertainment

The main motive of both groups was *doing active sport*. First-time visitors liked *to get to know a new ski-resort* and the regular tourists expressed *satisfaction with their accomodation* at the resort as an important motive.

Because of the increasing importance of snowboarders in the tourist industry, a comparison of travel motives between skiers and snowboarders was made:

Table 3. Comparison of travel motives between skiers and snowboarders.

Skier	Snowboarder
1. Doing active sports	1. Fun and entertainment
2. Fun and entertainment	2. Satisfaction with the accomodation
3. Satisfaction with the accommodation	3. Meeting friends and acquaintances

Snowboarders differed from skiers because snowboarders underlined the importance of *fun and entertainment* during their holiday, derived from the sport itself, and from the average age of the participants (94.7 % younger than 36 years). *Doing active sport* was characteristic for both groups.

Table 4. Comparison of travel motives focussed on the age of the tourists.

First time visitors	Regular tourists
1. Doing active sports	1. Doing active sports
2. To get to know a new ski-resort	2. Satisfaction with the accomodation
3. Fun and entertainment	3. Fun and entertainment

Younger tourists emphasized first, the motive *fun and entertainment* and second, the possibility *to meet friends and acquaintances*. Older tourists were interested in *doing active sport* and in *relaxing and recuperating* during their winter holiday.

Most Favorite Winter Sport Activities

Although the number of snowboarders is increasing, 89 % of the persons interviewed still preferred skiing as their favourite winter sport activity; only 10 % of the interviewees ranked snowboarding first. Based on the high interest in skiing and snowboarding as a winter sport activity, the relevance of skiing off the prepared slopes was analyzised.

Table 5. Reasons and intentions of the tourists for skiing off the prepared slopes (frequency values).

Reasons for skiing off the prepared slopes	Skiers	Snowboarders
1. sports challenge	43.5 %	53.3 %
2. experiencing unspoilt nature	25.8 %	33.4 %
3. thrill of danger	6.5 %	33.3 %

Skiers and snowboarders enjoyed skiing outside of the prepared areas, as is demonstrated in the table. Concerning the reasons for skiing off the prepared slopes, snowboarders liked the sporting *challenge* more than skiers do.

A distinction between skiers and snowboarders in the two age groups leads to the assumption that age influences the willingness to ski off the prepared slopes, as shown below:

Table 6. Influence of the age to the willingness to ski off the prepared slopes.

Age group	outside prepared slopes - YES	outside prepared slopes - NO
below 36 years	53.7 %	46.3 %
above 36 years	28.3 %	71.7 %

53.7 % of the tourists that were younger than 36 wanted to ski outside the prepared areas. 71.1 % of holiday makers that were older than 36 refused to ski off the prepared slopes. This result suggests that older tourists perceive more risk to be associated with skiing off the prepared slopes than younger people do. Tourists between 19 and 25 form the largest group of „off the prepared slope" skiers and snowboarders.

Another interesting result shows the distinction between male and female interviewees.

Table 7. Skiing off prepared slopes and gender.

Male	outside prepared slopes - YES	outside prepared slopes - NO
younger than 36	64 %	36 %
older than 36	32.1 %	67.9 %

Female	outside prepared slopes - YES	outside prepared slopes - NO
younger than 36	44.6 %	55.4 %
older than 36	6.9 %	93.1 %

By getting older, the interviewed male showed less intention of skiing off the prepared slopes.

An increase in age of the female participants in this survey was accompanied by a concomitant decreased willingness to ski outside the safe areas. This could correlate with the fact that women, in general, are more frightened than men, and with the increased responsibility of women who have family and children. These correlations were not tested in this survey and would need another specific study.

Conclusions

In general these results lead to the following implications for the tourist industry:

Tourism experts discuss which role winter sport activities and winter tourist destinations will play in the tourist's holiday planning process in the future. Nevertheless, doing active winter sport is still the most important and significant motive for spending a winter holiday in the Alps, in the opinion of the persons asked in this inquiry.

The intention of many winter tourists to ski outside the prepared slopes provides interesting results for tourism providers. Obviously, younger skiers and snowboarders show more interest in skiing off the safe areas than older tourists do. This reflects the occurrence of differences in the perception of risk, depending on the age of the people.

Although traditional winter sport became less attractive and popular in the last decade, new trends in the area of winter sports open new possibilities to enlarge and restructure existing tourist products. The motive of fun and entertainment has high relevance for winter tourists, especially for snowboarders and younger target groups. This implies a challenge for the tourist industry to create innovative offers focussing upon the fun and entertainment component.

Satisfaction with the accomodation demonstrates that feeling comfortable is an aspect of service quality that takes part in the tourist's holiday decision-making process, and should be considered by hotel and accomodation managers in the future.

