GROUND REACTION FORCE COMPARISON BETWEEN BOTH FEET DURING GIANT SLALOM TURNS IN ALPINE SKIING

Thomas Falda-Buscaiot[1,3,4], Frédérique Hintzy[1], Nicolas Coulmy[2]

[1]Laboratoire de Physiologie de l'Exercice (EA 4338), Université de Savoie, Chambéry, France
[2]Fédération Française de ski, Annecy, France
[3]Cluster Sporaltec, Saint Etienne, France
[4]Laboratoire Robioss (UPR3346), Université de Poitiers, Poitiers, France

The purpose of this study was to measure the difference in normal force under both feet during alpine skiing giant slalom turns. Eleven experienced alpine skiers performed a giant slalom course at race intensity. All trials were recorded synchronously using a video camera and a plantar pressure measuring system. The mean force on the grouped two feet varied from 0.7 BW at the start of a turn to 1.5 BW during the steering phase of a turn performed in a steep slope condition. When skiing on FLAT slope condition, it reached only 1.3 BW. Results also showed that the outside foot receives significantly more pressure than the inside foot during the entire turn except the initiation phase. This last finding is not affected by slope steepness.

KEYWORDS: normal force, plantar pressure, alpine skiing, kinematic, kinetic.

INTRODUCTION: In alpine skiing, different studies have used plantar pressure measurement systems to investigate forces applied at different foot regions (Lafontaine, Lamontagne et al., 1998; Lamontagne, 2001), or to compare the data to force plate measurements (Stricker et al., 2010; Nakazato et al., 2011 and 2013). Those articles gave precious results on the overall vertical component of the Ground reaction Force (vGRF) applied throughout a turn, and showed that it can go up to 1.2 BW on the outside foot when measured with pressure insoles. Later, they showed that pressure insoles can quite well estimate the Center Of Pressure trajectory on the Antero-Posterior axis only, but not on the Medio-Lateral axis. However, to the best of our knowledge, we can either have information on the total force acting throughout a turn, or some details about the mapping of plantar pressures averaged for a whole turn. Also, differences in vGRF at different characteristic moments of a turn have not been documented. This information would be useful to better understand turn characteristics, as Nakazato et al. (2011) have shown vGRF is not stable throughout a turn. Also, differences between inside and outside feet have not been documented. Skiers are often taught to press more on the outside foot, but this information has never been measured.
Therefore, the goal of our study was to investigate differences in vGRF between both inside and outside feet during giant slalom turns in racing alpine skiing. The effects of slope steepness and turn completion on the vGRF applied under both feet were also investigated.

METHOD: Eleven young experienced alpine skiers participated in the study (seven boys and four girls). Their mean age, mass and height were 17.5 ± 4.3 years, 59.8 ± 10.6 kg and 170.3 ± 8.2 cm, respectively. All skiers competed at national level at the time of the study.
A giant slalom run was set up by professional trainers. Linear distance and lateral offset between the gates was very consistent during the entire run. The top part of the slope was steep with a pitch of 38° (STEEP); the middle part of the run was less steep with a pitch of 11° (FLAT). After a free skiing warm up and an inspection of the track, the subjects performed one run at race intensity.
Plantar pressure was measured under both feet using a portable device (Pedar system, Novel GmbH, Munich, Germany) set at 50 Hz throughout the entire run. Pressure insoles were chosen as they allow unrestricted measurement of normal force acting under the feet's soles. A digital camera (Sony) was used for identification of turn phases, at a sample rate of

