SCIENCE AND SKIING IV

Edited by

Erich Müller
Stefan Lindinger
Thomas Stöggl

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Introduction

The Fourth International Congress on Science and Skiing was held at St. Christoph a. A., Tyrol, Austria. It was the follow up conference of the first two International Congresses on Skiing and Science, which were also held in St. Christoph a. A., Austria, in January 1996 and in January 2000 and of the Third International Congress on Science and Skiing, which was held in Aspen, Colorado, USA, in April 2004.

The conference was organized and hosted by the Department of Sport Science at the University os Salzburg, Austria, and by the Christian Doppler Laboratory "Biomechanics in Skiing", Salzburg, Austria. It was also again part of the programmes of the steering group "Science in Skiing" of the World Commission of Sports Science.

The scientific programme offered again a broad spectrum of current research work in Alpine and Nordic skiing and in snowboarding. The highlights of the congress were eight keynote and four invited lectures. The scientific programme of the congress was completed by 2 work shops, 82 oral presentations and 76 poster presentations.

In the proceedings of this congress, the keynotes and invited lectures as well as the oral presentations are published. The manuscripts were subject to peer review and editorial judgement prior to acceptance.

We hope that these congress proceedings will again stimulate many of our colleagues throughout the world to enhance research in the field of skiing so that at the Fifth

International Congress on Science and Skiing, which will be organized in the winter 2010/11, many new research projects will be presented.

Erich Müller
Stefan Lindinger
Thomas Stöggl

We would like to express our cordial thanks to Elke Lindenhofer for the time and the energy which she invested in the editting of this book.

Part One

Keynote Papers

Vibration exposure in alpine skiing and consequences for muscle activation levels

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1 Introduction

Vibration exposure is known to affect muscle physiology and neuromuscular activity. The effect of whole body vibrations on muscle activation has been studied in the context of balance and postural control, passenger safety in vehicles, and vibration training in sports. Mester et al. (1999) have shown that strong ski vibrations are generated at the ski-snow interface that propagate through the whole body of the skier. The vibrations create resonance phenomena in soft tissue compartments. Vibrations are especially harmful for the brain, the eyes or ears and organs sensitive to vibrations (Griffin, 1975; Zou et al., 2001). They further hamper motion control (steering quality) and increase the risk of falls and injuries.

To prevent the damaging effects of vibrations different damping mechanisms are used by the human body. The main damping is believed to occur in the leg joints: passively by the cartilage and soft tissue attached to the bones or actively by stiffening the joints by muscle contraction (co-contraction). Vibration dependent muscle tuning has been proposed as damping mechanism (Nigg, 1997; Nigg and Liu, 1999). Muscle tuning has been studied for walking and running using accelerometers for measuring the vibrations (Wakeling et al., 2003; Boyer & Nigg, 2007). However, vibrations and possible muscle tuning has not been studied in skiing, an activity with high soft tissue vibrations. Thus, the purpose of this study was

1. to characterize intensity and frequency content of equipment vibrations for different skiing techniques and for different snow conditions using the wavelet analysis method,

2. to quantify simultaneously vibration intensities and muscle activation signals on four muscles of the lower extremities during alpine skiing,

3. to characterize vibration damping within the body,

4. to determine resonance frequencies of the soft tissue compartments of calf, thigh, and hamstrings and

5. to determine whether muscle activation levels change for conditions with different vibration exposure.

2 Methods

Ten experienced skiers completed 24 runs performing 5–7 short turns, 6 carving turns, and gliding in tuck position. The 24 trials of each subject were conducted between 9am, and 12.30pm. For eight of the ten subjects, snow conditions changed from hard frozen to soft snow during this time.

The skiers were equipped with 1-D acceleration sensors (Analog Devices™ (ADXL series), range: 35 to 120g) placed in axial direction on the shaft of the ski boot (parallel to the tibia), on the muscle compartments of triceps surae, quadriceps and hamstrings, and on the skin covering bones close to the ankle, knee hip and neck joints. Muscle activation was measured using bipolar surface EMG sensors on the gastrocnemius, vastus medialis, vastus lateralis, and semitendinosus. All sensor signals were recorded with a mobile EMG measurement device (Biovision™) carried in a backpack. EMG and acceleration signals were collected at a frequency of 2000 Hz.

