ANALYSIS OF THE DISTRIBUTION OF PRESSURE UNDER THE FEET OF ELITE ALPINE SKI INSTRUCTORS

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INTRODUCTION: In alpine skiing, the feet are used as both a steering device and an important source of sensory input. It has become quite common for instructors and coaches to ask their pupils to feel pressure under certain parts of their feet in order to ski better. It has also been a trend in skiing to inform students to initiate turns through the application of pressure in the forefoot area and to progressively "roll" from the front to the back of their feet. All of these instructions rely on master instructors' perceptions of what they feel while executing a ski turn. Historically, it has been quite complicated to perform biomechanics research on alpine skiing on-site. This fact is so because of the environment where the sport is practised which does not lend itself well to biomechanical measures using traditional equipment.
Previous biomechanical research on alpine skiing has been done using a variety of data acquisition methods, for example installing strain gauges on the bindings of the skis (Wimmer, 1997), custom built sensor plates under the bindings (Friedrichs & van Bergen, 1997) or accelerometers mounted on the ski itself (Niessen, Müller, Raschner & Schwameder, 1997). The above mentioned techniques were used to estimate the loading imposed on the equipment during actual skiing as well as in laboratory settings. A previous (Schaff, Senner & Kaiser, 1997) in-boot pressure study has been performed using two different systems. It provided qualitative descriptions of the distribution of plantar pressures of elite ski racers. Ski instructors have not served as subjects for many ski related research, except for the development of a pressure measurement based learning tool the *Swingbeep*-feedback system by Schaff et al. (1997).
The purpose of this study is to measure the in-boot pressure distribution of elite alpine ski instructors during various types of turns. From the in-boot pressure distribution system, maximum and average vertical forces, maximum peak pressure, pressure distribution patterns and centre of pressure trajectory were calculated for all subjects during various conditions.

METHODS: Six internationally certified Canadian ski instructors volunteered to participate in this study. Their usual ski boots were outfitted with pressure sensitive insoles (PEDAR mobile, Novel GmbH, Munich) to allow for on-snow measurements of plantar pressure distribution. The insole pressure signal (99 cells per insole) was collected at 50 Hz and sent to a control unit, which the skiers wore on their backs. This control unit was equipped with a memory card that allowed for storage of the data. The testing area was a reserved slope closed off to the public for safety reasons. "Stubby" slalom gates were inserted into the snow to control turn size. Four different types of turns (Dynamic Parallel, Giant Slalom, Short Radius and Basic Parallel) were performed in four sections of the slope, with each section was made up of at least ten turns. Distances between the slalom gates were adjusted according to the types of turns that were set according to the demands of the terrain. The sections were separated by open spaces to facilitate the transitions between sections. A mobile camera followed the skiers as they made their way down the slope. The videotape data was obtained to facilitate analysis of the pressure distribution data. The pressure data were recorded continuously for the duration of the ski run, and subsequently split up for analysis according to type of turn. The pressure distribution, centre of pressure (COP) trajectory and maximum and average force data obtained for each subject were compared by types of turn. Pressure and maximum force data of all subjects were then grouped and compared to assess differences in pressure distribution and forces measured between turn sizes.

RESULTS: From the calculated force data, the maximal forces range between 522 N and 1454 N. However, our data also show differences in the maximal forces measured between the left and right foot of all the subjects and the same tendency is also true for all turn types except for the Dynamic Parallel (Table 1).

Table 1. Maximal and average forces (SD) under left and right foot during all turn types

	Maximum Force (N)		Average Force (N)	
Turn type/foot	Left	Right	Left	Right
Dynamic Parallel	958 (78)	1013 (65)	642 (56)	537 (87)
Giant Slalom	1454 (952)	880 (105)	689 (270)	518 (16)
Short Radius	1481 (334)	757 (141)	777 (238)	514 (31)
Basic Parallel	1397 (484)	522 (32)	738 (197)	399 (35)

The averaged maximal pressures were relatively similar for all types of turns ranging between 28 and 38 N/cm^2 (Table 2). The maximum pressures obtained during all types of turn reached up to 45 N/cm^2 for one of the subjects while performing Short Radius turns. The Short Radius turns again provided the highest average values.

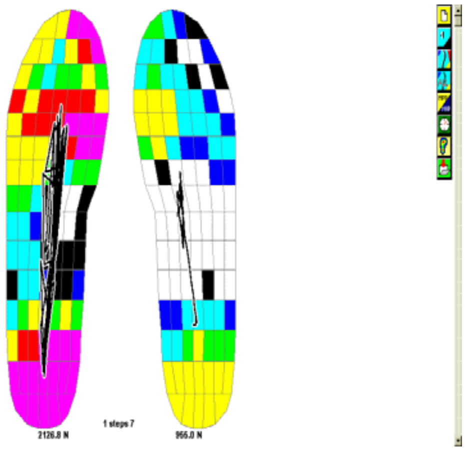
Table 2. Averages of maximal pressures (SD) recorded during all types of turns

Types of turn	Maximal Pressure (N/cm^2)
Dynamic Parallel	35 (7)
Giant Slalom	35 (6)
Short Radius	38 (11)
Basic Parallel	28 (4)

The trajectory of cop was consistent between both feet for all turn types. Results showed the cop following a near linear trajectory for the Dynamic Parallel, Short Radius and Basic Parallel turns. This trajectory had the cop move from the head of the first metatarsal at the beginning of the turns, and progressively migrate towards the medial aspect of the longitudinal arch near the end of the turns (Figure 1). However, the cop travelled from the head of the first metatarsal to the medial aspect of the heel during Giant Slalom turns (Figure 2).

