THE EFFECT OF BINDING POSITION ON KINETIC VARIABLES IN ALPINE SKIING

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INTRODUCTION

Turning in Alpine skiing is a highly dynamic locomotion primarily determined by the skills and the equipment of the skier (Yoneyama et al., 2000, Raschner et al., 2000, Nemec et al., 2000, Niessen et al. 1997) as well as by the snow and slope conditions. The turning characteristics of the skis are affected by the material properties, the ski geometry, the stiffness of the binding-riser system (Yoneyama et al. 2000, Nemec et al., 2000, Niessen et al., 1997) and by the position of the binding on the skis. The latter is the only short-term adjustable factor with the ability to change the turning characteristics of the skis. Some ski binding manufacturers use this fact by providing binding systems that are adjustable in anterior-posterior direction.

The kinetics of the ski-skier system has been investigated in the past using different methodological approaches (Quinn & Mote, 1992, Maxwell & Hull, 1989, Müller, 1994, Raschner et al. 1997, Niessen et al., 2000). The purposes of studying forces and moments acting on the ski are manifold. Investigations with the purpose of studying the effect of the binding position on the ski-skier kinetics, however, have not yet been published. Thus, the purpose of this study is to investigate how the forces and moments acting on the ski are affected by the binding position on the skis. It is hypothesized that (1) the change of the binding position affects the kinetics of the ski-skier system, (2) the effects are subjects-specific and (3) leg-specific.

METHODS

Data collection

The kinetic variables test was performed with four skiers of different abilities (1 former word cup racer [S1], 2 former Canadian junior racers [S2, S3] and 1 good recreational skier [S4]). Subjects skied through a symmetric giant slalom course of 13 gates on a homogeniously graded run of 25° with submaximal speed. The skis used in this study were Atomic 9.26 skis, 198cm long. Each ski was equipped with an aluminum plate (25mm thick), instrumented with two strain gauge cylinders (Fig. 1).

The stain gauges measured three force and three moment components for each ski (i.e. 12 channels) at 300 Hz. Atomic race 614 bindings were mounted onto the plates such that the midpoint of the boot sole length was aligned with the mark on the ski (provided be the manufacturer), when the binding was in neutral position. The bindings could be easily moved in two anterior positions (A = +14 mm; B = +7 mm), a neutral (C) and two posterior positions (D = -7 mm; E = -14 mm). Although the instrumented skis changed the turning characteristics of the skis considerably, each subject noticed differences in binding positions.

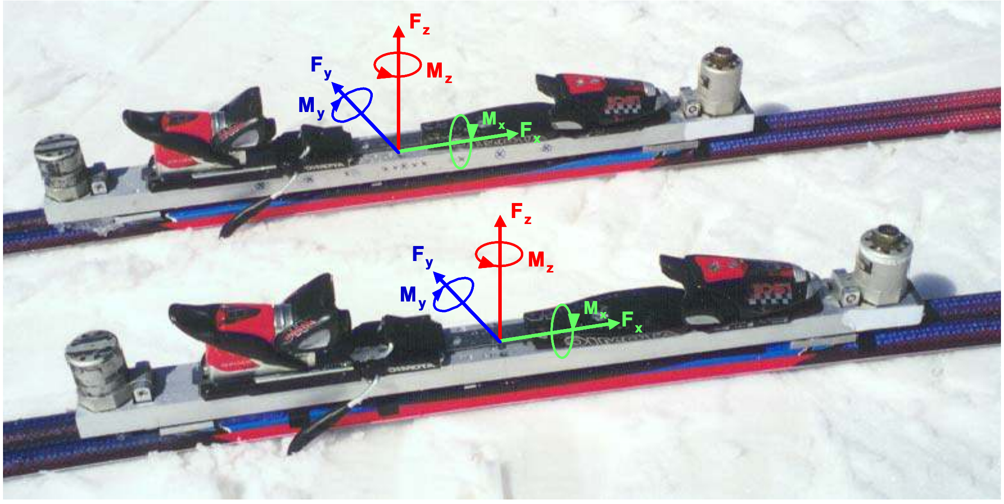

Fig. 1: Instrumented skis and local coordinate systems

A mobile data logger, attached to the strain gauge cylinders and carried around the subject's waist, collected 30 seconds of data, starting when the subject began the course. Data were collected for two runs in each binding position and were transferred to a computer after each trial. Positions were chosen randomly and duct tape was placed over the toe piece of each binding, keeping subjects visually unaware of the binding position.

