LOWER EXTREMITY JOINT LOADING IN CARVED SKI AND SNOWBOARD TURNS

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Skiing and snowboarding are the most popular winter sports in the Alps and are practiced by an increasing number of people. With the increasing number of practitioners, also the number of injuries increased. In skiing, most injuries are located in the lower extremities and in snowboarding about 1/3 of all injuries involve the lower extremities. To improve safety aspects in skiing and snowboarding, more knowledge is required about loading on the lower extremities joints. In the current paper, the loading at the knee and ankle joint in skiing and snowboarding are compared. Results showed that loading is more evenly distributed between the legs in snowboarding. Furthermore, the highest average and resultant peak forces at the knee were found in the outside leg in skiing. The highest forces at the ankle joint were observed at the outside leg in skiing, whereas the largest moments were found in the rear leg in snowboarding.

KEY WORDS: winter sport, joint loading, inverse dynamics

INTRODUCTION:

Skiing and snowboarding are the premier winter sports and practiced by an increasing number of people. The number of skier days increased by 16% in Austria during the last five years and by 50% in Germany in the last four years (Webmark Seilbahnen, 2006, p. 9; VDS, 2006). With the increased number of practitioners, also the number of injuries increased. In recreational skiing, about 40% – 64% of the injuries involve the lower extremities, predominately in the knee (31%) and in the ankle (7%). In snowboarding, most of the injuries involve the upper extremities (46% – 58%). Still about 1/3 of the injuries involve the lower extremities, with 15% and 12% in the knee and ankle, respectively (Klous, 2007). These values clearly show the vulnerability of the lower extremities in skiing and snowboarding.
To improve safety aspects in skiing and snowboarding, structural biomechanical research is required by determining the physical demands in skiing and snowboarding. More knowledge about joint loading in the ankle, knee, and hip can be used to improve safety and also enhance performance. In snowboarding no studies can be found about joint loading on the lower extremities. In skiing, several biomechanical studies roughly estimated joint loading in turning (Maxwell & Hull, 1989; Quinn & Mote, 1992) and on landing maneuvers after a jump (Read & Herzog, 1992; Nachbauer et al., 1996), but none in full 3D and with sufficient accuracy. From the study of Quinn & Mote (1992) can be concluded that 3D kinetic data collection is possible when a proper measuring device is available. Hence, the reason for this lack must be the complexity to collect accurate, representative 3D kinematic data. In alpine skiing and snowboarding field studies are essential for high quality analyses and conclusions. Full 3D movement reconstruction (translation and rotation) requires at least three markers in sight of at least two cameras for each segment during the entire movement. It is difficult to fulfill this demand. The main problem is the large range of motion in alpine skiing and snowboarding. Secondly, the angle between the two optical axes of the cameras should range between 60° and 120° in order to calculate accurate 3D marker positions. Thirdly, to have the same marker in sight of two cameras, the optical axes of the cameras must not be too large.
The present study is part of a larger project in which 3D joint loading in carved and skidded ski and snowboard turns were examined using inverse dynamics. The purpose of the present study was to compare joint loading on the lower extremities of a carved ski and snowboard turn. Based on the accident statistics, it is supposed that the loading in the knee joint is larger in skiing, whereas the loading in the ankle joint is larger in snowboarding.

METHODS:

Four subjects, two skiers and two regular snowboarders, participated in the experiment. In skiing only a left turn was performed assuming that joint loading in left and right turns were similar. In snowboarding, both a front side and a back side turn were performed. A turn was defined as the phase from one edge change to the subsequent one (Schwameder et al. 2001). Kinetic data were collected with mobile force plates (KISTLER) (200 Hz). The device was placed between riser and binding in skiing and between board and binding in snowboarding. Two force plates were mounted under each binding, one at the front and one at the rear part. Extensive validation of the mobile force plates showed a relative accuracy of ± 3% for measured force data and ± 8% for calculated torque data (Stricker et al., 2005). Kinematic data of both legs, pelvis and trunk were collected with five synchronized panning, tilting, and zooming cameras (50 Hz). Markers were manually digitized and 3D marker positions were calculated with Simi Motion. Several tests validated the methods used to collect and analyze 3D kinematic data (Klous, 2007). Systematic error margins are in the range of 1-2 cm on a measurement space of 20 m. Further analyses of kinetic and kinematic data, as well as the inverse dynamics were carried out with self developed software in Matlab. To calculate segment inertial parameters, an extended version of the human body model of Yeadon (1990) was developed. One representative carved ski turn and snowboard front side turn are presented comparatively.

