C2-1 ID54

VIBRATIONS IN RECREATIONAL ALPINE SKIING: A PILOT STUDY

Matej Supej[1,2]

Faculty of Sport, University of Ljubljana, Ljubljana, Slovenia[1]
Faculty of Mathematics, Natural Sciences and Information Technologies, University of Primorska, Koper, Slovenia[2]

The aim of the study was to determine whether there is a relationship between vibrations and the form of recreational skiing and/or if vibrations are transmitted to the body. We performed measurements with an inertial suit on one subject with above-average recreational skier abilities in three typical and different forms of skiing. Using the accelerometers in the suit we were able to calculate the power spectra of acceleration on the ski boots, knee joints, pelvis and the head. The results revealed that vibrations vary in various forms of recreational skiing and are transmitted from the ski boot all the way up to the skier's head. The most pronounced vibrations were observed in shorter skidded turns, while slightly fewer vibrations were observed in shorter carved turns and the least in longer carved turns.

KEY WORDS: 3D measurements, accelerometer, carving, inertial sensor motion capture suit, skidding

INTRODUCTION: The alpine skiing technique has been profoundly marked by the advent of skis with a pronounced side cut. According to some studies, these skis cause different vibrations which depend on the characteristics of their side cut (Kugovnik, Nemec, & Supej, 2000; Kugovnik, Nemec, Supej, & Coh, 2000). The study conducted by Mester (1997) demonstrated that the spectrum of the frequencies of vibrations while skiing straight differs from the one recorded while making a turn. In the next study, Mester et al. (2000) established that vibrations can importantly affect the functioning of individual body organs. This is reflected in the response of the organs based on their own frequencies and the associated resonances. In summary, different amplitudes and frequencies of vibrations can negatively affect humans (Jordan, Norris, Smith, & Herzog, 2005).
There are currently many possible ways to measure three-dimensional movement in alpine skiing, with those systems based on motion-capture sensors recently gaining ground (Brodie, Walmsley, & Page, 2008; Krüger & Edelmann-Nusser, 2010; Supej, 2010). Basically such systems also measure acceleration which makes it possible to investigate vibrations. The aims of this pilot study were: 1) to analyse the differences in spectra of vibrations to which skiers are exposed during three typical forms of recreational alpine skiing; and 2) to describe how vibrations are transmitted through the body.

METHODS: The pilot study was conducted on a single skier, a former member of the "Demo Team Slovenia". The skier was equipped with the MVN BIOMECH inertial motion capture system (Xsens Technologies, Enschede, The Netherlands) capturing data at the frequency of 120 Hz, which is according to Shannon-Hartley sampling theorem more than twice as high than minimally required for the current study. In our study the sensors on the feet, which are typically attached to the shoe laces, were fastened to the shell of the external part of the ski boot, and the head sensor was fastened to the skier's helmet (Figure 1). Before every run, the skier underwent the MVN system calibration procedure on a specially treated and flattened platform.
The skier used 165 cm long skis with a declared side cut radius of 13.5 m, as used by many recreational skiers. The experiment included three different forms of alpine skiing technique, encompassing at least ten turns with five repetitions. Fifteen measurements were conducted in total, with more than 150 turns being measured. The three measured forms of skiing

technique included: 1) carve turning in a wide corridor; 2) carve turning in a narrow corridor; and 3) turning in a narrow corridor with velocity control achieved by skidding sideways.
The carve turning in a wide corridor was performed on medium-steep terrain, the carve turning in a narrow corridor was performed on relatively flat terrain, whereas turning in a narrow corridor with skidding was performed on steep terrain, all of which corresponds to the descriptions of the Slovenian national skiing school (Lešnik & Žvan, 2010). To facilitate the further analysis of the skiing, all runs were recorded with a Full High Definition Sony HDR-HC7 video-camera (Sony corp., Tokyo, Japan).