Data analysis

The data were decomposed and filtered using wavelet analysis (von Tscharner & Schwameder, 2000). From each data set 10 turns (number 2-11) were separated, triggered by the moment about the longitudinal axis of the skis (M_x, fig. 2). Therefore each turn is defined as the phase from one edge switch (M_x = 0) to the next. Joining the data sets of the two trials in each position yielded 10 left and 10 right turns each. The data were time normalized and averaged for each channel over the turns. The application point a_x of the force in x-direction (longitudinal axis of the ski) was calculated using force and moment data.

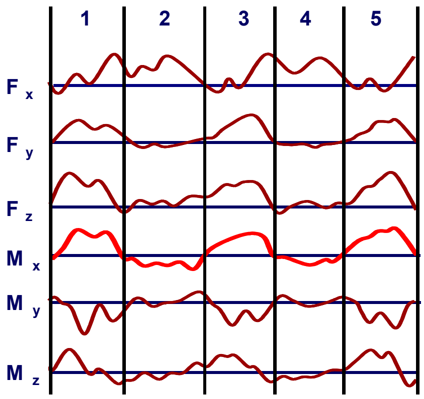

Fig. 2: Separation of the turns by the lateral moment (M_x)

RESULTS

Fig. 3 displays the mean maximal values, with standard deviations, for the three force and three moment components measured during 20 turns in each binding position for subject 1. The anterior-posterior moment and the torsion moment both display a continuous trend of decreasing value with a more posterior binding position for this subject. The other components show no real trend.

