MUSCULAR RESPONSES TO SKI WIDTH WHEN SKIING ON GROOMED AND POWDER SNOW CONDITIONS

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Introduction

Wide skis were originally designed to be used in powder snow conditions where the design of the ski did not allow the skier to sink as deep into the snow as with narrow width skis. Wide skis are currently among the top sellers of ski types sold in the United States market (SIA, 2017). Due to being marketed as an all-around ski, these skis are now routinely being skied on groomed runs as well as in powder.

However, there is not a standard definition of what width constitutes a 'wide' ski. Certainly, the overall width is greater with a wide ski than a narrow ski. Wide skis are typically lighter in weight and found with softer flex in the tip and tail than narrow skis, may possess rockered tip and tail, and may have a flat or inverted camber. Additionally, these skis generally possess less torsional stiffness than a traditional narrow ski. These ski characteristics may exert a significant influence on the biomechanics and physiological responses during skiing.

Zorko et al. (2015) reported on knee joint kinematics of three different ski widths. Those authors noted significant differences between the skis for knee flexion, knee abduction, and timing of peak ground reaction force. Seifert et al. (2018) reported electromyographic (EMG) responses were different on wide skis than when skiing narrow skis in an elite skier in standardized and self-selected turns. However, both studies were performed only on groomed, packed snow.

It is not known how ski width would affect muscular responses when wide and narrow skis were tested in powder snow conditions. Thus, the purpose of this study was to compare the electromyographic (EMG) responses between wide and narrow skis when skiing on groomed and in powder snow conditions.

Methods

The Montana State University Institutional Review Board approved this project and all subjects provided written informed consent. Four males (average age: 41.5 $\pm$10.3 y) and one female (52 y) expert level skiers (based on the Professional Ski Instructors of American ratings) participated. Two of the skiers were former national ski team members and two were former national champions. Mean FIS point for the three elite racers was 13.37.

Skiers skied on their own skis for this project. Underfoot ski widths for the narrow skis ranged from 67 to 71 mm and 94 to 102 mm for the WS under four testing conditions. The four conditions were: wide skis on groomed snow and in powder and narrow skis on groomed snow and in powder. The four conditions were counterbalanced.

All testing was completed on the same run at Bridger Bowl Ski Area, Bozeman, MT, USA. The run had an average pitch of 23^{o}. Approximately half the width of this run was machine groomed in the early morning of the testing day while the other half was left to use for the powder skiing condition. Turns were not standardized, but skiers were instructed to keep their turns as consistent as possible.

Electromyographic analyses were performed on *bicep femoris, rectus femoris, gluteus medius,* and *vastus lateralis* of the right leg. A 4-bar bipolar Ag/AgCl EMG sensor was placed over the belly of the muscle in line with the pentation angle of the muscle fibers according to Rainoldi et al. (2004). Analog EMG signals were amplified at the source with a sampling frequency of 1926 Hz (Delsys Inc, Boston, MA, USA).

Data was collected from the right leg during five double turns once skiers reached a stable speed. All measurement turns started with the fifth turn. Root mean square (RMS) was calculated for each right foot turn and then averaged to give a single value per skier per muscle. To establish a relative contraction intensity, the average voltage of the five measurement turns was divided by voltage range taken from those five turns. Absolute EMG voltages are also reported. Analyses of the absolute voltages were performed on three equal segments of each turn; the switch-initiation phase (P1), steering phase (P2), and the completion phase (P3).

A 9-channel motion sensor was used to define turn durations (Electronic Realization, Bozeman, MT, USA). The motion sensor was attached to the right ski boot above the heel binding and had a sampling frequency of 100 Hz. A turn began and finished when the right ski was flat between turns (Supej et al., 2003).

A Wilcoxon Rank Test was used to compare relative means. Alpha level of significance was set at $p \leq 0.05$. Due to lack of statistical power for the number of independent variables and interactions, the Wilcoxon Rank Test was not performed on absolute data. Instead, the Cohen's *d* effect size (ES) was calculated between skis and between snow conditions for relative values and absolute values per turn phase. Values < 0.2 defined a low effect size, 0.3 - 0.7: a moderate effect size, and > 0.8: large effect. All data listed as mean ±SD.