50 Hz. Once in the starting gate, the skiers had to stomp with their right foot to ensure synchronisation of pressure and video data. Turns were divided using the video data into 4 phases, similarly to the method used by Hintermeister et al. (1995). The initiation phase (phase 1) was characterized by an edge change from the inside edge of the outside ski, to the inside edge of the novel outside ski. The steering phase was characterized by an increased edging, until the maximum of hip and knee flexion and the return of angulation. This phase was divided into 2 distinct phases: one from the end of the initiation phase to the gate passing (phase 2), and one from the gate to the start of the completion phase (phase 3). The completion phase (phase 4) was made of the rest of the turn, until the skis were flat on the ground and the beginning of the initiation phase of the next turn.
Pressure outputs were first multiplied by their own corresponding sensor's surface in order to calculate normal force for each sensor. The mean force (Fmean in N) under the whole foot was computed as the sum of the normal force data of each sensor for the defined turn phases. The Force values were normalized with the body weight (N/BW). Both feet were expressed relative to their position during a turn: inside (INS) or outside (OUT) foot. Fmean was expressed as the sum of Fmean for both feet (total Fmean), or as a percentage of Fmean applied on the OUT or INS foot compared to the total Fmean. As raw data were made of several spikes, we first filtered them using a zero-phase low-pass 4th order Butterworth filter (also used in Stricker et al., 2010; Nakazato et al., 2011). The threshold was set at 6 Hz.
The mean (SD) was calculated for all variables. Statistical analyses were performed using Statistica10 software (Statsoft, Tulsa, OK, USA). Two-way ANOVA with repeated measures were performed with Fmean as the dependant variable. Statistical significance was accepted at $p<0.05$.

RESULTS: Fig. 1 represented the total Fmean (mean normal force under the grouped two feet) for both slope conditions and for the four turn phases. Two-way ANOVA results indicated that total Fmean varied significantly according to slope steepness ($p<.05$), with Fmean being higher on STEEP *vs.* FLAT. Total Fmean also varied according to turn phase ($p<.001$). Post-hoc tests revealed that total Fmean during phase 1 < Tot Fmean phase 4 < Tot Fmean phase 2 < Tot Fmean phase 3. The cross effect slope * turn phase was also shown ($p<.001$). Post-hoc tests indicated that total Fmean was higher in steep slope condition compared to flat slope condition for turn phases 2 and 3.

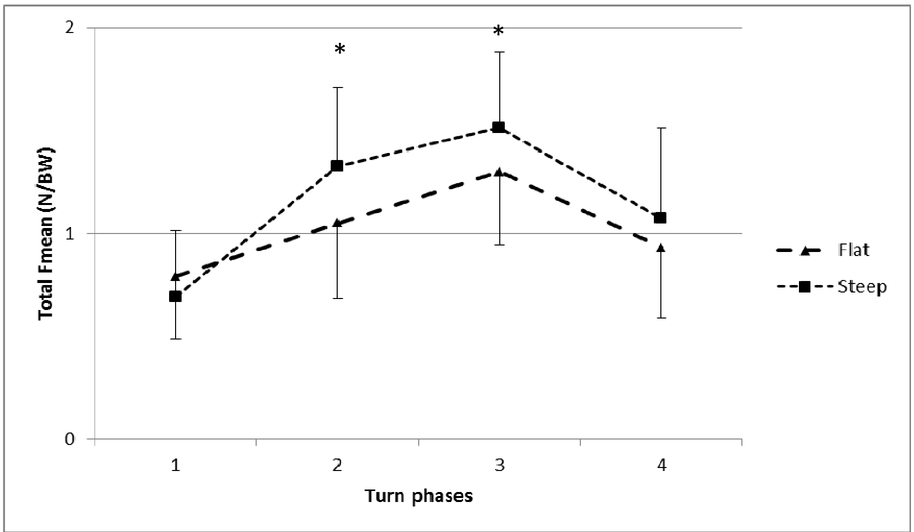
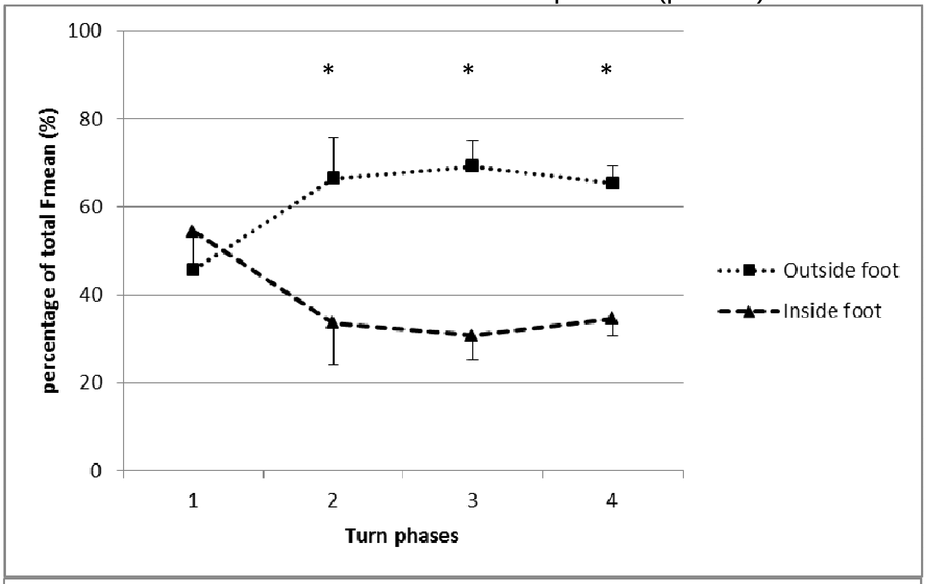