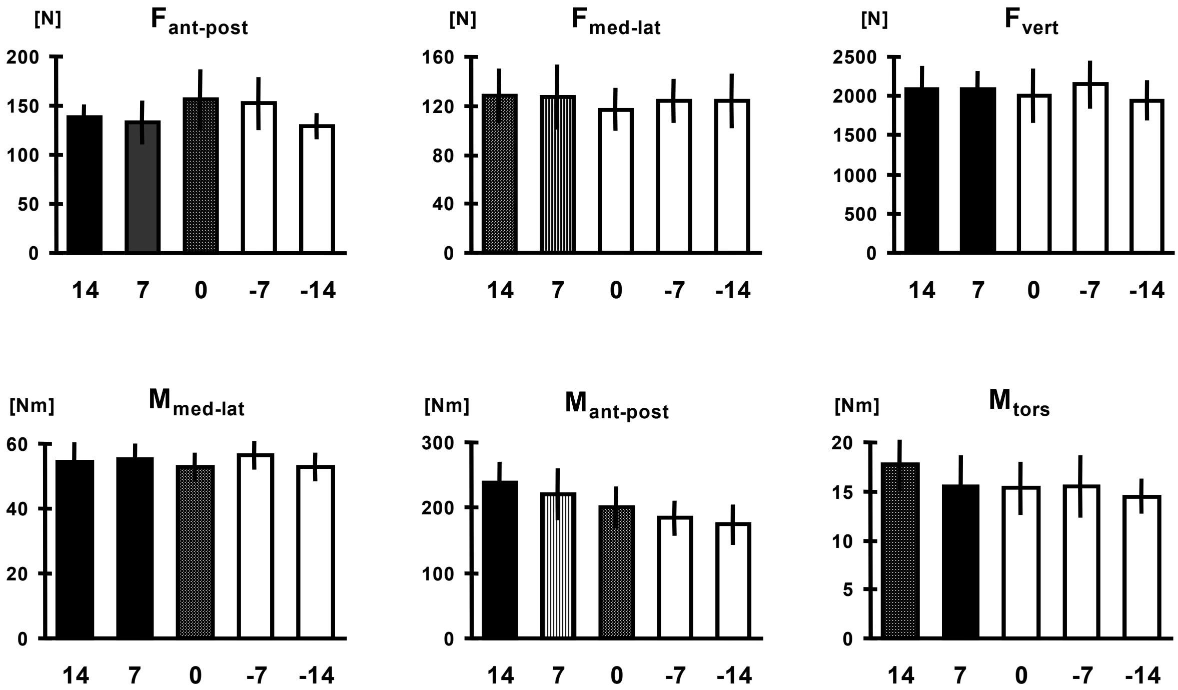

Fig. 3: Maximal values of the three force and moment components in each binding position for subject 1 (means and standard deviations of 20 turns each)

The mean maximal values, with standard deviations, of the anterior-posterior moments for each of the 4 subjects in each different binding position are displayed in fig. 4. While the results are subject specific, a trend of decreased value with more posterior binding position seen clearly for subject 1, 2 and 3, the most experienced skiers. No trend is seen in the results of subject 4.

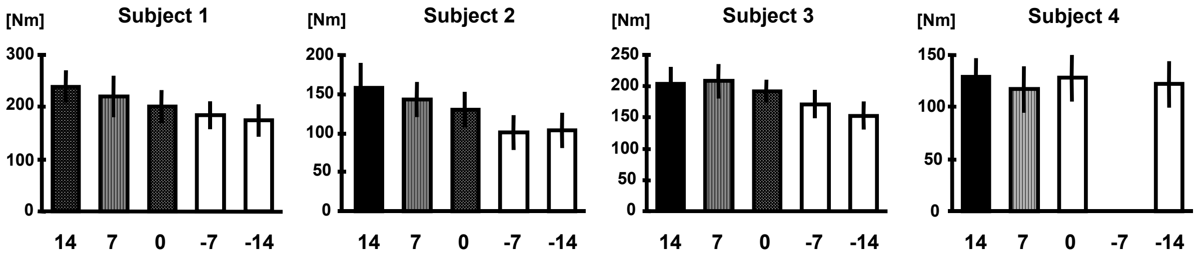

Fig. 4: Maximal values for the anterior-posterior moment in each binding position for subjects 1 - 4 (means and standard deviations of 20 turns each)

The means and standard deviations of the maximal values of the torsion moments for the 4 subjects in the different binding positions are shown in fig. 5. A consistent decrease with more posterior binding position is seen for subject 1. Subjects 2 and 3 showed a similar trend however it was less pronounced. There was no trend in the results of subject 4. These results indicate that this trend develops with increasing skiing experience.

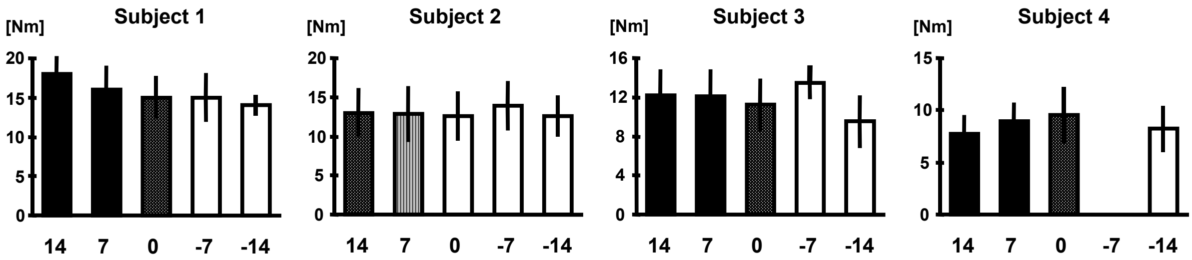

Fig. 5: Maximal values for the torsion moment in each binding position for subjects 1 - 4 (means and standard deviations of 20 turns each)

The time course of the anterior-posterior moments for each of the 4 subjects is seen in fig. 6. The results are again subject specific. For subject 1 a clear and consistent decrease in more posterior positions and higher values for more anterior positions is seen. This trend continues quite consistently thoughout the entire turn. The trend described is less consistent but still present for subject 2. The results are increasingly inconsistent from most to least experienced skier and subject 4 displays no real pattern across binding positions throughout the turn.

