KINETIC AND KINEMATIC COMPARISON OF ALPINE SKI RACING DISCIPLINES AS A BASE FOR SPECIFIC CONDITIONING REGIMES

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The purpose of this preliminary case study was to compare the alpine ski racing competition disciplines slalom and giant-slalom with respect to principal kinematics of the lower limbs and the acting forces. Knee angles and ground reaction forces of one high level athlete were determined using inertial sensors and pressure insoles, respectively. Slalom was characterized by a "high dynamic skiing mode" with a distinct "knee angle and loading synchronism" between the inside leg and the outside leg. For giant slalom, a polarized situation was observed: "higher quasi static loads at high knee angles" on the outside leg and "lower eccentric-concentric loads at low knee angles" on the inside leg. These findings may help to increase the specificity of conditioning training and developing more discipline-specific exercises.

KEY WORDS: alpine skiing, movement analysis, specific conditioning

INTRODUCTION: The principle of "kinematic, kinetic, and neuromuscular correspondence" states that specific training regimes and their exercises must be related to those parameters of movement which characterize the structure of the competition technique (Müller, Benko, Raschner, & Schwameder, 2000). In this context, information from biomechanical movement analysis of the specific competition techniques is essential to enhance the quality of conditioning training. There is common agreement that the influence of the quadriceps muscles is dominant throughout a turning cycle in elite alpine skiing (Berg & Eiken, 1999). Hence, with respect to specific training of this muscle group, detailed knowledge on the kinematics of the lower limbs and the occurring ground reaction forces (GRF) is essential.
Athletes have to deal with different physiological and neuromuscular demands when competing in the different disciplines of alpine ski racing. It is known from earlier studies that even between the two technical disciplines of giant-slalom (GS) and slalom (SL) the average turn times are substantially different: 0.86s for SL (Supej, Kipp, & Holmberg, 2011) and 1.72s for GS (Spörri, Kröll, Schwameder, & Müller, 2012). Therefore, substantial differences of joint angle and force time-courses might be present.
Regarding lower limb kinematics, it has already been shown that the knee angles (full extension = 180°), at which SL and GS racers perform their turns, seems to be different as GS turns result in lower knee angles and angular velocities than SL (Berg & Eiken, 1999). However, these relatively old kinematic data might not have high validity with respect to current skiing techniques, as shown recently for GS (Kröll, Spörri, Fasel, Müller, & Schwameder, 2015).
With respect to GRF, no direct comparison (same measurement setup) between SL and GS exists in the published literature. Moreover, since turn force depends on both turn speed and turn radius, it is not a priori clear whether GRF is lower as well, despite the lower speed in SL. From a biomechanical perspective, the smaller turn radius in SL may mitigate the decreasing force effect of the slower speed. A similar mechanism was recently shown when comparing GS with super-G and downhill (Gilgien, Spörri, Kröll, Crivelli, & Müller, 2014).
Consequently the purpose of this study was to describe and compare the current SL and GS techniques with respect to limb kinematics and GRF. The findings might help to overcome

the lack of knowledge (old kinematic data; no direct comparison of GRF) and to increase the specificity and quality of conditioning training.

METHODS: In this preliminary paper a descriptive case report of one representative high level athlete is served. The athlete (17.4 FIS Points in SL) performed four runs on a SL course with 20 turns (11 analysed) and four runs on a GS course with 16 turns (11 analysed). The two fastest runs of each condition were considered, resulting in a total of 22 turns per discipline. The athlete was allowed to use his own equipment. The kinematic and kinetic measurement was performed bilateral, which means that each turn provides data from the outside leg (*OUTSIDE*) as well as the inside leg (*INSIDE*).
Knee angles were determined based on four inertial measurement units (IMU) at 500Hz, which were fixed on the shank and thigh of both legs. For the calculation of the knee angle, skiing-specific evaluation algorithms were developed and validated. The validation against a video camera reference system depicted an accuracy of -1.4° and a precision of 5.5° (Fasel, Spörri, Chardonnens, Gilgien, Kröll, Müller et al., 2013). Simultaneous with the *knee angle* measurements, the *GRF* was measured with the PEDAR Insole System of Novel (100Hz).
The *TOTAL GRF*, calculated as the sum of the *OUTSIDE GRF* and *INSIDE GRF*, was used for automatic detection of beginning and end of the turn via functional minima during the turn switch. All data were filtered using a low-pass Butterworth filter with a cut-off frequency of 6Hz and time normalized to 100% of the turn cycle. For each turn and parameter (*knee angle OUTSIDE, knee angle INSIDE, GRF TOTAL, GRF OUTSIDE, GRF INSIDE*) the mean, minimum (Min) and maximum (Max) values were calculated and subsequently averaged across all turns within each discipline. The same procedure was followed for the *turn times*. Time normalized turns were averaged for illustrating descriptive course differences.