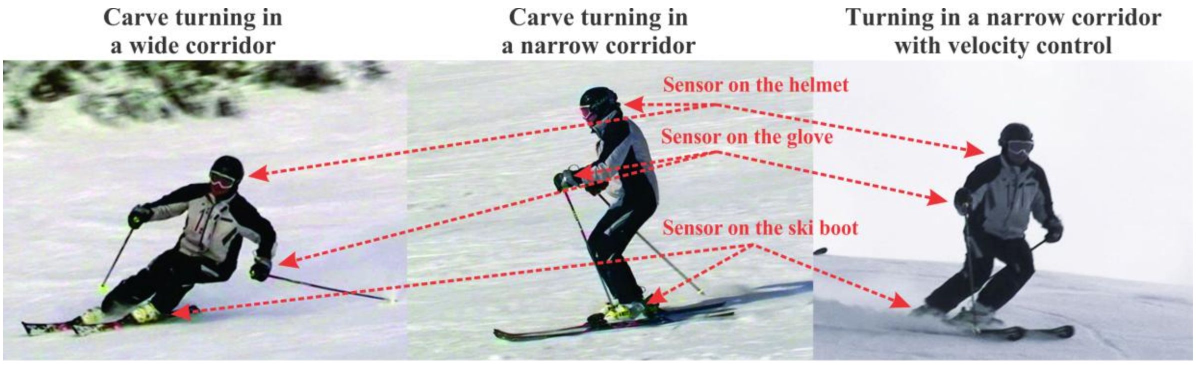

Figure 1: Three forms of the alpine skiing technique and the location of the sensors that are visible on the skier

The measurements from the MVN system were cut so that the clips started exactly before the beginning of the first turn and finished at the end of the last turn before the skier started decelerating. Such clipped data were imported into Matlab R2007a (MathWorks, Natick, MA, USA) to analyse the acceleration data for the following: both ski boots (feet), both knee joints, the pelvis and the head. The measurement accuracy equalled ±0.002 of gravitational acceleration (Supej, 2010).
The acceleration in all captured turns in every measurement was used to calculate the power spectrum in a range between 0 and 60 Hz. Then all measurements of runs using the same form of skiing were combined to calculate the average value and standard deviation of the power spectrum. As the data from the left and right ski boots and from the left and right knee joints were equivalent, they were combined together in the power spectrum for a ski boot and for a knee joint, respectively. For the sake of illustration, graphs of the spectrum of vibrations were drawn in a logarithmic scale and smoothed with a 10 Hz and 4th order Butterworth digital filter. The power spectrum of the ski boot was analysed only in the direction of the normal of the sliding ski base. By analogy to other body segments, this axis was named longitudinal as it is the longitudinal/vertical axis of a human body or body segments. Concerning other body segments, all three axes were analysed, namely besides the longitudinal also the transversal (medio-lateral) and the sagittal (forwards-backwards) axes.

RESULTS: The three different forms of skiing resulted in different power spectra in all analysed parts of the body and the ski boot; e.g. the power spectra for the ski boot are shown in Figure 2. The power spectrum of the acceleration on the ski boot shows that the skier achieved the highest intensity of the power spectrum in the range between 0 and approximately 25 Hz. The first peaks are related to the frequency of turning: in the wide corridor the skier recorded the first peak at 0.46 Hz, in the narrow corridor when skiing in a carving technique at 1.41 Hz and in the narrow corridor with velocity control (skidding) at 1.53 Hz. The power spectrum plummets after these peaks, yet there is another peak in the wide corridor at 5.5 Hz and two more peaks in both skiing techniques in the narrow corridor: the first at 6.5 Hz and the second between 20 and 21 Hz. The peak at the highest frequency of the power spectrum is substantially higher when skidding than when carving, whereas in the wide

corridor there is no such peak. The strength of the power spectrum decreases the slowest while skiing in the narrow corridor with skidding and the fastest in the wide corridor.
The power spectra of the knee joint up to the frequency of about 25 Hz are very similar to those of the ski boot. The differences between the forms of skiing resemble those seen in the power spectrum of the ski boot. However, there are substantially higher intensities of the power spectrum in the knee joint than on the ski boot. After 25 Hz the power spectra on the knee joint decrease very rapidly in all forms of skiing. In frequencies up to 6 Hz, the power spectrum in all three axes of the pelvis is similar to that in the ski boot, only the intensity is lower. After 6 Hz the power spectrum decreases very rapidly in all three observed axes. Nevertheless, a peak is observed at about 23 Hz and is only pronounced in the narrow corridor with skidding. The highest intensities are seen in the transversal direction, slightly lower in the sagittal and the lowest in the longitudinal direction.