Results

Measurements were collected on three separate days. Snow depths on those days were 33, 37, 36 cm with a resort reported water content of the snow of 4.5%, 9%, and 7%, respectively.

Table 1 contains relative EMG signals. No statistical differences between skis or snow conditions were observed for relative EMG responses for any of the muscles. Although there was no statistical difference for the relative measures, a large effect size (1.99) for snow condition was observed in *bicep femoris* activity. Ski type exhibited a moderate effect size (0.31) where *rectus femoris* muscle activity was higher while skiing the narrow skis than wide skis. Snow condition also exhibited a moderate effect (0.31) where *rectus femoris* activity was higher in the powder than on groomed snow. Large effect sizes (1.23) were noted for ski type and snow condition where relative *gluteus medius* activity was greater with the narrow skis than wide skis and groomed snowed was greater than wide skis. A large effect size (1.27) was observed for the *vastus lateralis* for ski type where wide skis had a greater effect on *vastus lateralis* activity than narrow skis.

Table 1 *Relative EMG signal across full turn (%, ±SD).*

	NS Groomed	WS Groomed	NS Powder	WS Powder	ES Skis	ES Snow
Bicep Femoris	39 (2)	37 (3)	32 (2)	33 (4)	0.15	1.99
Rectus Femoris	30 (3)	32 (4)	35 (4)	30 (8)	0.31	0.31
Gluteus Medius	38 (3)	35 (4)	35 (3)	30 (3)	1.23	1.23
Vastus Lateralis	36 (2)	43 (4)	40 (3)	40 (2)	1.27	0.18

NS: Narrow skis, WS: Wide skis; ES Skis: Effect size of WS vs. NS; ES Snow: Effect size of groomed vs. powder

Absolute EMG voltage of the *bicep femoris* was greater in powder than on groomed snow (Figure 1). Muscle activities were 25% higher in P3 than P1 on groomed snow (ES: 1.8) and 22% lower in P2 than P1 and P3 in powder for the wide skis (ES: 0.8). While on the narrow skis, *bicep femoris* activity was stable on groomed snow, but there was 20% more activity in P2 than P1 during powder skiing (ES: 0.5).

NG: Narrow ski groomed snow; WG: Wide ski groomed snow; NP: Narrow ski powder snow; WP: Wide ski powder snow; P1: Phase 1, P2: Phase 2; P3: Phase 3.

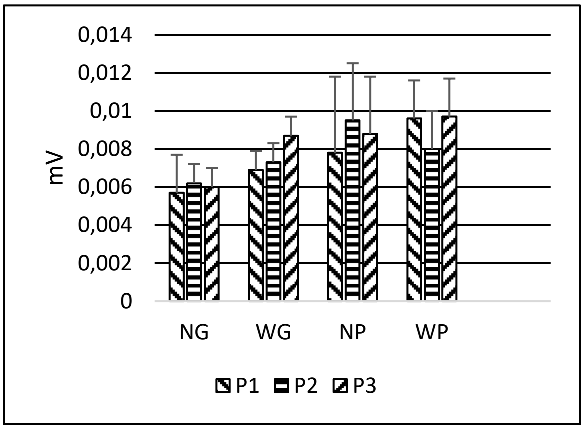

Figure 1 *Absolute voltage of bicep femoris*.

