EXPERIMENTAL SETUP TO COLLECT INPUT DATA FOR CALCULATING LOADING ON THE LOWER EXTREMITIES IN SKIING AND SNOWBOARDING

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Little is known about the loading on the lower extremities in skiing and snowboarding. The reason for this is the difficulty to collect representative 3D kinetic and kinematic data which serves as input to calculate the loading parameters. Field studies in alpine skiing and snowboarding are essential to collect representative data. Full 3D movement reconstruction requires at least three markers in sight of at least two cameras for each segment during the complete movement. It is difficult to fulfill this demand, due to several reasons. The purpose of this study is to describe the experimental setup to collect representative 3D kinetic and kinematic data. A new kinematical method that allows full 3D movement reconstruction with a reduced marker set is introduced. Furthermore, the measuring device for kinetic data is validated. Results show that the proposed experimental setup provides appropriate kinetic and kinematic data in skiing and snowboarding.

KEY WORDS: experimental setup, 3D movement analysis, dynamics, kinematics.

INTRODUCTION: Alpine skiing and snowboarding are the most popular winter sports in the Alps and are practiced by an increasing number of people. Snowboarding has developed strongly since the middle eighties. Especially among youth, this sport became very popular. The growing popularity in snowboarding caused a stagnation or even reduction in skiing days at the beginning of the nineties. Since the ski industry developed the carving ski at the end of the nineties, the popularity for skiing increased again.

With the increased number of practitioners also the number of injuries increased. In skiing most of the injuries occur in the lower extremities, especially in the knee with a percentage of 20-25% (McConkey, 1986) and 20-32% (Finch & Kelsall, 1998). In snowboarding, most of the injuries occur in the wrist with 19-28% (Müller et al., 2000) and in the knee with 15-21% (Müller et al., 2000). In order to reduce the amount of injuries it is necessary to know more about the mechanical loading on the body, especially the lower extremities, during skiing and snowboarding. In snowboarding no studies can be found about mechanical loading on the lower extremities. In skiing, a couple of studies have been carried out (Bogert et al., 1999; Müller 1994; Quinn & Mote, 1992; Read & Herzog, 1992). Only in the study of Quinn & Mote (1992) loading on the lower extremities was calculated. Two 6 DOF dynamometer were used to measure the 6 load components at the boot-dynamometer interface. Instead of a kinematic analysis joint angles were measured with goniometers.

In conclusion, little is known about the loading on the lower extremities in skiing and snowboarding. The reason for this is the difficulty to collect representative 3D kinetic and kinematic data which serves as input to calculate the loading parameters. 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 complete movement. It is difficult to fulfill this demand, due to several reasons. 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 use the algorithm for calculating the 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.

Thus, the purpose of this study was to describe the experimental setup to collect representative 3D kinetic and kinematic data, so loading parameters can be calculated. In the first part (project A) the measuring device for kinetic data is validated. In the second part (project B), the kinematical experimental setup is described and a new kinematical method that allows full 3D movement reconstruction with a reduced marker set (less then three markers per segment) is introduced. With both kinetic and kinematic data, loading on the lower extremities can be determined, by using inverse dynamic calculations.

METHODS: Project A - Kinetics: Data acquisition and data analysis: To collect 3D dynamic data a mobile force plate from KISTLER was used (fig. 1).

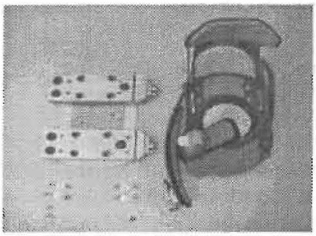

Figure 1: mobile force plate.

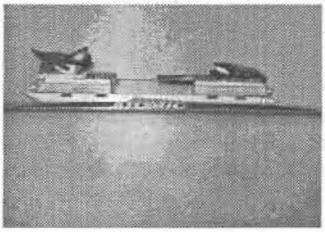

Figure 2: mobile force plate, placed on a ski.