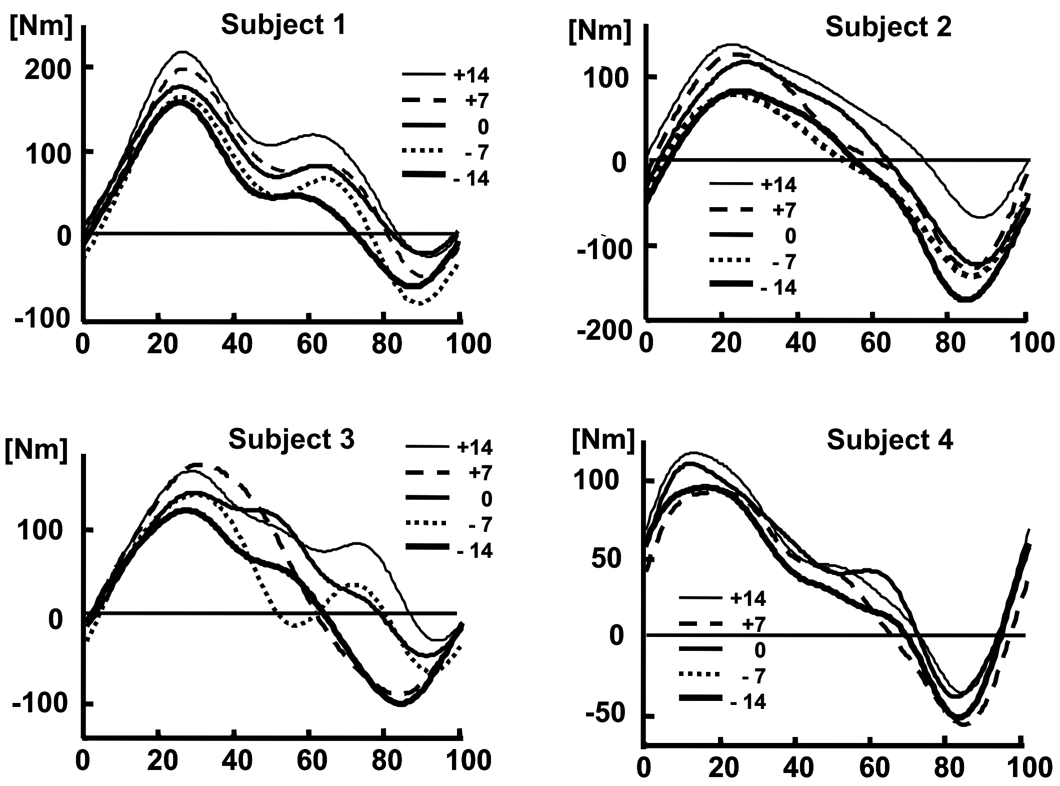

Fig. 6: Time course of the anterior-posterior moments in eachbinding position for subjects 1 – 4 (means of 20 turns each)

Figs. 7 and 8 are comparisons of the patterns created by the time course of the anterior-posterior moments (fig. 7) and the torsion moments (fig. 8) produced while turning. The graphs compare the time history of the the most anterior position to neutral (upper row) and the most posterior postion to neutral (lower row). A straight line would represent a perfect correlation and would indicate that the patterns produced in the two situations being compared did not change. Inconsistencies in the line would indicate that the time histories produced were altered in response to the change in conditions.

Fig. 7 displays a comparision of the time course of the anterior-posterior moments for the 4 subjects. The results are again subject specific. Subject 1 and 2 display a fairly linear correlation for both the most anterior and posterior positions to neutral. So this demonstrates that the moment pattern has been hardly affected by the change in binding position. The time course comparison for subject 3 is less linear with a more pronounced phase shift of the pattern. Subject 4, the least experienced skier, shows quite a few irregularities indicating pattern change in response to changes in binding position.

