

Comparison of Skiing Time and Vertical Ground Reaction Force between the Short Turn and Basic Parallel Turn during Alpine Skiing

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Objective: This study aimed to investigate the differences in skiing time and vertical ground reaction force (vGRF) between the basic parallel turn and short turn.

Method: Eleven alpine ski instructors (age: 28.73±4.29 yrs, height: 172.36±6.30 cm, body mass: 71.45±9.16 kg, career: 11.09±2.70 yrs) participated in this study. Each skier was asked to perform a basic parallel turn and short turn on a 16° groomed slope. A foot pressure measurement system was used to measure the skiing time and vGRF under the three plantar regions (forefoot, midfoot, rearfoot).

Results: Skiing time decreased significantly in all three phases during the short turn ($p<.05$). In the initiation phase, the vGRF showed a greater decrease on the midfoot and rearfoot during the short turn ($p<.05$). In the steering phase 1, the vGRF showed a greater increase on the forefoot and decreased on the midfoot during the short turn ($p<.05$). In the steering phase 2, the vGRF showed a greater increase on the forefoot and rearfoot during the short turn ($p<.05$).

Conclusion: Our findings proved that the skiing time and vGRF changed during the short turn. Consequently, we suggest that recreational skiers should decrease the skiing time of the steering phase compared to that of the initiation phase and increase the vGRF on the forefoot and rearfoot in the steering phase.

Keywords: Alpine ski, Short turn, Basic parallel turn, Vertical GRF

INTRODUCTION

Alpine skiing is a sport wherein skiers slide down snow-covered hills; skiers must descend with limited speed and turning radius depending on the terrain features (Gilgien, Crivelli, Spörri, Kröll & Müller, 2015). Turning techniques to control the speed of descent and turning radius have been continuously researched and developed in alpine skiing; skiers learn turning techniques of varying difficulties according to their performance level. Most novice alpine skiers learn a basic braking technique called the snowplow (Kim, 2004, 2006a, 2006b; Hyun, 2000). In the snowplow, both skis are maintained in an A-shape to increase the friction between the snow surface and skis through skidding, thereby decreasing the speed. To ensure a greater braking force, skiers train to make larger snowplow and edging angles (Kim, Kim, Ryu, Yoon & Park, 2016). Once skiers learn the basic methods of controlling speed, they learn how to turn by using the changes in the center of mass and ground reaction force (GRF) while maintaining the snowplow posture in order to control the direction (Koo, Lee, Kweon, Hyun & Eun, 2014). After learning these two basic techniques, skiers then learn the stem turn to glide with their skis aligned parallel to each other. The stem turn

is a technique of repeatedly performing the snowplow and bringing the skis parallel; aligning the skis parallel after steering is called the down-stem turn while aligning the skis parallel before steering is called the up-stem turn (Müller et al., 1998). The stem turn enables a skier to smoothly bring the skis parallel by appropriately moving their body weight; the ultimate goal is to enable the skier to take basic parallel turns. Unlike in a carved turn, the directions of the skis and descent are different in basic parallel turns. This generates an attack angle, which leads to deceleration and turning as the skis skid and induce friction; for this reason, this is classified as a skidded turn (Hirano, 2006; Mössner et al., 2014). Müller et al. (1998) and Kim et al. (2014) reported that for basic parallel turns, skiers must extend their knee and hip joints to ensure unweighting in the transitions between turns; after crossing the fall line, the counter-rotation position and inward lean angle must be increased such that the edging angle is increased to prevent excessive skidding (Yoon et al., 2017). Furthermore, Hintermeister, O'Connor, Lange, Dillman, and Steadman (1997) and Kim et al. (2014) emphasized skiing centered on the outside ski when performing a basic parallel turn and stressed a sequential vertical GRF pattern from the forefoot to the rearfoot depending on the skiing phase.

In general, recreational skiers must be able to perform the carved turn (where skidding is minimized to increase gliding speed) and the short turn (with progressively shorter radii) to progress from an intermediate skier to an advanced skier. Therefore, intermediate skiers who have learned parallel runs and moving weight during their basic parallel turn training must choose between the carved and short turn as the next stage of training to become advanced skiers. For carved turns, there is a training guideline for recreational skiers that was developed based on quantified databases, as kinematic analyses have been performed in various fields since the introduction of carving ski using side-cuts. However, even though many intermediate skiers train to learn the short turn, training is dependent only on empirical knowledge due to the lack of quantitative research.

In alpine skiing, the reaction force between the snow surface and skis causes a turn, and the property and size of the reaction force determine the gliding speed and turning radius (Mössner, Nachbauer, Innerhofer, & Schretter, 2003; Mössner et al., 2014). Previous studies report that the GRF that occurs during alpine skiing exceeds 6,000 N (Babiel, Hartmann, Spitzenpfeil & Mester, 1997) and various aspects of GRF are being studied to improve alpine skiing techniques. Supej, Hébert-Losier, and Holmberg (2015) and Supej and Holmberg (2010) suggested a strategy for minimizing energy loss through their investigation of GRF required for skiing with acceleration caused by slope and skiing with a limited turning radius. Klous, Müller, and Schwameder (2012), Yoneyama, Kagawa, Okamoto, and Sawada (2000) examined the GRF occurring during carved and skidded turns and presented indices for successfully performing these techniques. Furthermore, GRF may also be used as a predictor of successful steering (Supej, Kipp & Holmberg, 2011).