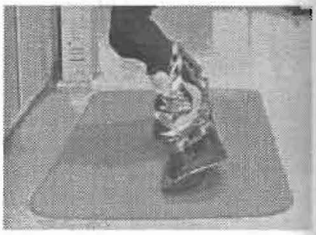

Figure 3: mobile force plate placed on a snowboard.

Each force plate has a dimension of 229.5x64x36 mm with a mass of 0.9 kg. This device is placed between the binding plate of the ski and the binding for skiing and between the board and the binding in snowboarding (fig. 2 and 3). So, two force plates per binding, one at the front and one at the back. Additionally, the subject carries a backpack with 4 charging amplifiers (0.3 kg each) and 2 IPAQS for data storage. Each force plate is connected with the corresponding amplifier by a cable with a mass of 0.4 kg. All together the backpack weighs about 2.5 kg (figure 4). Several experiments have already been carried out with the mobile force plate, in both skiing and snowboarding.

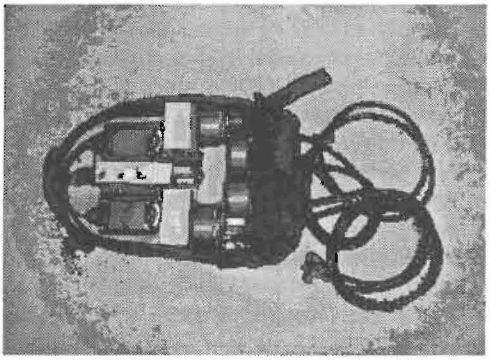

Figure 4: backpack with 2 IPAQS and 4 charging amplifiers.

Figure 5: suit developed to collect kinematical data.

Project B - Kinematics: Data acquisition: Kinematic data was collected in a laboratory experiment with four Panasonic F15 cameras (50 Hz). The subject was wearing ski boots and was standing on a pair of skis. Markers were placed at the following segments: right and left shoe, right and left calf, right and left thigh and the trunk. The subject performed a similar movement as done in the snow when making a left turn and a right turn. For the experiment a special suit was developed to increase the localization and visibility of the markers (figure 5).
Data analysis: In the data analysis, a new method for 3D kinematic analysis in skiing and snowboarding was used. The basis of this analysis is the definition of a plane through the hip, a marker on the thigh and a marker on the calf. The position of the hip is calculated according to Klous & Van Soest (2002) using the 3D-coordinates of at least 3 markers of the trunk (to reconstruct its 3D position and orientation) and one marker on the thigh. This step made the hip a spherical joint. The plane through the hip and the two markers mentioned above, defines the orientation of the knee and effectively turns it into a hinge joint. I.e. the rotational axis of the knee is the axis perpendicular to this plane. The full 3D movement reconstruction of a segment

requires the unambiguous definition of a local coordinate system (3 axes and an origin) for each segment at each instant of time. One of the axes for the local coordinate system (LCS) of the thigh is the rotational axis of the knee (y-axis). The other axis is the vector from the marker on the thigh to the hip (z-axis). The third axis is the vector perpendicular to the other two axes (x-axis). The marker on the thigh can be used as origin of this LCS to complete the definition. Since the position and orientation of the thigh is now fully reconstructed, the same technique can be used to determine the position of the knee. The LCS for the calf uses the rotational axis of the knee as y-axis for its LCS as well. The z-axis is defined by the vector from the marker on the calf to the knee. The x-axis is the vector perpendicular to the other two axes. The marker on the calf is used as origin for this LCS. All segments now have a full 3D reconstruction of their motion.
The accuracy of this new method was evaluated by a comparison to a conventional 3D kinematic analysis for a chain of segments, described by Klous & Van Soest (2002). Therefore, the global positions and velocities of the hip and knee, calculated by the two methods, were compared.