Figure 1: Total Fmean (mean and SD) under the grouped two feet, according to slope steepness and turn phases. * indicates a significant difference between total Fmean measured for steep vs. flat slope condition.

Fig. 2 shows the percentage of the total mean force applied separately on the outside or inside foot. This percentage is not affected by slope steepness. The turn phase has an effect (p<.001). For both slope steepness, the foot effect is also shown (p<.001). The percentage of total Fmean applied on both feet is not different at turn phase 1, but is superior on the outside foot for the three other turn phases (p<.001).



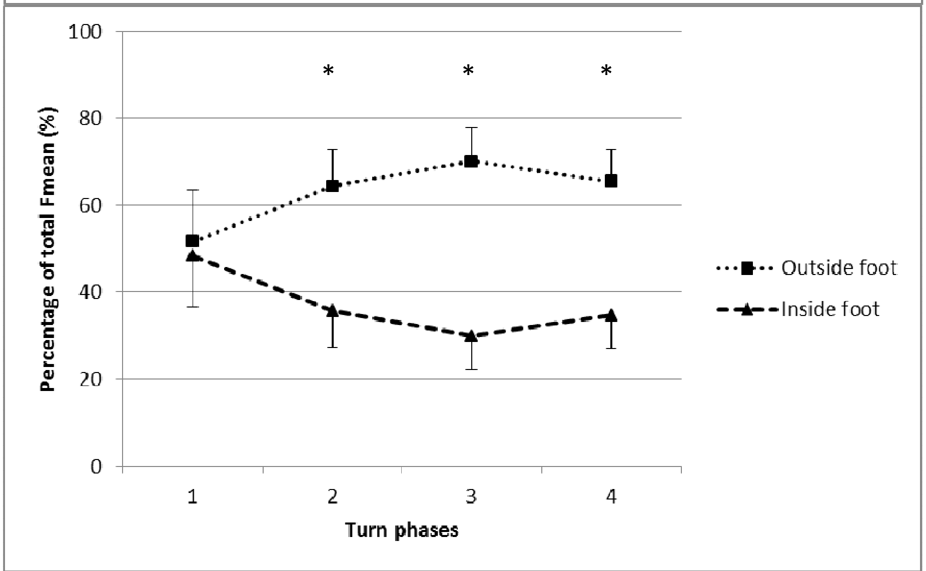


Figure 2a (top) and b (bottom): Percentage of the total Fmean applied on the outside and inside foot, according to turn phases, for a) flat slope and b) steep slope. * indicates a significant difference between the percentage of total Fmean applied on the inside and outside foot.