For each run three specific movements were selected for further analysis: four consecutive short turns (2.8 ± 0.3 sec.), four consecutive carving turns (6.4 ± 0.6 sec.) and two seconds of gliding in tuck position. Short turns are highly dynamic movements in which the muscles act mainly concentric. Carving turns are executed at high speeds with little body motion. Due to centripetal forces the skiers' muscles are loaded mainly eccentrically. Gliding was executed in the tuck position, characterized by relatively small hip and knee angles. In this position the muscles are mainly isometrically contracted.

The recorded acceleration signal was resolved with a wavelet transformation into intensities calculated for a set of 22 center frequencies between 0.6 and 80 Hz. EMG data was resolved using 13 wavelets with center frequencies between 6.9 and 542 Hz. In both cases, wavelet transformations (von Tscharner, 2000) were used, because the intensity calculated for each wavelet (each frequency range) is normalized with respect to the energy content of the analyzed signal. At a given time, the total intensity was calculated by adding the intensities of all wavelets. The square root of the total intensity is proportional to the signal amplitude and was called magnitude of the signal. The mean total intensity of a signal (EMG or acceleration) during a specific movement was calculated by averaging the total intensity over time. The mean total intensity characterized the vibration intensity or muscle activation level of the selected movement and can be compared between trials.

The spectrum of a signal (EMG or acceleration) was calculated by integrating the intensity of each wavelet over time. Hence, the frequency range and frequency resolution of the spectrum derived from the wavelet analysis depended on the number wavelets and on their center frequencies.

Vibration damping within the skier’s body was characterized by dividing the vibration magnitudes determined at hip and neck by the vibration magnitudes measured at the ankle. Ankle vibrations were considered input vibrations for the body. This procedure provided only approximate values for the damping because all vibration signals were recorded with 1-D acceleration sensors.

Resonances of soft tissue compartments were determined by dividing the intensity spectrum measured at a soft tissue compartment by the intensity spectrum measured at the ankle (vibration input). The resonance frequency was determined as the frequency at which this quotient was maximal. Frequencies below 10 Hz were not considered, because the skiing movements are in this range.

To determine if muscle activation levels change if the intensity of the vibration exposure changes, Pearson’s correlation coefficient r between mean total intensity of the EMG signal and the mean total intensity of the acceleration signal was calculated for the 24 trials of each subject.

3 Results

Equipment vibrations measured at the ski boot showed peak accelerations between 20 to 30 g in the steering phase in short turns. Vibrations were small during turn initiation (~2 g) and during gliding (~5 g). In carving vibration amplitudes were in the range of 5 to 20 g. It seemed that vibrations were high when the ski skidded, and when the ground reaction forces were high. Frequency spectra were highly subject specific, but in all subjects the peak intensities were found in the range of 5 to 30 Hz. As the snow turned softer in the course of the day, frequencies above 15 to 20 Hz were increasingly damped.

All subjects showed strong vibration damping within the body. At 10 Hz, mean vibration magnitudes measured at the hip and neck decreased to 30% and 20%, respectively, compared to vibration amplitudes measured at the subject’s ankle. With increasing frequency these vibration amplitudes decreased further. Above 60 Hz the vibration amplitudes were less than 12% for the hip and less than 5% for the ankle.

Resonances frequencies of the muscle compartments were subject, muscle and movement specific. During short and during carving turns resonance frequencies occurred typically in the range of 10 to 30 Hz, in gliding the resonance frequencies were for most subjects and must muscles higher, typically in the 20 to 40 Hz range.