RESULTS AND DISCUSSION: Project A - Kinetics: In figure 6 a typical example is shown of kinetic data during snowboarding

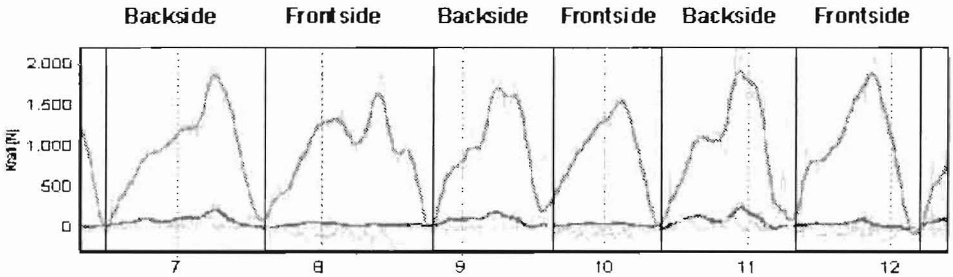

Figure 6: kinetic data during snowboarding. Fz = ——, Fy = ——, Fx =

As can be seen, kinetic data seems to be plausible. The force in vertical direction is clearly higher then the forces in the two other directions and increases during both the frontside and the backside turn. Furthermore, subjects told us that the force plates do not influence the ski and snowboarding technique substantially, even though they are standing about 36 mm higher as normally. The kinetic results are also compared with a study of Knünz et al. (2001) in which also forces at the boot sole during snowboarding are measured. In the study of Knünz et al. (2001) only one force plate is placed under each binding in the length axis of the foot. The results show quite similar characteristics and also the absolute values are quite similar.

Project B - Kinematics: In figure 7 the velocity of the hip is shown for a conventional 3D kinematic analysis and the new kinematic method, introduced above.

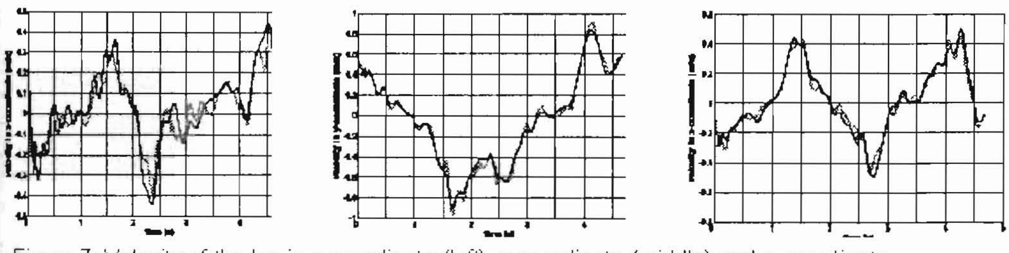
Figure 7: Velocity of the hip in x-coordinate (left), y-coordinate (middle) and z-coordinate (right) in m/s. The thick (black) represents the results of the introduced method and the thin (blue) line the conventional 3D kinematic analysis.

As can be seen in figure 7, only small differences were found between the new kinematical method and the conventional kinematical method. The difference found between the two methods seems to be acceptable when inaccuracies during the experiment, like skin movement artifacts are taken into account. According to Cappozzo et al. (1996) the error caused by skin movement artifacts ranges from a few millimeters up to 40 mm. Also inaccuracies occur when marker positions are manually digitalized, for example when a marker is only partly seen by the camera it is not possible to digitalize the middle of the marker. Depending on the marker size, errors will occur in our case errors up to 2 cm. Therefore, it can be concluded that an acceptable description of the position of the hip is found when the introduced method is used. Similar results have been found for the knee joint coordinates.

CONCLUSION: It can be concluded that the proposed experimental setup provides appropriate kinetic and kinematic data in skiing and snowboarding. Most likely, the input data are accurate enough to calculate valid loading parameters. This has to be shown by a field study design using the methods described above.

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