Body vibration and its transmission in alpine ski racing

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Abstract – The aim of the study was to quantify the vibrations occurring at the lower limbs and the trunk during alpine ski racing. Four European Cup level athletes skied each three runs on a typical giant slalom course. For each turn, power spectral density (PSD) of the measured accelerations along the segment's longitudinal axes was computed. Run-average PSD for each body segment and the PSD ratio between neighboring body segments were reported. With regard to the latter, results were consistent to previous studies analyzing the vibration transmission between different body segments when exposed to vibrating plates or shocks from the foot strike during running. Vibration transmission was nonlinear. The knee was attenuating 75% of the vibrations from 8-12Hz whereas the hip did not attenuate any vibration below 10Hz. The trunk attenuated frequencies below 10Hz but not between 10 and 25Hz. In future, the proposed method might help to better understand of the effects of body vibrations on muscle activation and balance/motion control, and might provide deeper insights of the cause and for the prevention of overuse injuries.

Keywords – vibration; alpine ski racing; inertial sensors; accelerometers

1. Introduction

Vibrations from shocks and ski-snow surface interaction are inherent in alpine ski racing. The human body is naturally dampening these vibrations while the body response depends on the posture [1]–[3]. Past studies used skin- or bone-fixed accelerometers for measuring the vibrations and investigated the response to a single stimulus of known frequency and amplitude [1]–[3] or to a given event such as for example foot strike in running [4]. [5], [6] measured vibrations during recreational skiing and reported different vibration amplitudes for different snow conditions and turn types (e.g. carving, short turns). All studies reported a nonlinear vibration transmission between the different body segments, i.e. different frequencies were attenuated differently. Additionally, the occurrence of resonant frequencies, resulting in segment peak accelerations may be 5 times larger than the stimuli's peak accelerations [1]. In recreational skiing, the effects of skiing-related whole vibrations have been discussed in different contexts, such as muscle activation, balance/motion control, and the development of overuse injuries [5]. With the aim of better understanding these aspects in a competitive setting it would, therefore, be useful to describe the vibrations and their transmission in alpine ski racing. In contrast to laboratory studies, in field experiments as required to analyze alpine ski racing, the vibration stimuli cannot be controlled externally and the vibrations are highly non-stationary.

Therefore, the goal of this study was to use inertial sensors to approximate the vibrations and their transmission between body segments that occur in alpine ski racing.

2. Material and Methods

Protocol and Materials

Four European Cup-level athletes were recruited for the study. They each skied three runs on a typical giant slalom course with constant linear gate distances of 25m and gate offsets of 10m. The slope was constantly inclined with an angle of 25°. For each run a central section of 8 turns (4 left turns and 4 right turns) was selected for the further analysis. The study has been approved by the Ethics Committee of the Department of Sport Science and Kinesiology at the University of Salzburg.

The athletes were equipped with 6 miniature inertial sensor units (Physilog® IV, GaitUp, Switzerland) placed on the sternum, sacrum, left and right thigh, and left and right shank using a custom made underwear suit (Fig. 1). The athletes wore their racing suit on top, providing additional fixation and minimizing any self-resonance of the sensors. Acceleration and angular velocity were measured at 500Hz and were low-pass filtered at 100Hz during analog to digital conversion. The accelerometers had a range of ±16g and were calibrated using the procedure from [7]. Before each run functional calibration movements consisting of upright still standing, slow squats, vertical trunk rotation and hip abduction/adduction movements were performed to align the sensor frames with the anatomical frames of each body segment [8].