In summary, regular winter tourists still assess a winter holiday in the alps as attractive, because of the unchanging attractions and experiences offered by these particular regions.

2 Touristic Domains and Dimensions of Service Quality

Together with the inception of the newly formed Institute of Tourism and Service Sector Economics at the University of Innsbruck, (Austria) in 1992, a long-term oriented and broader based research project was established. It was to investigate the typical development trajectory of alpine tourist resorts, discuss relevant economic, social and ecological derivatives and consequences of this development, and in turn, translate these findings into implications for further and future tourism expansion and development. The resorts which in the end were chosen for participating in this research were primarily and singularly interested in questions of future resort competitiveness.

Given the large population and varying nature of alpine resorts in Austria our study of nine Austrian and two Italian resorts must be termed exploratory even though the two-year-long research involved detailed extraction and analysis of resort data. Altogether 1822 tourists who vacationed in the months of January, February and March 1994, in eleven resorts in Austria and South Tyrol, were randomly sampled through a standardised questionnaire (this survey was complemented by another set of interviews with the purpose of blue-printing the most positive and most negative vacation experiences of tourists). We also took data from 283 tourism enterprises in these resorts, but within this presentation we will refer only to the guest-survey.

Our empirical inquiry was focused on different aspects of service quality, because of the following reasons: tourism in the Austrian alpine regions will in the foreseeable future have little leverage over cost and prices, on account of lacking economies of the scale and scope associated with the size configuration of firms in its various branches and industries of tourism, the high and rising level of wages combined with the environmental costs of alpine tourism, and the high and stable value of its currency. Thus, for the practical purposes of introducing and/or positioning new and existing alpine tourist products and services on the market, the quality of services and destinations will be the dominating issues with respect to the competitiveness of Austrian resorts.

Methodology

For measuring service quality in winter sport resorts we have chosen seven domains of touristic activities and seven quality attributes which we have combined. For example, in the touristic domain, food and accomodation have been tested in aesthetic dimensions, in safety dimensions, etc. Thus the questionnaire yielded a matrix of 7×7 touristic service-quality statements for relevant touristic activities, which were administered to randomly sampled vacationers who in turn answered twice, once in terms of the expected importance, and a second time in terms of the experienced (received) satisfaction, which were recorded on a 5-point Likert-scale. As it is usual to define quality as the between expectations and experiences, we could measure quality in all the statements. Additionally, we took information from the so-called blue-printing-method, which means that the guests state the most positive and the most negative experiences they had during their stay.

Results

Nearly 80% of the respondents were foreigners, 58.2% were male. There was a large sample of young respondents (55% under 40 years), which may be due to the young age of the interviewers, as one knows that the whole Austrian tourist industry complains about the increase in the percentage of older vacationers. Close to the Austrian average, is the percentage of German guests at 54.9%. Below, we present the average scores of indicated importance and experienced satisfaction (1 indicates very important or very satisfied and 5 indicates not very important and/or not very satisfied):

Table 8. Average scores of indicated importance and experienced atisfaction.

Touristic Domains	Importance	Satisfaction
Skiing	1.53	1.89
Accomodation & Food	1.54	1.77
Nature	1.56	1.80
Sports activities	1.85	2.09
Transportation	1.94	2.17
Shops	2.22	2.27
Entertainment	2.76	2.63

Order of rank importance	Order of rank satisfaction
1. Skiing	1. Accomodation & Food
2. Accomodation & Food	2. Nature
3. Nature	3. Skiing

Quality Dimensions	Importance	Satisfaction
Safety & Security	1.71	1.85
Punctuality & Reliability	1.77	1.97
Freedom of activity	1.78	1.87
Aesthetic	1.89	2.09
Honesty/Authenticity	1.91	2.12
Accessibility	2.03	2.20
Animation & Fun	2.05	2.40

Order of rank importance	Order of rank satisfaction
1. Safety & Security	1. Safety & Security
2. Punctuality & Reliability	2. Freedom of activity
3. Freedom of activity	3. Punctuality & Reliability

Conclusions

Of priority to the guests are the domains: *skiing, accomodation & food,* and *nature & landscape,* and the dimensions *safety & security, punctuality & reliability,* and *freedom of activity.* In winter, the guests visited the resorts for skiing activities, they looked for cost effectiveness, they loved the natural landscape, and also the authentic alpine character of the village.

Especially in the domain of skiing, the guests mentioned the aspect of *safety & security,* which may be due to the increasing number of accidents in the ski area during the last years. The younger guests ranked highly the number of ski-lifts and cable cars, the conditions of the ski-run, the supply of ski-runs, and the accessibility of the ski-lifts, which means that they singled out the technical aspects of skiing. The older people emphasized the aspects of safety and security, the suitable fit of ski-lifts and landscape, and the waiting period at the lift stations.