RESULTS AND DISCUSSION:

Figure 1 shows the resultant forces (top) and moments (middle) as well as the knee joint angle (bottom) of the inside and outside leg in skiing. Figure 2 shows these data for the front and rear leg in snowboarding.

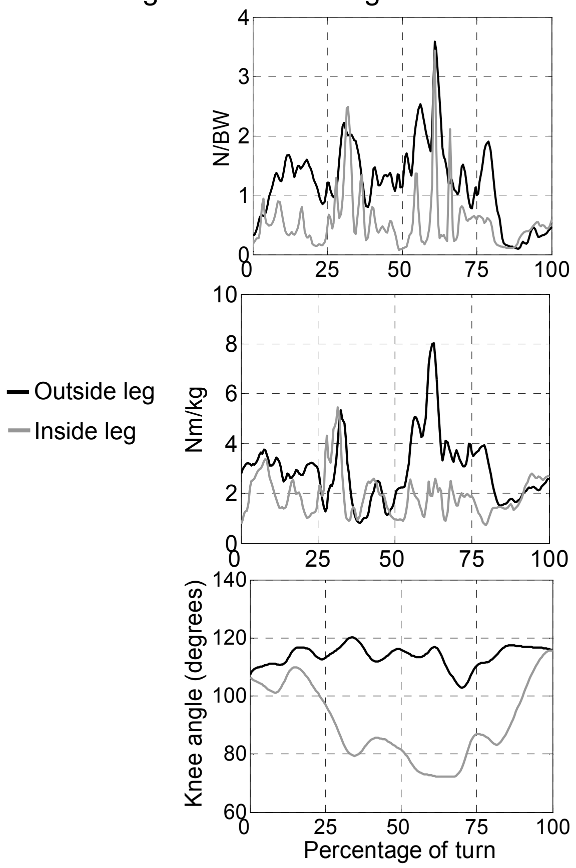

Fig. 1: Resultant forces (top), resultant moments (middle) and knee angle (bottom) of the outside and inside leg in skiing

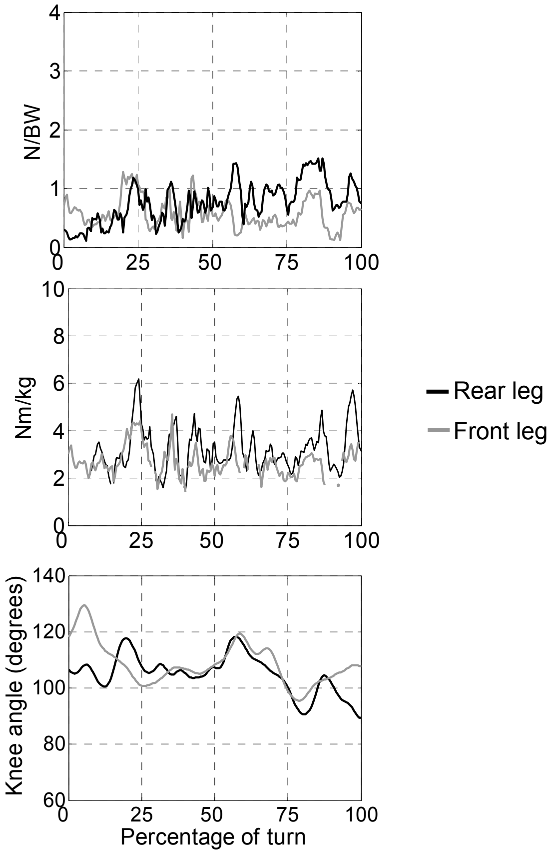

Fig 2: Resultant forces (top), resultant moments (middle) and knee angle (bottom) of the front and rear leg in snowboarding