Data processing

Segment orientation and a three dimensional (3D) body model were computed as described in [9], [10]. From this model the distance between left and right ankle joint center and athlete's center of mass was computed for each time sample [9]. Turn switch (i.e. change from left to right turn or vice versa) was defined to occur at the intersection of those two distances, i.e. when the distances between athlete's center of mass and the left and right ankle joints were equal. The eight central turns were extracted automatically and the power spectral density (PSD) of the accelerations along each longitudinal segment axis was computed for each turn independently using the Fast Fourier Transform of length 2048 [4]. All eight turns from one run (left and right sides) were averaged to form one run-specific PSD, denoted $psd(\omega)_r^s$ where ω is the frequency in Hz, s the segment (i.e. shank, thigh, sacrum, sternum) and r the run number (total number of runs 12). The attenuation $a(\omega)_{sd}^{sp}$ was defined as the ratio between the PSD of two neighboring segments (1) [1], [2], [4]:

$$a(\omega)_{sd}^{sp} = \frac{psd(\omega)_r^{sp}}{psd(\omega)_r^{sd}} \quad (1)$$

where sp and sd, respectively, denote the proximal and distal segments of a joint (e.g. thigh and shank for the knee). Finally, overall median and interquartile curves for both the PSD and the attenuation were computed.

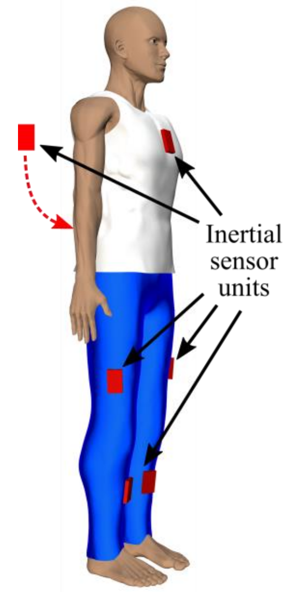

Figure 1. Placement of the inertial sensors on the athlete.

3. Results

The vibrations were largest for the shank and were smaller for each subsequent segment, being smallest for the sternum (Fig. 2). For the shank and thigh the vibrations were most powerful between 15Hz and 25Hz. For the sacrum and sternum, vibrations had the largest power below 10Hz. Vibration power in the thigh were at least 50% less than in the shank with frequencies around 10Hz particularly well attenuated (Fig. 3). Between thigh and sacrum there was no attenuation for frequencies below 10Hz whereas attenuation was largest below 10Hz between the sacrum and sternum. Over 90% of the vibrations above 15Hz were attenuated between the thigh and sacrum (Fig. 3).

4. Discussion

The proposed setup allowed the investigation of vibrations occurring in alpine ski racing. The vibrations were quantified using the PSD for the shank, thigh, sacrum, and sternum. The vibration attenuation between the body segments observed in this study, was consistent with previous literature findings. The current results confirmed the findings for recreational skiing reported by Federolf et al. [5] and Supej et al. [6]. However, compared to data presented for running [4], vibrations in alpine ski racing were up to twice as large for the tibia and were present over a larger range. This difference could be explained by the different origin of the vibrations: in running the vibration has its origin in the impact shock during the foot strike, whereas in giant slalom skiing, the vibration has its origin in the chattering of the 195 cm long skis when interacting with the snow surface while turning. Moreover, in alpine ski racing, vibration peaks were observed to be larger (reaching up to 15g), and their attenuation was found to be better than reported for running [4]. Such an improved attenuation for higher amplitude vibrations was also reported by Lafortune et al. [2] for vibration transmission of controlled impacts to the foot. Placing accelerometers on multiple body segments allowed them to investigate the vibration attenuation for the different body parts and not only for the overall system between foot and head.

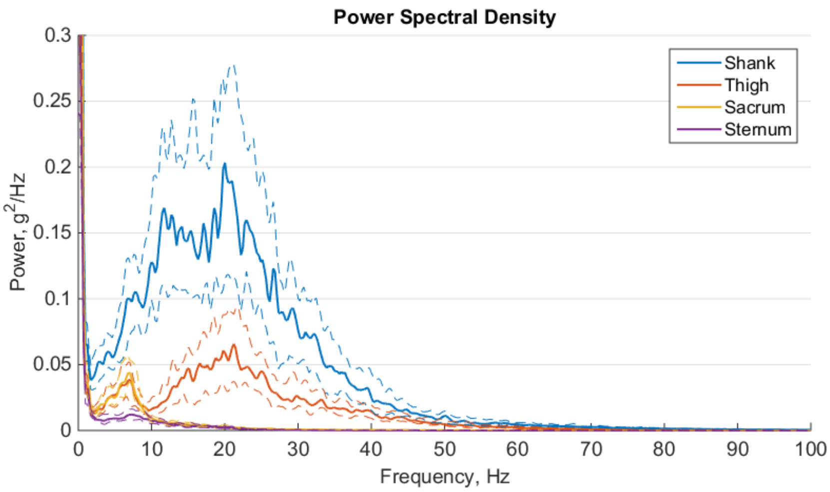

Figure 2. Power spectral density (PSD) for the different body segments. The solid line is the median PSD and the dashed lines mark the 25th and 75th percentiles.

