PLANTAR PRESSURE DISTRIBUTION AND FORCES MEASURED DURING SLALOM AND GIANT SLALOM TURNS PERFORMED BY ELITE SKIERS

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The purpose of the study was to measure plantar force and pressure distribution during slalom (S) and giant slalom (SG) runs performed by elite professional ski instructors. Three elite professional ski instructors performed three slalom and two giant slalom runs. All test trials were recorded synchronously with a video camera and a plantar pressure distribution. The total maximum forces compared between left and right foot for foot position during the turn are not significantly different. However, the total maximal force is about 1.2 to 2 times larger for the outside foot. The regional maximum mean pressure is applied under the medial aspect of the forefoot and the heel. This provides more steering control and forces during both types of turns. It should be noted that the inside foot has less steering contribution for S and GS turns.

KEY WORDS: plantar pressure, force, elite instructors, alpine skiing, slalom, giant slalom

INTRODUCTION: Biomechanics research in the field in downhill skiing is very challenging since measuring kinematics or kinetics variables during dynamic performance is generally very difficult. Kinematic measurements in downhill skiing are confined to large fields of view reducing the accuracy of the collected data. Similarly, kinetic measurements are limited to light weight measuring instruments that minimally affect the skiers' performance. Various investigators have attempted to measure on-site kinetic parameters (Friedrichs et al., 1997; Leppävuori et al., 1993; Medoff et al., 1985; van Bergen, 1997; Wimmer et al., 1997) during on-the-snow performance. Most of these investigations measured the reaction forces between the skis and boots which give limited information. In-shoe pressure measurement systems were initially used in the laboratory with ski boots and the subjects assumed different positions like during on-snow performance. Recent developments in in-shoe pressure measurement reduced the size of the data acquisition and storage instrument allowing measurements in the field (Schattner, Asang, Hauser, & Velho, 1985; Lafontaine, Lamontagne, Dupuis, Diallo, 1998a, 1998b). Some earlier systems measured only a few specific areas under the feet with limited data sampling. New portable systems weighing less than 500 gm allowed a complete mapping of the plantar surface with 99 capacitive sensors at a sampling rate reaching 100 Hz. Most of the kinetics research addressed issues of the force application during dynamic performances for racers. Very few investigations ((Schattner et al.,1985); (Lafontaine, 1998a, 1998b) have looked at the plantar pressure distribution during on-snow performance for instructors. The findings of those studies that focus on racers are difficult to apply due to the difference in measured kinetic parameters and the style of assessed skiers. Raschner et al. (1998) have conducted a kinematic, kinetic and electromyographic investigation of ski racing and high performance skiing and reported peak forces of up to 1700 N during Giant Slalom racing using an in-shoe pressure measurement system. Schaff (1997) reported that plantar pressure measurements provide valuable information on gliding and steering performance.

Our interest was to measure plantar pressure distributions of elite professional ski instructors performing downhill skiing. The objectives of the current study were to provide information on the plantar pressure distribution and normal forces applied to different regions under the feet. The purpose of the study was to measure plantar force and pressure distribution during slalom (S) and giant slalom (SG) runs performed by elite professional ski instructors.

METHODS: Three elite professional ski instructors agreed to participate at one session of three hours for this study. Two parallel courses (one slalom and the other giant slalom) were mounted by the ski school director in the training facilities at Courchevel, France. Each participant performed three slalom and two giant slalom runs. Prior to the measurement participants were allowed a familiarization run with the plantar pressure distribution systems (Pedar mobile; Novel Electronics gmbh). Plantar pressure distribution systems consisted of a pair of insoles (99 sensors per insole), the control and datalogger unit (sampling rate at 50 Hz for two insoles and 8MB storage card), the cables connecting the insoles and the recording unit, a camera flash (for synchronization with the video camera) and a switch button. Pressure measuring insoles were inserted into the participant's ski boots. The instrumented insoles were connected to the control and datalogger unit, which was inserted into an insulated neoprene backpack and attached at the waist level. The same pair of pressure sensitive insoles (XS372R, XS368S) was used to test all of the participants in order to reduce the variability due to the instrumentation. All test trials were recorded with a super 8mm video camera (Sony TR-11) and synchronized with the Pedar mobile system using an external camera flash connected to its synchronization output to facilitate the data analysis. The participants performed their three slalom and two GS test runs as closely grouped as possible to avoid changes in snow conditions.

The pressure and force data was analyzed using PEDAR mobile and NOVEL-WIN processing software and standard spreadsheets. The pressure recordings of all participants were separated by type of turns (S or GS) through time matching the video recording and the foot pressure data. Subsequently each run was divided into several cycles. A cycle consisted of three turns such as a left turn followed by a right turn and finishing with a left turn. All cycles are initiated at the gate and terminated at the second gate. Then the turns were grouped in left and right foot for the outside foot and for the inside foot. Analyses were made to determine whether the type of turn or the foot side affected the pressure distribution under the entire plantar surface as well as in specific anatomical regions by using custom designed masks (Figure 1). Maximum forces and maximum mean pressures were calculated for each type of turn and position of the foot during the turns.

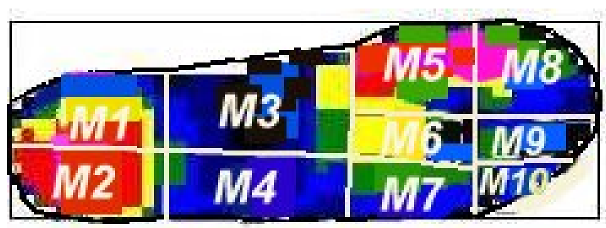

Figure 1 - Mask distribution under the right foot.