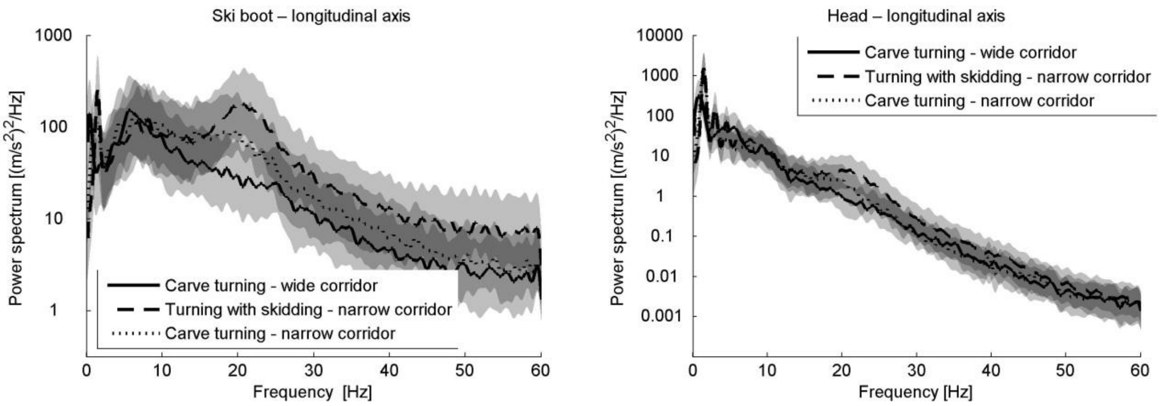

Figure 2: The power spectrum of acceleration for the ski boot (left) and for the longitudinal axis of the head (right) for the three skiing techniques. The gray colour denotes the interval of standard deviation; the darker shade of gray represents the overlapping of the standard deviation intervals between the skiing techniques. Note: The scale in one graph differs from the scale of the other to allow the greater clarity of each graph.

The lowest intensities of the power spectrum are observed on the head (Figure 3). Nevertheless, the peaks are still similar to those in other previously discussed segments. Turning in the wide corridor was characterised by a slightly higher intensity of the power spectrum in the transversal axis at about 6 Hz compared to turning in the narrow corridor. On the other hand, at a frequency of about 21 Hz peak intensity is still observed on the head in the longitudinal axis. The intensities at this peak gradually increase from the carve turning in the wide corridor, through the carve turning in the narrow corridor, to the turning in the narrow corridor with skidding. Also on the sagittal axis at around 21 Hz we can see a slightly stronger frequency response in the narrow corridor with skidding.

DISCUSSION: The pilot study's measurements of vibrations showed that vibrations in different forms of recreational alpine skiing differ and can be transmitted from the ski boot all the way to the head. The most pronounced vibrations were observed while turning in the narrow corridor with velocity control (skidding) where the intensities of the power spectrum were the highest; slightly less pronounced vibrations were seen while carve turning in the narrow corridor and the least while carve turning in the wide corridor.
In all determined segments we noticed three peaks of the power spectrum (vibrations), where the first peak (the range between 0.4 and 1.5 Hz) can be ascribed, by video analysis, to the frequency of turns, the second peak around 6 Hz to the smoothing of moguls and the skier's movement (technique), whereas higher frequencies which also include the third peak around 20 Hz are mostly ascribed to skidding and potentially smaller ridges (bumps) on the terrain. Using simple harmonious oscillations we can calculate that the peak at around 20 Hz involves

amplitudes of a size ranging from several millimetres to slightly less than 1 cm. This concurs with previous studies of vibrations and amplitudes where skis with a pronounced side cut were used (Kugovnik, Nemec, & Supej, 2000; Kugovnik, Nemec, Supej, et al., 2000). It was in this area of the last peak that the largest significant differences between the forms of skiing were observed.