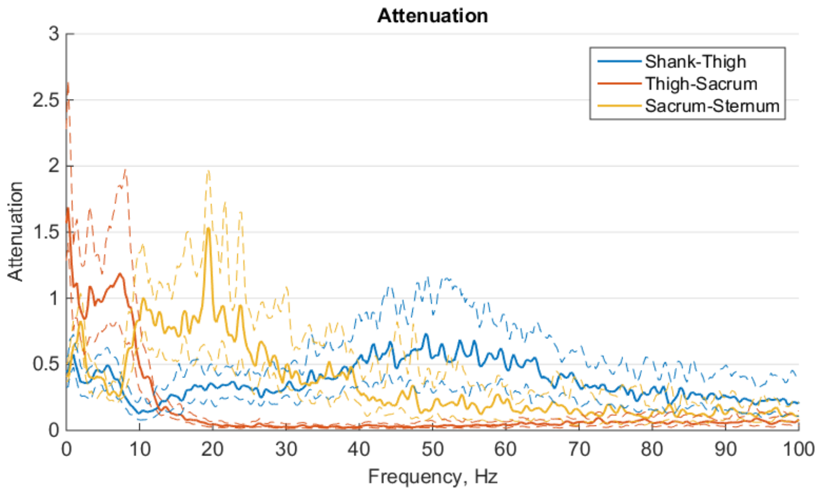

Figure 3. Attenuation between the neighboring body segments. A value above 1 indicates signal amplification whereas a value below 1 indicates signal attenuation between the two segments. The solid line is the median attenuation and the dashed lines mark the 25th and 75th percentiles.

Interestingly, in the current study, the largest overall attenuation was observed between the thigh and sacrum. It seemed that the hip joint was able to attenuate most vibrations larger than 15Hz but no vibrations below 10Hz. This is in line with previous findings that indicated the presence of a resonance in the hip for frequencies <15Hz [1], [3]. The attenuation pattern observed for the trunk (i.e. sternum versus sacrum) was partially consistent to the findings of [1], who reported a trunk amplification at 10Hz. In contrast to their results, limited attenuation was observed for frequencies of up to 25Hz which could originate in the different measurement protocol or be related to the resonant frequency of individual spines of around 25Hz [11]. The findings regarding the attenuation between the shank and thigh did not agree with the findings of Kiiski et al. [1]. In contrast to our study, [1] reported an amplification of the vibration between 10Hz and 25Hz for the knee. This disagreement could originate in the posture difference (i.e. knee flexion) between skiing and their investigated movement tasks: while in their setup the subjects' knees were almost fully extended, in our study, their knees were highly flexed. Thus, this circumstance might have made a significant effect on the mechanics of attenuation. Despite being in good agreement to past literature, the current study also has some methodological limitations: the inertial sensors were attached to the skin by means of a custom made underwear and a racing suit. Therefore, especially for the thigh, relative movements between sensors and bones might have be present (potential causes: soft tissue artefacts, muscle wobbling, relative displacement of the suits, and resonance of the sensor). Thus, peak acceleration may be overestimated by up to 20% and the between-individual variance may be increased as well [1]. This drawback was considered acceptable since a different setup such as bone pins for outdoor measurements would not be feasible.

In conclusion, the current study illustrated the overall potential to quantify the body vibrations that occur while skiing by the use of accelerations measured along the longitudinal segment axes. However, a technical validation should be performed, before the validity of the proposed method can be judged as conclusive. In future, the proposed method might help to better understand of the effects of body vibrations on muscle activation and balance/motion control, and might provide deeper insights of the cause and for the prevention of overuse injuries.

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