RESULTS / DISCUSSION: In general, the results of the actual case study are in good correspondence with earlier group mean data for GS (Kröll et al., 2015). For SL, the mean *turn time* was 0.83s±0.07, which is in line with previous findings (Supej et al., 2011). For GS, the mean *turn time* was 1.39s±0.11, which is slightly less than previously reported (Spörri et al., 2012), but can be interpreted as representative according to actual gate to gate analysis (e.g. World Championship 2015 Men: 1st run=1.31s / 2nd run=1.41s). Therefore, the time structure of the current data seems to be reasonable and useful for interpretations towards actual conditioning aspects. With respect to the *knee angle* measurements, the *OUTSIDE* leg has greater knee angles during the GS turns compared to SL turns (Table 1). This result is in opposite to previous literature reports (Berg & Eiken, 1999; Szmedra, Im, Nioka, Chance, & Rundell, 2001) and shows that current competition techniques have different requirements compared to skiing techniques from years ago. On the other hand, the *INSIDE* leg has distinctly smaller *knee angles* for GS compared to SL.

Table 1
Values of the knee angle (n=22 turns per discipline, ±SD)

	OUTSIDE leg			INSIDE leg		
	Mean	Min	Max	Mean	Min	Max
Slalom [°]	112±5	81±7	132±6	101±7	80±7	118±9
Giant-Slalom [°]	122±6	95±8	138±8	88±7	67±9	113±8

Concerning the shape of changes in the *knee angle,* one can identify similar characteristics between the *OUTSIDE* leg during GS and the *OUTSIDE* and *INSIDE* legs during SL (Figure 1A). Pronounced knee extension can be observed in the early phase of the turn, which is accompanied by rather low *GRF*. During the main phase of the turn, where the forces are highest, the *knee angle* remains relatively constant. This is an indicator that quasi static muscle work is dominant since the changes in angle and the angular velocities are very small during this phase. Knee flexion then occurs during the last quarter of the turn. This eccentric phase occurs already in the unloading phase and, therefore, is accompanied with rather low forces. A distinctly different shape of the *knee angle* is shown by the *INSIDE* leg in GS: a clear sequence of knee flexion to a minimum of about 65° (occurring at about 50% of the turn) and a subsequent extension of the knee. Those rather low *knee angles* are accompanied by forces which are not as high for the *INSIDE* leg as on the *OUTSIDE* leg. However, with respect to the low *knee angles,* the forces are still quite substantial and should be considered in the training process as specific feature of the GS discipline. The pronounced difference between *OUTSIDE* and *INSIDE* legs in GS can be explained from a functional perspective by the greater whole body inclination in GS.

Table 2:
Values of the ground reaction forces (n=22 turns per discipline; 1 BW =817N)

	TOTAL		OUTSIDE leg	INSIDE leg
	Mean	Max	Mean	Mean
Slalom [BW]	1.74±0.10	3.15±0.31	0.98±0.14	0.76±0.13
Giant-Slalom [BW]	1.95±0.15	3.15±0.21	1.31±0.16	0.69±0.11