The results showed that the power spectrum intensifies in the knee joint compared to that in the ski boot. This phenomenon can be described by the fact that the skier dampens the vibrations through their musculoskeletal system where the knee joint – with the relative movement of the ankle joint towards the hip joint – also moves in the sagittal and/or transversal direction. This increases the amplitudes of the movement and consequently also the acceleration which appears at the same time in all three directions.

A limitation of this pilot study is that it was conducted with just one subject. Moreover, the subject had above-average skiing abilities. It was necessary to select such a skier to ensure that the repetitions truly reflect the three different assumed forms of skiing. On the other hand, we do not know whether worse skiers would react to the vibrations in the same way. It may be expected that worse skiers would be worse at lessening the same vibrations (Boyer & Nigg, 2004; Spitzenpfeil, Schwarzer, Seifriz, & Mester, 2000). Another limitation is the fastening of the sensors to the body. Even though the sensors feature special strips and are always fastened around the body segment where the contact with the bone is nearly direct, it can be expected that some of the vibrations in the knee joints and the pelvis can be associated with vibrations in the soft tissues.

CONCLUSIONS: The study shows that vibrations most likely depend on the form of skiing, especially on whether the skier skids while turning. The results also reveal that these vibrations are transmitted all the way up to the head and it would be reasonable to consider some solutions to avoid them, by using appropriate skiing equipment, snow surface, perhaps even an appropriate skiing technique and suitable ski runs.

REFERENCES:

Boyer, K. A., & Nigg, B. M. (2004). Muscle activity in the leg is tuned in response to impact force characteristics. *J Biomech, 37*(10), 1583-1588. doi: 10.1016/j.jbiomech.2004.01.002

Brodie, M., Walmsley, A., & Page, W. (2008). Fusion motion capture: a prototype system using inertial measurement units and GPS for the biomechanical analysis of ski racing. *Sports Technology, 1*(1), 17-28.

Jordan, M. J., Norris, S. R., Smith, D. J., & Herzog, W. (2005). Vibration Training: An Overview of the Area, Training Consequences, and Future Considerations. *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.), 19*(2), 459-466.

Krüger, A., & Edelmann-Nusser, J. (2010). Application of a full body inertial measurement system in alpine skiing: A comparison with an optical video based system. *J Appl Biomech, 26*(4), 516-521.

Kugovnik, O., Nemec, B., & Supej, M. (2000). A skidding model for carving skis. *Kinesiology, 32*(2), 42-50.

Kugovnik, O., Nemec, B., Supej, M., & Coh, M. (2000). Influence of the ski side cut on vibrations in alpine skiing. / Vpliv stranskega loka smuci na vibracije pri alpskem smucanju. *Kinesiologia Slovenica, 6*(1/2), 47-50.

Lešnik, B., & Žvan, M. (2010). *A turn to move on : alpine skiing - Slovenian way : theory and methodology of alpine skiing : a university textbook and official syllabus developed for training courses for levels 1, 2 and 3 ski instructors*. Ljubljana: Faculty of Sport.

Mester, J. (1997). Movement regulation in alpine skiing *In, Mueller, E. (ed.) et al., Science and skiing, London, E & FN Spon, c1997, p. 333-348.* United Kingdom.

Mester, J., Hartmann, U., Hoffmann, U., Seifriz, F., Schwarzer, J., & Spitzenpfeil, P. (2000). Biological response to vibration load: general principles, lab and field studies in alpine skiing *In Science and skiing II, Hamburg, Verlag Dr. Kovac, c2001, p.325-344.* Germany, Federal Republic of.

Spitzenpfeil, P., Schwarzer, J., Seifriz, F., & Mester, J. (2000). Vibration: interaction of strength and motor control in alpine skiing *In Science and skiing II, Hamburg, Verlag Dr. Kovac, c2001, p.353-365.* Germany, Federal Republic of.

Supej, M. (2010). 3D measurements of alpine skiing with an inertial sensor motion capture suit and GNSS RTK system. *J Sports Sci, 28*(7), 759-769.

Acknowledgements:

We would like to extend our gratitude to the Slovenian Research Agency and the Foundation for Financing Sport Organisations for having co-financed our study. We are also thankful to Elan d.d. for the test skis and Mr. A. Sitar and Mr. M. Miklavec for their assistance during the measurements.