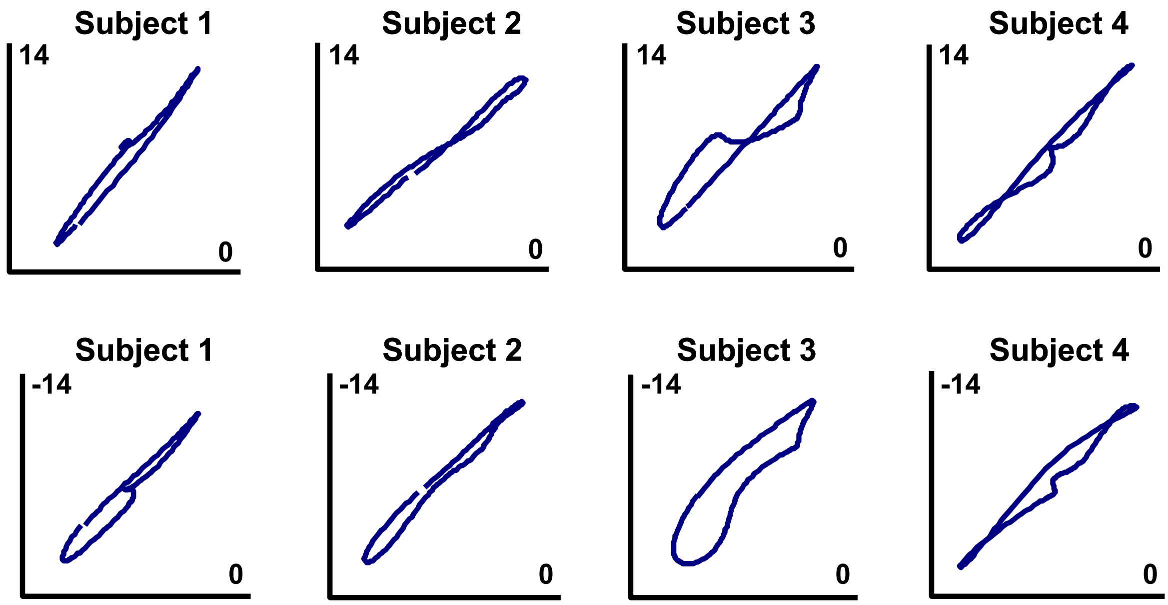

Fig. 7: Pattern correlation for the time course of the anterior-posterior moment for each subject. Comparison between the most anterior to neutral position (upper row) and the most posterior position to neutral (lower row).

Fig. 8 shows the correlation between the torsion moments in the most anterior position and neutral and the correlation between the most posterior position and neutral thoughout the turn for each of the 4 subjects. For position A (+14 mm) versus C (0 mm), the most experienced skiers, subjects 1, 2 and 3, show a high correlation throughout the turn, except at the very end of the time course representing the initiation phase of the next turn. For subject 4 a more pronounced pattern change has been detected. For the most posterior position subject 1 and 2 show high correlations. Irregularities are seen increasingly from subject 1 to 4.