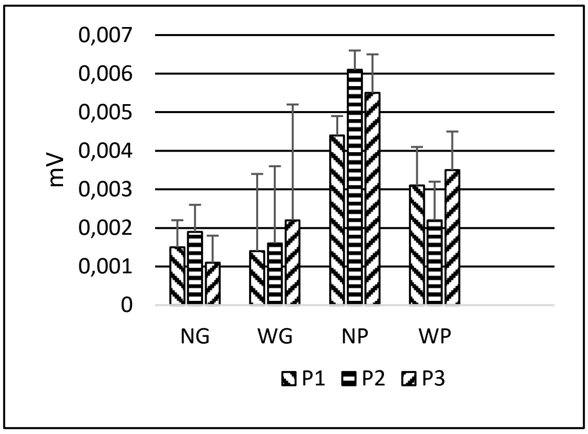

Figure 2 *Absolute voltage of rectus femoris.*

Skiing powder resulted in greater *rectus femoris* activity than when on the groomed snow (Figure 2). A similar trend in muscle activity was observed for *rectus femoris* as was seen for bicep *femoris* while skiing wide skis. High muscle activity was observed in P3 during skiing on groomed snow (ES: 1.14) while substantially lower activity in P2 than P1 and P3, by about 33%, during powder skiing on the wide skis (ES: 1.39). *Rectus femoris* activity was highest during Phase 2 in the powder condition for the narrow skis compared to P1 (ES: 1.7).

Gluteus medius activity can be found in Figure 3. Powder skiing elicited slightly more gluteus medius activity than skiing on groomed snow. As with the other muscles, *gluteus medius* activity was highest in P3 for wide skis on groomed snow (ES: 3.92) but was lowest during P2 for the powder condition (ES: 4.5). Skiing phases 2 and 3 produced greater muscle activity than P1 on groomed and powder conditions for the narrow skis (ES: 5.0 and 5.7, respectively).

Figure 4 contains the absolute voltage output of the *vastus lateralis*. Muscle activity increased throughout the turn for the wide skis and was highest in P3 on groomed snow (ES: 1.99). *Vastus lateralis* activity followed the same trend as the other muscles where there was more activity in P1 and P3 than P2 while skiing powder for wide skis

(ES: 1.77). Activity of the *vastus lateralis* was consistent throughout the three phases while skiing on the groomed run for narrow skis. In contrast to wide skis in the powder, the highest *vastus lateralis* activity for narrow skis in the powder was found in P2 (ES: 2.75)

NG: Narrow ski groomed snow; WG: Wide ski groomed snow; NP: Narrow ski powder snow; WP: Wide ski powder snow; P1: Phase 1, P2: Phase 2; P3: Phase 3.

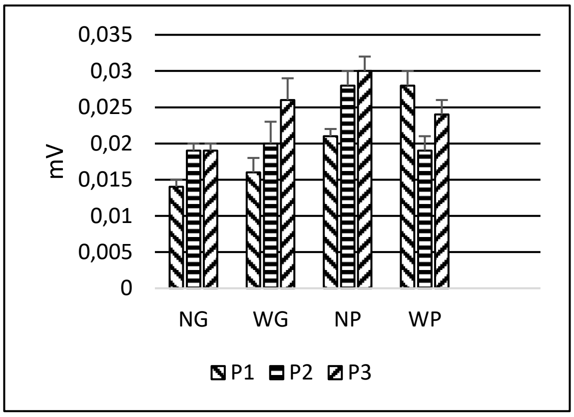

***Figure 3** Absolute voltage of gluteus medius.*

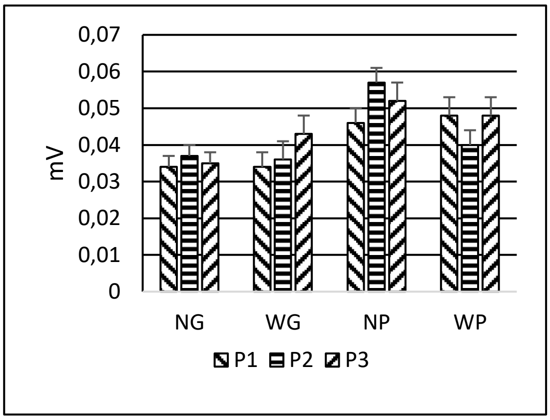

***Figure 4** Absolute voltage of vastus lateralis.*

Discussion

The purpose of this study was to compare the EMG responses between wide and narrow skis while skiing on groomed and in powder snow conditions. In general, results demonstrate that relative muscle activities were similar between wide and narrow skis over the full turn cycle, skiing powder elicited greater absolute muscle activity than when on groomed snow, skiing wide skis induced more absolute EMG activity throughout the turn phases than narrow skis when skiing on groomed snow but skiing narrow skis in the powder resulted in more EMG activity during the turning phases, skiing on narrow skis resulted in more muscle activity during P2 than P1 regardless of snow conditions, and muscle activity was lowest in P2 and highest during P1 and P3 for the wide skis while powder skiing.