For eight subjects the snow turned significantly softer during the course of the day. In these cases the intensity of the vibrations the skiers were exposed to decreased significantly. The mean total intensity measured at the ankle decreased for short turns and carving by a factor between 2 and 3.5. In straight gliding the vibration intensities decreased by a factor of about 1.5. For short turns and carving, a concurrent decrease of muscle activation levels was observed. In short turns, the correlation coefficient r between the mean total intensity of the vibration exposure and the mean total intensity of the EMG signal was between 0.4 and 0.9. For the muscles the biceps femoris, gastrocnemius, vastus lateralis, and vastus medials the correlation was statistically significant for 6, 7, 6, and 5 of the subjects, respectively. In carving, statistically significant correlations were found for 7, 8, 6, and 5 subjects. Although the variability of

the vibration intensity in straight gliding was much smaller, significant correlations were found for 1, 2, 2, and 3 subjects.

4 Discussion

Vibration intensities observed at the equipment level (at the ski boot) differ for different skiing styles. This can be explained by different speeds, different skisnow interaction mechanisms (e.g. lateral skidding vs. cutting of the snow surface vs. gliding), or different equipment resonances (e.g. in case of edged skis torsional modes are excited, in case of flat skis mainly bending modes are excited). The results of this study also clearly indicate that the snow properties have substantial effect on the vibration intensity.

The vibrations present at the equipment level can be considered as the input vibrations the skier’s body is exposed to. Even at slow speeds and simple skiing styles used in this study, which are typical for recreational skiing, substantial and potentially hazardous vibration exposure levels were found. Accelerations measured during straight gliding exceeded the recommended limits of vibration exposure of international standards for work place safety (ISO Standard 2631) by a factor 10. Accelerations measured during carving or short turns exceeded these limits by a factor 20 or 30, respectively.

The high acceleration values found in this study at the ski level (input) may suggest that in addition to the motion control issues created by vibrations, the skier may also be at risk of sustaining injuries directly induced by vibrations. The most sensitive organs for vibrations injuries are the sensory systems of eyes (Griffin 1975) and ears (Zou et al., 2001). However, vibration injuries due to skiing were so far not reported and professions involving skiing, such as ski instructor or mountain guide, have not been associated with chronic injuries of the sensory organs. A possible explanation for this discrepancy is that the body posture assumed in skiing, with angled ankle, knee and hip joints, is well suited for damping the vibrations the body is exposed to. As a result, the sensitive organs in the head are well protected from the vibrations originating at the feet. This explanation is supported by the data found in this study: The vibration intensities measured at ankles, hip, and neck of the subjects indicate that vibrations are effectively damped within the body.

There are different damping mechanisms which might be used by the body including joint damping and damping through muscle tuning. In both cases, muscle action is needed to either maintain a desired joint angle, or to tune muscle stiffness. Consequently, it was expected that muscle activation levels increase if the intensity of the vibration exposure increases. During short turns and during carving the majority of the correlation coefficients calculated between EMG and acceleration data in fact showed a clear and statistically significant positive correlation. However, while all skiers showed this correlation in two or more of their muscles, most skiers also had muscles whose activity did not correlate with the vibration exposure levels. Two points should be considered when interpreting this result: (a) the primary function of muscle activity is the execution of the movement task. Although the movement task was similar during the 24 trials of each subject, fluctuations from changing choice in the route, from different snow surface conditions, and other influencing factors will create fluctuations in the muscle activation and might obscure the impact of vibration exposure levels. (b) when considering muscle tuning: only one muscle is required to change the resonance properties of the whole muscle compartment. It might be a more effective damping strategy, if the body avoids resonance by activating only specific muscles instead of all muscles in the muscle compartment. In gliding, only a small fraction of the subjects showed the expected correlation between muscle activation levels and vibration exposure levels. This can be explained by two additional points: (a) in gliding, compared to the other analyzed movements, the differences in vibration levels was much smaller, hence, fluctuations have a more severe effect on the calculated correlation. (b) In executing gliding the skiers have more “degrees of freedom” in their choice of body position and movements compared to short turns or carving turns which are well trained, automated movements, executed very similarly each time. In gliding, skiers may for example shift their weight between left leg and right leg to prevent fatigue. Such voluntary movements will cause strong fluctuations in the muscle activation levels, which render a correlation to vibration levels impossible.