RESULTS AND DISCUSSION: The average maximum force and average mean pressure under the entire foot are presented for the two types of turns, foot laterality and positions during turns (Figure 2). The data were analyzed by grouping the right foot data while the foot position was inside and outside during the turns. As shown in the figure 2, there was no significant difference between the right and left foot while compared to a given position during the specific turns. From this initial analysis, force and pressure data from the right and left foot were combined together in relation to the foot position during the turns. Subsequent data analyses comprised 36 and 24 trials for the S and GS turns respectively. In figure 3, total maximum force data are presented for the various types (S and GS) of turns. The total maximum force is much larger for the outside foot than the inside foot independent of the type of turn. The total maximum force on the outside foot represents about two times body weight (BW) while the force on the inside foot is about 1.2 times BW. This concurs with previous

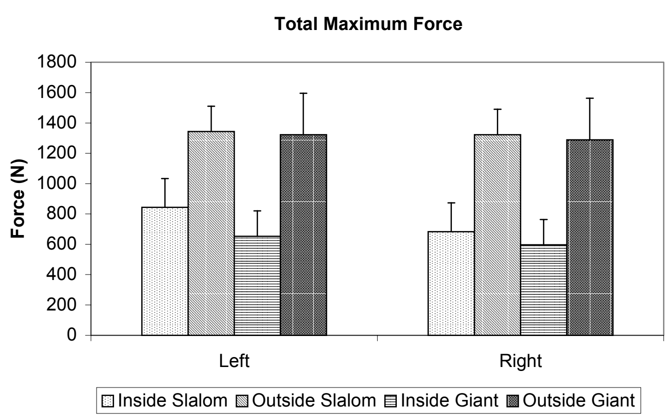

Figure 2 - Total maximum force for the left and right foot.

investigations [Lafontaine, 1998 #51; Schaff, 1997 #43].

The maximum mean pressure values as distributed by plantar regions are shown in the figure 4. The largest pressures are recorded in region 8, 5, 1 and 2 for the outside foot for both types of turns. This pressure distribution pattern indicates that the steering forces are produced by the big toe, first metatarsal and the heel of the outside foot. Whereas the inside foot produces less steering forces for both turns as also shown in figure 3. Similar findings have been reported by Schaff(1997), however, their reported lateral heel pressure was smaller than the one presented in this study. This could be explained by the use of fewer sensors per insole. Only seven sensors were used to record the overall plantar pressure distribution.

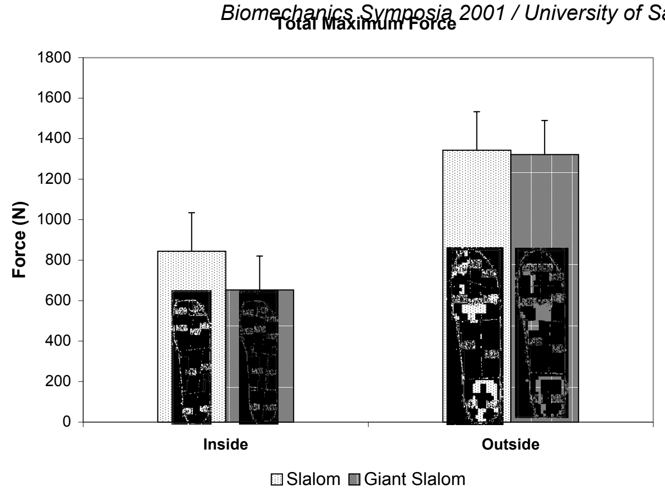

Figure 3 - Total maximum force for the foot position during S and GS turns.

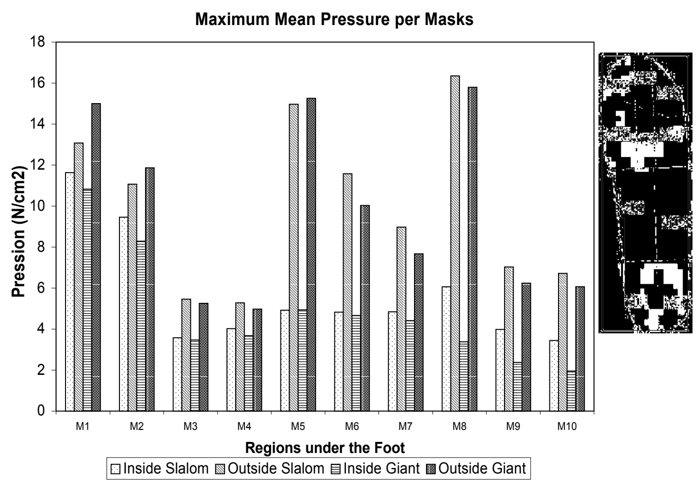

Figure 4 - Maximum mean pressure distributed by plantar regions.

CONCLUSIONS: The total maximum forces compared between left and right foot for the foot position in the turn are not significantly different. However, the difference of total maximal force between the inside and outside foot is about 1.2 to 2 times larger for the outside foot. The regional maximum mean pressure is applied under the medial aspect of the forefoot and the heel. This provides more steering control and forces during both types of turns. It should be noted that the inside foot has less steering contribution for S and GS turns. This research protocol might be used to train high-level skiers to adjust the level of pressure applied and the area where the pressure is applied during a run. Also ski instructors can used this information for improving their teaching.

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