DISCUSSION: This study highlighted the influence of turn phases, slope steepness and foot on the mean force measured with pressure insoles in alpine skiing. Firstly, total Fmean can go up to 1.5 times body weight on steep slope. On flat slope, it reaches lower values of around 1.3 BW. Those data are consistent with the ones found by Nakazato et al. (2011). Those higher values are found at the end of the steering phase. During initiation phase however, total Fmean reached values under 1 BW, at around 0.7 BW on both flat and steep slopes. For both slope steepness, total Fmean increases throughout the turn until the end of the steering phase.

The second step of our study was to analyse the repartition of total Fmean between inside and outside feet. Results show that Fmean is equally distributed on both feet during the initiation phase, i.e. when total Fmean was low. This may be due to the edge changing taking place during this phase. As turn progresses however, the percentage of Fmean applied on the outside foot increased to reach a 75%/25% repartition on the outside/inside feet, respectively. This is seen for both steep and flat slope steepness. Analysis of the standard

deviation indicated that force repartition between both feet is a lot more consistent than the actual amount of normal force.
Then those results showed that the increase in total Fmean which is observed throughout turns is solely done by an increase in Fmean on the outside foot. The slope steepness does not modify the force repartition between both feet. However, it increased the overall force value, except at the initiation phase of turns. Those data highlighted the different role played by both feet during an alpine skiing turn. Indeed, the inside foot received a steady force value throughout the turn, whereas the force applied on the outside foot increased throughout a turn. Both feet are responsible for the skier's equilibrium, although only the outside foot has an active motor role in turn completion.
To the best of our knowledge, this is the first time that the ground reaction force is represented as a sum of both feet in alpine skiing. Also, we have not found any information on the force measurement for different turn phases, as it is shown in this paper.
To go forward in this analysis, it could be useful to measure detailed pressure values under different zones of the foot sole. Indeed, one may think the modifications highlighted in this article may be accompanied with modifications of the plantar pressure repartition under the foot sole.

CONCLUSION: The normal forces values force values measured in this paper indicated a distinct role played by both feet in giant slalom turns in alpine skiing. The increase in force through a giant slalom turn is only accompanied by an increase in force on the outside foot. It may be useful to link those findings with kinematical data, and to further investigate detailed plantar pressure repartition under different regions of the foot. Our chosen method does not allow the assessment of the complete GRF but only of the normal force under the feet's sole. The shin applies a part of the force which was obviously not measurable with this method.

REFERENCES:

Hintermeister, R.A., O'Connor, D.D., Dillman, C.J., Suplizio, C.L., Lange, G.W., & Steadman, R.J. (1995). Muscle activity in slalom and giant slalom skiing. *Medicine and science in sport and exercise* 27(3): 315-322.

Lafontaine, D., Lamontagne, M., Dupuis, D., & Diallo, B. (1998). Analysis of the distribution of pressure under the feet of elite alpine ski instructors. Paper presented at the *XVIth conference of the International Society of Biomechanics in Sports.* Konstanz, Germany.

Lamontagne, M. (2001). Plantar pressure distribution and forces measured during slalom and giant slalom turns performed by elite skiers. Paper presented at the *XVIVth conference of the International Society of Biomechanics in Sports.* San Francisco, USA.

Nakazato, K., Scheiber, P., & Müller, E. (2011). A comparison of ground reaction forces determined by portable force-plate and pressure-insole systems in alpine skiing. *Journal of Sports Sciences and Medicine* 10(4): 754-762.

Nakazato, K., Scheiber, P., & Müller, E. (2013). Comparison between the force application point determined by portable force plate system and the center of pressure determined by pressure insole system during alpine skiing. *Sports Engineering* 16(4): 297-307.

Stricker, G., Scheiber, P., Lindenhofer, E., & Müller, E. (2010). Determination of forces in alpine skiing and snowboarding: Validation of a mobile data acquisition system. *European Journal of Sport Science* 10(1): 31-41.