In alpine skiing, knee joint forces at the outside leg increase from 0.5 times body weight at edge changing up to more than 3 times body weight at about 60% of the turn. Then forces decrease again to 0.3 times body weight at edge changing of the subsequent turn. The forces at the inside leg are rather constant and clearly smaller, except for some outliers. In snowboarding the loading at the knee of the front and rear leg are similar and about 0.5 times body weight during the entire turn. In general, the resultant forces and moments working at the front and rear leg in snowboarding are more equally distributed than the resultant forces and moments working at the inside and outside leg in skiing. Also the variation in knee angle between the inside and outside leg is higher in skiing. The smaller variation in knee angle for the front and rear leg in snowboarding can be explained by the fact that both legs are fixed to one board. Table 1 gives an overview of the average resultant forces and moments at both legs in skiing and snowboarding, respectively. Since not only the size of forces and moments are relevant, but also the direction, average values are also given for each force (F_x, F_y, F_z) and moment (M_x, M_y, M_z) component. The z-direction is defined in the length axis of the segment, the x-direction in medial – lateral direction and the y-direction is defined in anterior-posterior direction regarding the segment.

Table 1: Average forces (SD) and average moments (SD) at the knee in each direction as well as the average resultant forces and moments at the knee for the inside and outside leg in skiing and the front and rear leg in a front side snowboard (SB) turn

	F_x (N/BW)	F_y (N/BW)	F_z (N/BW)	F_{tot} (N/BW)	M_x (Nm/kg)	M_y (Nm/kg)	M_z (Nm/kg)	M_{tot} (Nm/kg)
Ski – outside	0.46 (0.38)	0.72 (0.45)	0.78 (0.45)	1.21 (0.65)	0.14 (1.76)	-1.56 (1.23)	1.47 (1.08)	2.94 (1.31)
Ski – inside	-0.16 (0.26)	0.47 (0.43)	0.16 (0.11)	0.55 (0.48)	1.57 (0.96)	0.00 (0.66)	0.33 (0.73)	1.93 (0.85)
SB – front	-0.31 (0.15)	0.32 (0.36)	0.15 (0.16)	0.58 (0.25)	1.74 (0.96)	1.75 (0.43)	-0.24 (0.64)	2.49 (0.85)
SB – rear	-0.14 (0.25)	0.64 (0.38)	0.20 (0.14)	0.76 (0.35)	2.03 (1.21)	1.06 (0.69)	1.84 (0.81)	3.06 (1.04)

Average forces and moments in all directions are more equally distributed between front and rear leg in snowboarding than between inside and outside leg in skiing, except for the internal/external rotation moment. Furthermore, average forces at the inside leg in skiing are the lowest, except for F_y, whereas the average forces at the outside leg in skiing are the largest. Also the highest resultant peak forces (~3.5 times bodyweight) and resultant peak moments (~8 Nm/kg) are found at the outside leg in skiing. The abduction/adduction moment and the internal/external rotation moment show average values of 1.5 times body weight. These high values at the outside leg in skiing might be a reason for the higher number of knee injuries in skiing compared to snowboarding.
Table 2 shows the average ankle forces (SD) and ankle moments (SD) in each direction and the average resultant forces and moments at the ankle for the inside and outside leg in skiing and the front and rear leg in snowboarding.