Although the guests did not call for *animation & fun,* or for *entertainment* in our inquiry, perhaps due to the fact that we asked the guests in the ski area and not in the village, they were not satisfied with the supply. Particularly they mentioned the existing and/or non-existent supply of „Apres-Ski", and the supply of shops and services, which can be added to the domain of *animation & fun* or *entertainment,* as *shopping* surely guarantees entertainment or fun for many people. If one looks to other studies and other trend reports, we dare to say that in these domains an urgent need for action exists. Through cooperation and networks one should expand the tourism supply in this way, so that *animation and fun* is guaranteed for the guests.

The main *negative aspects* mentioned are: *the volume of traffic, the aesthetic aspect of the landscape, the protection of the authentic village character,* and *the honesty/reliability of the tourist promotion*. Concerning this last aspect, guests criticized tourist promotions for often promising animation and fun at the destination, yet when the guests stay at this destination, there is neither animation & fun, nor entertainment: there is simply ,,nothing". To promise more than one can offer, seems to be a widespread problem in winter destinations, because this mistake was also explicitly mentioned in the blue-prints.

Because a battery of personal-characteristics data on tourists was available in the survey, it was possible to check differences in perceived quality importance and satisfaction among tourist groupings. Generally speaking, differences were found to be very small and not all were significant. Since age and the distinction between domestic and foreign visitors have often been discussed as important and discriminating factors with respect to attitudes towards the touristic infra- and suprastructure of ski resorts, and the evaluation of skiing relative to other activities, they will be further analysed below.

In order to obtain an indication of differences between *domestic and foreign visitors* in quality importance and satisfaction scores, we first investigated such differences in the domain of nature and landscape. A number of nature- and landscape-specific statements were used to test our quality attributes. Altogether, domestic visitors generally consider all quality aspects of nature and landscape as more important than their foreign counterparts, and they were also more satisfied with the offer of alpine winter resorts. These findings seem to hold true for all activities, too. Domestic tourists are equally more satisfied with various touristic service quality dimensions and touristic activities, as compared to foreign tourists.

In a second step, we analyzed more closely aspects of *safety and security* which in this survey appear to have been very important quality dimensions.

Possible individual determinants for safety concerns could be age, as older people tend to be relatively more concerned with health and safety, as well as risk aversion associated with uncertainty.This suggests that, a priori, domestic tourists should be better informed, and will therefore be less concerned with uncertainties concerning safety and security. As to be expected, safety and security concerns dominate in the touristic activities of skiing and related activities, transportation, and nature and landscape. Older people attach more value to aesthetics, safety and security, and honesty, in comparison to those under 40 years of age. Younger people put more emphasis on animation and accessibility, in comparison to those 40 years and older.

Concerning information, friends and relatives are by far the most *important source of getting information* (over 73.6%), followed by travel agencies (15.6%), and local and national tourist organisations (10.8%).

Finally we wanted to know whether *previous winter holiday experiences caused appreciable differences* in either the perceived importance of or realized satisfaction with service quality and its various dimensions. While differences are small it appears that frequent winter holiday tourists are more satisfied than those who have only taken a few skiing holidays, or experienced their very first skiing holiday. This seems to suggest a self selection phenomenon, whereby frequent ski holiday-makers are better informed, and know with greater certainty what to expect, hence they invariably will receive the quality that they expect. The latter has rather important implications with respect to the ongoing debate over the relative value of image versus informative tourist advertising.

In summary, one can say that our study agrees with other alpine studies and trend-reports and that they all show the same tendencies. In the future the following domains will dominate: *animation & fun, contrasts, sports activities, relaxation, harmony with nature and family*. Guests do not accept anymore mass tourist programmes, but they are autonomous consumers, searching for individualism, freedom and authenticity. To be brief, they are more self-assured and entrepreneurs know that customers are no longer uninformed!

3 Discussion

The guest consumes the holiday as a package, and therefore it has to be offered as a package, which means that the whole of service quality—from transportation to skiing, other sport activities, animation, accomodation and food, etc.—must take each of its other aspects into account and each must be produced at a similar quality. Some motives, domains and dimensions seem to be more important in winter holidays for the guests, and that is why they must be produced very carefully.

Due to these aspects, the work of many tourist organisations trying to realize touristic models and operative plans based on democratic principles is becoming more difficult. Only if one knows the different needs and quality standards of the different touristic activities of the guests, will one be able to develop something like a value-chain for different touristic segments and/or for winter sport resorts. Priority should be focussed on the first step, to discover the motives, the needs, the wants of the guest, because the touristic supply must adapt to the touristic demand. This means that the permanent cooperation of market researchers and those who are responsible towards tourism is essential and necessary.

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