DISCUSSION AND CONCLUSIONS: Our results show that the skiers generated the highest maximal and average forces and maximum pressures while performing the shortest turns (SR). These findings are logical with the manner in which these shorter turns are executed. Although efforts are made to make the short turns as smooth as possible, they still are executed in a more "choppy" fashion. This lower smoothness results in higher forces applied to the snow, and sent back up through the boots. As well when performing short turns, the skis are bent more rapidly than during longer turns, and this as well results in higher forces registered.

Interestingly, the average peak pressures are quite similar for all types of turns. The similarity is more evident when the higher end turns (Short Radius, Dynamic Parallel and Giant Slalom) are being considered. The main difference between these types of turns, is the rhythm at which they are executed, while the speed also varies. All of the turns provided results of peak forces ranging close to two times body-weight.



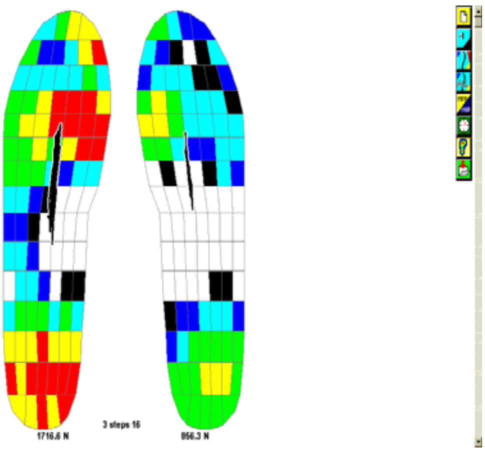


Figure 1. Trajectory of cop during SR turns   Figure 2. Trajectory of cop during GS turns

Of interest, is the apparent trend for the peak forces to be higher under the left foot in three out of the four types of turns. A possible explanation for this phenomenon is that the terrain where the tests were conducted had a slight side-hill fall line towards the right of the subjects. This trait of the testing environment may have caused for the right foot of the subjects to drift out from under their bodies, thus lowering the forces registered under that foot. A factor that was not controlled during data collection was the equipment worn by the subjects. The skiers wore different boots, and used different skis, although two of them had the same brand and model of skis and boots. It still has yet to be determined if that factor had any effect on the results. A point that all the skis that the subjects used had in common is that the skis were all sharp side-cut skis (also called shaped skis). Another equipment variation which may have affected in-boot measurements, is that some subjects (n=5) wore custom designed footbeds, while the other did not. As was stated for the skis and boots, it has yet to be determined if this piece of equipment affected results or not.

From a ski technique standpoint, it was clear when analysing the data that as the skiers made their way through the turns, there was more pressure applied with the foot that was towards the outside of the curve, while during the transition between turns, both feet were loaded equally. This finding is in complete accordance with the principles being taught in ski schools. Of interest however is the short distance travelled by the cop during most of the turns. It was only during Giant Slalom that the cop was seen going from the front part of the foot to the medial aspect of the heel. In the other types of turns, the cop remained in a limited area, going from under the head of the first metatarsal to the front of the longitudinal arch. Even though the cop did not travel as much during DP, BP and SR turns, the peak pressures were recorded under the same regions of the foot as during GS turns.

Further studies are required to make a more comprehensive analysis of alpine skiing. These further studies should include Electromyographical (EMG) recordings to assess differences between types of turns from a muscular standpoint. Full body kinetic and kinematic analyses of the different types of turns are required to assess differences in joint loading, relative to the type of turn performed. More subjects are also needed to establish a sufficient database to determine if trends exist in skiing technique.

REFERENCES:

Hall, B. L. (1991). Dynamic Displacement and Pressure Distribution in Alpine Ski Boots. Microform Publications. Eugene: University of Oregon, College of Human Development and Performance.

Müller, E. (1994). Analysis of the Biomechanical Characteristics of Different Swinging Techniques in Alpine Skiing. *J. of Sports Sciences* **12**, 261-278.

Schaff, P., Senner, V., Kaiser, F. (1997). Pressure Distribution Measurement for the Alpine Skier from the Biomechanical High Tech Measurement to its Application as Swingbeep-Feedback System. In E. Müller et al., *Science and Skiing* (pp. 159-172). London: E & F Spon.

van Bergen, B. (1997). Different Possibilities of Measuring Force Transmission between Ski and Binding. In E. Müller et al., *Science and Skiing* (pp. 189-199), London: E & F Spon.

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