Table 2: Average forces (SD), average moments (SD) in each direction, and average resultant forces and moments at the ankle joint for the inside and outside leg in skiing and the front and rear leg in a front side snowboard (SB) turn

	F_x (N/BW)	F_y (N/BW)	F_z (N/BW)	F_{tot} (N/BW)	M_x (Nm/kg)	M_y (Nm/kg)	M_z (Nm/kg)	M_{tot} (Nm/kg)
Ski – outside	0.07 (0.29)	-0.53 (0.30)	1.00 (0.64)	1.19 (0.68)	0.95 (1.50)	-1.26 (1.75)	-0.70 (0.97)	2.41 (1.85)
Ski – inside	-0.06 (0.14)	-0.13 (0.12)	0.49 (0.48)	0.53 (0.50)	1.69 (1.01)	0.19 (0.62)	0.02 (0.40)	1.87 (0.98)
SB – front	-0.37 (0.21)	-0.24 (0.19)	0.25 (0.28)	0.58 (0.28)	1.47 (1.12)	-0.47 (0.61)	1.46 (0.64)	2.08 (1.26)
SB – rear	-0.31 (0.25)	-0.32 (0.24)	0.60 (0.33)	0.81 (0.37)	2.99 (0.86)	-1.70 (1.07)	1.68 (0.71)	3.73 (1.35)

A similar trend is observed for the ankle joint loading as for the knee joint loading. The loads are more evenly distributed between front and rear leg in snowboarding than between inside and outside leg in skiing. However, even though the highest forces are still produced in the outside leg in skiing, the largest ankle joint moments occur in the rear leg in snowboarding. Also at the front leg, flexion/extension moments and internal/external rotation moments are similar or higher than in skiing. These higher moments can be explained by the larger range of ankle joint motion in snowboard soft boots compared to those in hard-shell ski boots, which might explain the higher amount of ankle joint injuries in snowboarding than in skiing. Comparing skiing and snowboarding with other kinds of movements, peak flexion/extension moments at the knee in skiing and snowboarding are comparable with peak values at the knee during drop landings from 0.72 m and 1.28 m (McNitt-Gray, 1993). In skiing these moments are 4.61 Nm/kg and 5.66 Nm/kg for the outside leg and inside leg, respectively. In snowboarding, peak moments of 5.57 Nm/kg for the front leg and 6.29 Nm/kg for the rear leg are found. The peak flexion/extension moments in the ankle joint in skiing and snowboarding are comparable with the peak flexion/extension moments in jumping from 0.32 m (~4.5 Nm/kg). Note that jumping from these heights is mostly not a repeated movement, whereas in skiing these peak values probably occur during most of the turns. In running, peak flexion/extension moments of 2 Nm/kg and abduction/adduction peak values of 0.8 Nm/kg during push off occur (Besier et al., 2001). In skiing and snowboarding peak abduction/adduction moments of at least 2 Nm/kg were found, hence knee joint peak loading in running is clearly smaller compared to skiing and snowboarding. Schwameder (2004) reported average 2D joint loading at the lower extremities during the stance phase in (uphill/downhill) walking. Average flexion/extension knee joint moments at the outside leg in skiing are comparable to flat walking, whereas the knee joint moment at the inside leg in skiing and the front and rear leg in snowboarding are clearly higher than the average knee joint moments of 1.14 Nm/kg when walking downhill at 24°. The highest average flexion/extension moment at the ankle of 1.19 Nm/kg was found when walking uphill with 24°. Except for the outside leg in skiing, average flexion/extension moments at the ankle in skiing and snowboarding are clearly higher.

CONCLUSION:

Ankle joint loading and knee joint loading are more evenly distributed between the front and rear leg in snowboarding compared to the inside and outside leg in skiing. Furthermore, since the soft snowboard boot allows movement in the ankle, large moments can occur in the ankle joint and might explain the higher number of ankle injuries in snowboarding than in skiing. In skiing the hard shell boot does hardly allow any movement in the ankle. Large moments will therefore occur in the knee joint and might explain the higher number of knee injuries in skiing. Comparing lower extremity joint loading in skiing and snowboarding with other kinds of movements, it is supposed that the average joint loading not directly cause troubles in ankle and knee joint, but the repeated peak forces and moments might cause discomfort in the lower extremity joints when skiing or snowboarding for several hours.

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