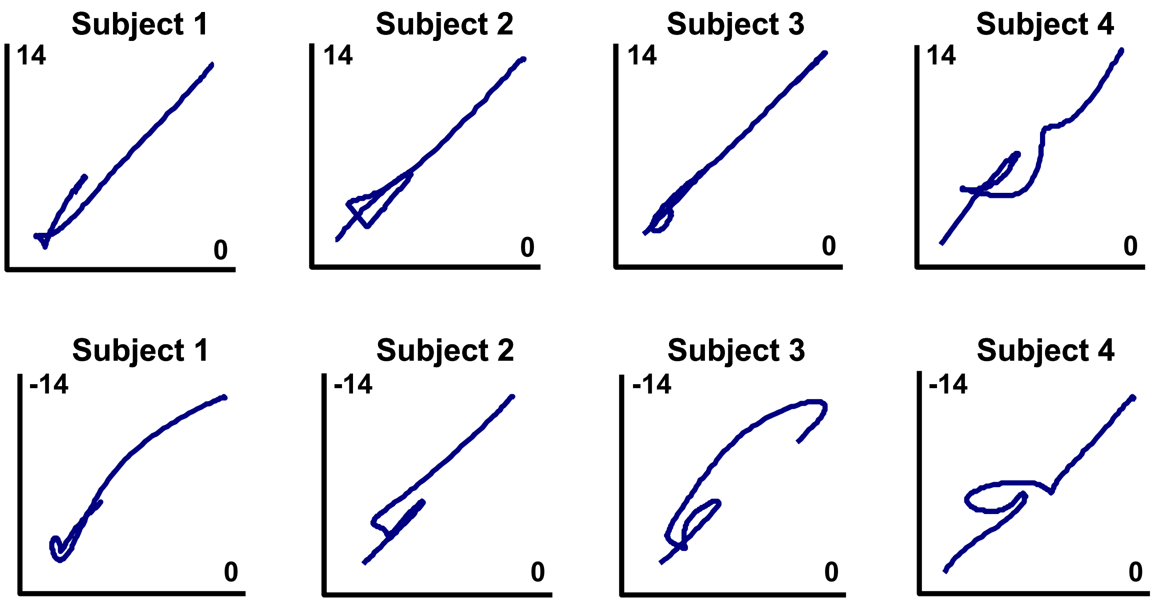

Fig. 8: Pattern correlation for the time course of the torsion moment for each subject. Comparison between the most anterior to neutral position (upper row) and the most posterior position to neutral (lower row).

The time course of the application point of the anterior-posterior moment for subjects 1 and 3 is displayed in fig. 9. For subject 1, a consistent shift to a more anterior point of application for each increasingly anterior binding position has been observed. This graph is analogous to fig. 6 and therefore comparable results can be seen. It is interesting to note, however, that a change in binding positon of 28 mm results in a change in the point of application of the moment of approximately the same amount. The last 20% of the turn was not graphed due to the unreliability of the results with low forces.

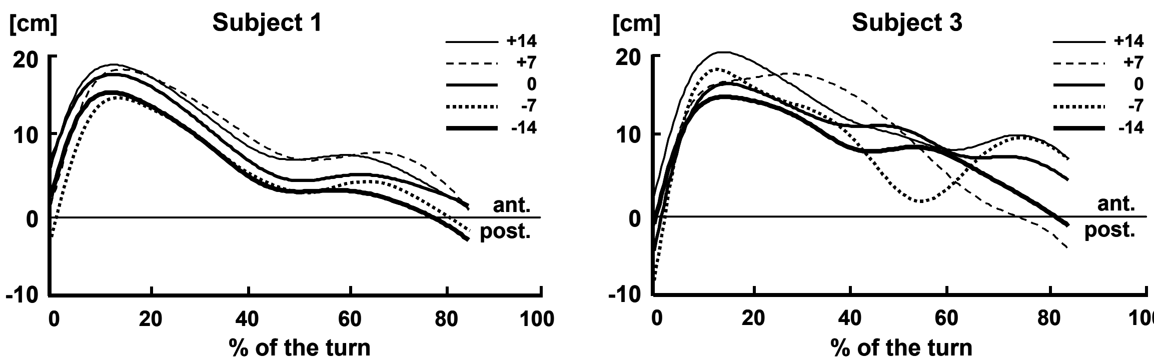

Fig. 8: Time courses of the point of application in anterior-posterior direction for each of the binding positions of subject 1 and 3.

Differences in the turning kinetics of the left and right legs are predicted and therefore also differences in the effect of the change in binding position. Fig. 10 shows a lateral comparison of the time course of subject 1 during a left and a right turn separated between outside and inside ski. Differences of up to 3 cm can be seen, indicating that an optimal binding position would not necessarily be the same for each leg. Due to the inacuracies in the results with low forces those parts of the results were not graphed.