There were distinct changes in EMG activities between the two skis as well as snow conditions during the turn phases. There was greater muscle loading late in the turns for wide skis as noted by high muscle activities in P3 in for groomed and powder conditions whereas high activity patterns generally occurred in P2 for narrow skis. These data correspond to the results reported by Zorko et al.'s (2015) where peak ground reaction force occurred at about 60% of the turn for narrow skis but in the late phase, at about 85% of turn completion, for the wide skis while on groomed snow.

It is also interesting to note that muscle activity was substantially lower in P2 compared to P1 and P3 in powder snow when skiing wide skis. This would indicate that skiers were using a longer radius turn, or skiing more parallel to the fall-line, resulting in lower ground reaction force during P2. Thus, lower muscle activity during this phase. This is plausible as Kipp et al. (2019) reported skiers on wide skis had significantly slower turn times than narrow skis in both groomed (by 39%) and powder (by 10%) conditions. Regarding the high EMG activities in P1 and P3 for the wide ski in powder, it makes sense that with high muscle activity (due to high ground reaction force) near the end of the turn that the skier now has to prolong muscle contractions or provide additional force to redirect the skis and initiate the next turn. This may, in part, explain why muscle activity was high in P1 for the wide ski in powder.

One issue of this type of research is that there is no conventional definition of a wide ski. Zorko et al. (2015) defined a wide ski as an underfoot ski width of 110 mm, a mid-wide as 88 mm underfoot, and a narrow ski with an underfoot width of 65 mm. Seifert et al. (2018), however, only differentiated narrow from a wide ski. Those authors defined a wide ski as a ski with an underfoot width of greater than 85 mm. However, a popular press magazine, Ski Magazine Ski Guide (2018), defined a narrow ski as one with an underfoot width of less than 95 mm. The need for standardization becomes apparent.

There are areas of potential criticisms of this study. Those include skiers using their own skis instead of having a standardized pair of skis, measurement turns were not standardized, variable snow conditions between the three days of testing, and low number of subjects. However, to counter these criticisms, the learning effect could be substantial by having skiers switch to different or unfamiliar skis, thus, altering skiing technique. The decision was made to have skiers use their own skis as they are familiar with how their skis respond. It was observed that there was a difference in turn characteristics between the two skis in the various snow conditions. It was also decided to let skiers ski self-select turns as not to disrupt the powder conditions. Skiers, though, were given instructions to keep their turns as consistent as possible. Snow variability was minimized as skiers completed their runs in a single day of testing. Lastly, having limited space and waiting for similar snow conditions (snow depth and water content) limited the research to a small number of subjects.

Conclusion

There were substantial differences in EMG activities between narrow and wide skis as well as groomed vs. powder snow conditions. There were also distinct differences within and between skis for the phases of the turn depending on turn shape and pressure development. Skiers used more of an arcing turn into the fall-line with narrow skis presumably through increasing ski pressure during P2. In contrast, skiers performed more of a ‘J’ turn with wide skis where they generated more ski pressure late in the turn. Skiers also tended to ski more parallel to the fall-line with a longer turn radius with their wide skis than the narrow skis. The results of this study may have implications for the developing skier and establishing neurological patterns of muscle contraction. It is assumed that the high activity levels seen for narrow skis occurred near the apex of the turn whereas high muscle activities occurred late in the turn with wide skis. This may be due to the wide ski characteristic to rise in the snow surface during a turn in powder snow and the difficulty of getting the ski to an optimal edge angle to carve a turn on groomed snow.

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