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Importance of sensorimotor training for injury prevention and athletic performance

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1 Introduction

A vast number of public campaigns propagate that active life style and participation in sports has many benefits for health. Alpine skiing is popular and attractive and definitely the most important winter sport activity at all. From elite Alpine Skiing we receive fascinating impressions about the flexibility, the powerful actions as well as the highly skilled compensative reactions necessary to preserve movement control in difficult situations. Bodily fitness and highly developed motor coordination is a prerequisite to exert and/or counteract rapid forces changes and to activate and control the limbs and the body during a downhill race or slalom competition.

Participation in sports, however, can also be harmful (Bahr et al 2003). In Alpine Skiing the technical development of the skiers and the bindings reduced a larger number of injuries by approximately one half (Duncan et al 1995). However, the rate of the knee injuries, more specifically, the rate for anterior cruciate ligament (ACL) injuries is increasingly high. Pujol et al (2007) provided evidence that 10% of all injuries in snow sports are injuries to the ACL. In their comparison of the top 30 athletes in the world, they reported an injury rate for males and females of 50% for ACL injuries during 25 years of competitive skiing.

Due to the long lever arms of the thigh and the shank and due to the fixation of the skiboot on the skies, the knee joint complex has especially in Alpine Skiing to tolerate and compesate huge rotational moments. For the ACL injuries in skiing two mechanisms are discussed: (A) A combination of hyperextension and anterior pivot shift when landing on the ski tails with extended knees and (B) a coincident valgus-flexions-external rotation moment applied typically occurring when the skier straddles the gate.

In the past, knee injuries have been related to deficits in muscular strength and strength training was consequently applied to meet the requirements of the sport discipline. In recent years an increasing number of papers showed that intra- and inter-muscular coordination of the muscles encompassing the knee joint complex is of high importance. Thus, in order to minimize the injury risks, preventive training setups are designed to address coordinative adaptation. For Alpine Skiing, however, an assessment of their potential role is still not investigated under controlled conditions.

2 Mechanical and/or sensory function of the ACL?

In the present chapter the functional neuromuscular properties of the hamstring muscles and the ACL are discussed in order to “motivate” specific training programs for an improved active knee joint control.

The mechanical function of the ACL in conjunction with PCL to ensure passively knee joint stability has been intensively investigated (Woo et al 1991). Quite a few histological research papers revealed that the ACL contains also mechanoreceptors (Freeman/Wyke 1967; Haus/Halata 1990) and it has been discussed whether these receptors may have functional importance as a feedback loop to secure and control the integrity of the knee joint. It has been argued that the hamstring muscles need to provide effective tension in order to avoid excessive anterior tibia displacements (Johansson et al 1990, 1991; Solomonow et al 1987). More recent studies confirmed the existence of a reflex arc between the ACL and the hamstrings in humans (Friemert et al 2005a; Friemert et al 2005b). Functionally, an intact reflex connexion between ACL and hamstring muscle could lead to a quick muscular reaction if the ligament is stretched. This would ensure a muscular security against excessive anterior tibia displacements. The segmented hamstring reflex activity found in the experiments was attributed to a short latency response (SLR) and a medium latency response (MLR) (Friemert et al 2005b).

Based on biomechanical and neurophysiological research Melnyk et al (2007) could show, that the MLR reflex response is functionally specific: In patients with a history of ACL rupture, the excitability of the stretch evoked reflex was considerably changed. Compared to the healthy leg, the latency of the MLR was prolonged and the amplitude of the anterior tibia translation which was measured with a standardized test stimulus significantly increased. From subjects reporting “giving way” symptoms after ACL injury they presented data that this “feeling” is not simply related to the decrease in mechanical joint stability. For the MLR component of the stretch response a significant prolonged latency could be observed. Thus, “giving way” is also associated with altered stretch reflex excitability that takes place on the spinal level. In their paper they concluded, that sensorimotor function may be influenced by appropriate training stimuli. It was suggested that sensorimotor training early after ACL rupture might be promising for a rapid restoration of joint function.