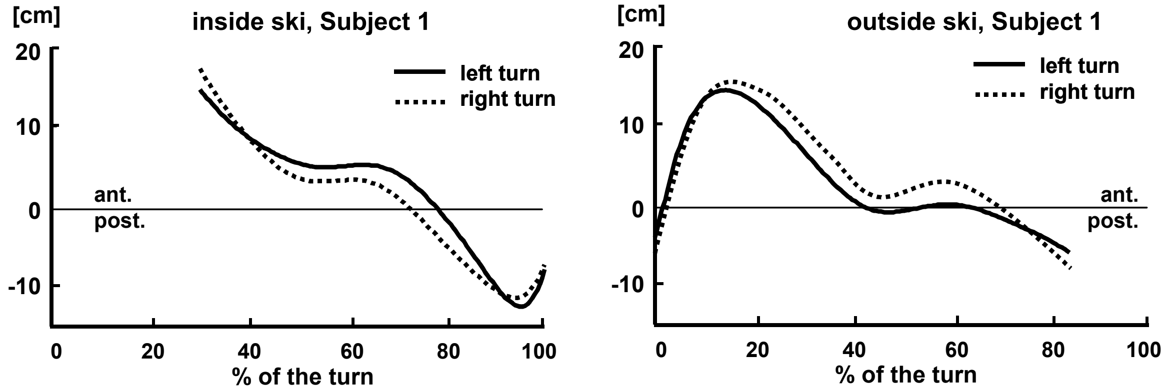

Fig. 10: Time history of the point of application in anterior-posterior direction for left and right turns separated between inside and outside ski for subject 1.

DISCUSSION

The results showed that changing the binding position in the anertior-posterior direction produced differences concerning the kinetic variables of the turn. These differences were neither systematic nor consistent for the three forces and the lateral moment for any of the subjects. The anterior-posterior moment, the torsion moment and the application point of the force in the anterior-posterior direction did, however, show consistent and systematic changes associated with the change in binding position. The consistency of these differences was correlated to the skiing ability of the subjects. Generally, the better the skier, the more consistent the differences were. The differences were observed for (1) discrete values within the turn (fig.2), (2) the entire turn (fig. 4), (3) the pattern of the turn in the different binding positons (fig. 5, 6).

For the elite skier, the point of application of the force in the anterior-posterior direction (a_x) moved in relation to the binding position and the pattern of the moment, or its time course, changed very little. The elite skier acted on the skis to keep a constant relative position between body and skis. It should be noted that it is in the initiation phase of the turn that most of the effects of change in binding position could be seen. This result indicated the initiation phase as the most sensitive phase in skiing. A comparison of two groups of differently experienced skiers also found the major differences in the initiation phase of different turning techniques (Mueller et al., 1998). Because a_x affects the turning characteristics of the ski, the skier should prefer one position over the others.

The good skier reacted to the change in the turning characteristics of the ski by altering the relative body position in response to the change in binding position. The results were inconsistent because, for each of the different binding positions, the skier had to find a different body position to best turn the ski. Because this reaction was more or less pronounced, depending on the binding position, an optimal position should exist, where the skier feels most comfortable and natural. In contrast to the elite skier, effects of the change in binding position were seen throughout the entire turn, instead of only in one particular phase.

These interpretations are subject to certain limitations. The number of subjects used in the study was small. The instrumentation itself, mounted on the skis to measure the kinetics of the turn, affected the turning characteristics of the ski. The grade of the slope, snow conditions and turning radii were all consistent which limits the expansion of the results to different situations.

Despite these limitations, certain speculations can be made from these results. The alignment of the ski-boot system turned out to be an optimization problem. A resolution would result in a higher level of comfort and performance in skiing. Due to the decreased effort required for turning skiing would be easier and more fun, less fatigue and fewer injuries would result. This study only measured the effects of altering the anterior-posterior position of the binding. The true optimal position, however, would not only depend on moving the binding anteriorly-posteriorly, but also in the medio-lateral direction and/or altering the height with the use of risers. Additionally, the differences in the left and right turn should be considered by mounting the binding on the two skis differently. The type of course, the grade of the slope, the turning radii, the speed of the skier and possibly other factors should also be taken into account as the optimal position may vary, depending on skiing conditions.

With so many influencing variables, it is evident that more research is required to tune the ski-skier system optimally. However, the ability to determine an optimal position would provide an easy way to optimize each specific skiing experience.

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