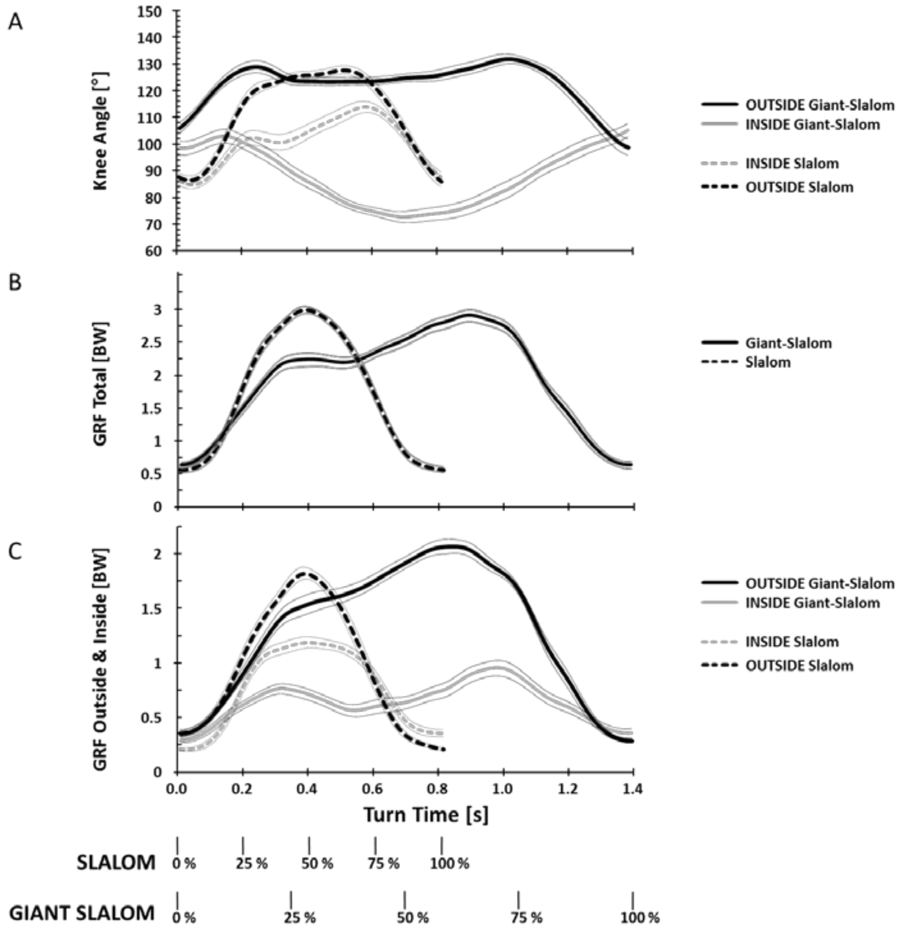

Figure 1: (A) Course *of knee angle OUTSIDE* and *knee angle INSIDE*. (B) Course of *GRF TOTAL*. (C) Course of *GRF OUTSIDE* and *GRF INSIDE*. Data are presented as time normalized mean±sem. For better comparison of the disciplines, data are plotted along the mean *run time* for slalom (0.83s±0.07) and giant-slalom (1.39s±0.11). 1 BW =817N.

The mean *TOTAL GRF* is greater for GS compared to SL, although the maximum forces are similar (Table 2). This indicates that the relative time which the skier is exposed to high loads is substantially shorter in SL. A unique feature in alpine skiing is that the total load has to be distributed with respect to functional aspects of the ski-snow interaction in a specific way between *OUTSIDE* and *INSIDE* leg of a turn. Comparing GS and SL, a more balanced distribution between the two legs can be observed in SL, and a much more pronounced load of the *OUTSIDE* leg can be observed for GS (Figure 1 and Table 2). This results in the highest mean and peak forces on the *OUTSIDE* leg during GS accompanied with the lowest mean and peak forces on the *INSIDE* leg (Table 2). The shape of *GRF* depicts a substantially higher rate of force development for SL on both *OUTSIDE* and *INSIDE* compared to GS. A distinct feature of the *GRF* in GS *OUTSIDE* leg is the very long time of quasi static contraction with high forces. This load characteristic is known to affect the blood flow to working muscle and, therefore, the performance of muscle (Szmedra et al., 2001). Specific training exercise may help to counter this decrease in performance.

CONCLUSION: The comparison between the two selected competition disciplines depicts some different fundamental features. Slalom is characterized by a “high dynamic skiing mode” with distinct “knee angle and loading synchronism” between the inside leg and the outside leg”. This means that specific conditioning exercises should focus on synchronous loading of both legs with knee angles varying between 90° and 120°. Furthermore, the time structure of a slalom turn cycle and, therefore, the high rate of force development on the one hand and the short quasi static load on the other hand should be targeted. For giant slalom, a polarized situation was observed: “high quasi static loads at high knee angles” on the *OUTSIDE* leg and “lower eccentric-concentric loads at low knee angles” on the *INSIDE* leg. Therefore, high knee angles (135°) and high loads with quasi static contractions over a substantial time span (>1s) should be targeted with respect to OUTSIDE leg specificity. On the other hand, exercises at rather low knee angles (from 100° towards 65°), with a rather slow eccentric-concentric (time span 1.4s), should be part of a training regime with respect to giant-slalom INSIDE LEG specificity. However, all of the conclusions drawn at this point have to be considered carefully, since they base on a case study only. Nevertheless, the current conclusions seem to be plausible, since it is known from earlier giant-slalom studies (Kröll et al., 2015), that general features of the technique are omnipresent among racers.

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