Vaverka, Vodickova, and Elfmark (2012) emphasized the GRF patterns of each skiing phase while steering in alpine skiing. Alpine skiing involves repeated steering with varying features in each skiing phase. The initiation phase is a linear phase for transitioning from one turn to the next turn, in which unweighting and edge change occurs. Steering phase 1 is the phase from the start of the steering to the fall line, and steering phase 2 is the phase from the fall line to the linear phase (Müller et al., 1998). All turn techniques in alpine skiing consist of these three phases, and the size and duration of GRF in each phase determines the success of each turning technique. Therefore, quantifying the differences in GRF patterns between the basic parallel and short turns is important to help intermediate skiers to learn the short turn after mastering basic parallel turns. In this context, this study aims to analyze the differences of phase-specific skiing time and GRF on the forefoot, midfoot, and rearfoot for basic parallel turns and short turns.

METHODS

1. Participants

Eleven male ski instructors with a level 3 instructor license registered with the Korean Ski Instructor Association (KSIA) who had at least seven years of teaching experience and were adequately capable of performing both the short turn and basic parallel turn were enrolled in this study (Table 1). The study was conducted only on participants who provided

informed consents.

Table 1. Summary information for the participants

	KSIA level-3 instructors (n=11)
Age (yrs)	28.73±4.29
Body mass (kg)	71.45±9.16
Height (cm)	172.36±6.30
Career (yrs)	11.09±2.70

2. Measurements

Skiing time and GRF during the basic parallel turn and short turn were measured with a 2-mm insole foot pressure system (Pedar-X, Novel, Germany) comprising 99 capacitive pressure sensors. The sampling rate was set to 100 Hz. Participants used their own ski boots, and the existing insole was removed before installing the pressure sensor to eliminate the effects of the functional features of the previous insole and the thickness of the pressure sensor. The data logger and battery pack (one set weighing 1 kg) were placed around the skier's waist, and the receptor and laptop were placed on the follower, who was instructed to maintain an appropriate distance so as not to affect the skier's movements. To establish the skiing phases, we synchronized with a video camera. To minimize the effects of ski structure and materials, all participants used the same slalom ski (165 cm) for the experiment (Rossignol Worldcup SL, Rossignol, France).

Prior to the experiment, all skiers performed adequate warm-up exercises and practiced basic parallel turns and short turns. The average temperature at the ski slope was -6°C, and the experiment was conducted on an intermediate-advanced slope (width 70 m, length 800 m) with an average slope of 16°; this course is used as the main course for practice for intermediate skiers learning basic parallel turns and short turns.

3. Data processing

Each skier performed at least eight basic parallel turns and eight short turns. After eliminating the first three turns, five consecutive turns on the right were used for analysis. Each turn was divided into three phases: initiation phase (linear phase transitioning from one turn to the next turn), steering phase 1 (from beginning of the turn to the fall line) and steering phase 2 (from the fall line to the beginning of the next linear phase) for the analysis (Figure 1; Müller et al., 1998).

The collected right foot GRF data were analyzed by dividing the data into forefoot, midfoot, and rearfoot to compute the mean and standard deviation of time and vertical GRF (vGRF) of each skiing phase. The vGRF was computed by summing the measurements from 99 pressure sensors and normalizing it by dividing the number by each skier's body mass before calculating the mean and standard deviation (Nakazato, Scheiber & Müller, 2013; Spörri, Kröll, Haid, Fasel & Müller, 2015).

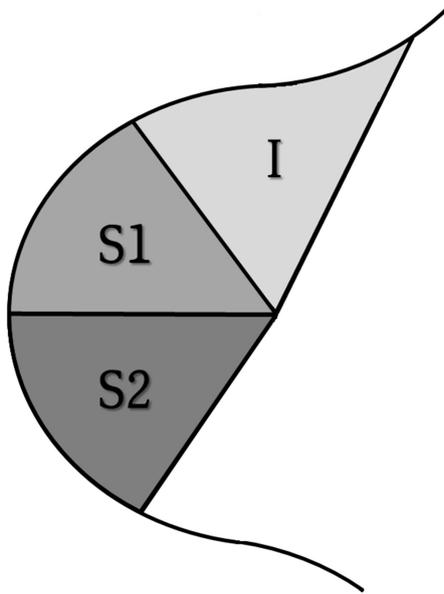


Figure 1. Skiing phases (I: initiation phase, S1: steering phase 1, S2: steering phase 2; Kim et al., 2014)

4. Statistical analysis

The differences in time and vGRF on the forefoot, midfoot, and rearfoot during basic parallel turns and short turns were analyzed using paired *t*-tests. Statistical significance was set at $\alpha=.05$.

RESULTS

1. Skiing time

Skiing time for the initiation phase was 0.26 ± 0.05 seconds during the short turn, and 0.50 ± 0.16 seconds for the basic parallel turn, showing a significant reduction of time during the short turn ($p<.05$, Figure 2(A), Table 2).

Skiing time for the steering phase 1 was 0.19 ± 0.08 during the short turn and 1.14 ± 0.40 seconds for the basic parallel turn, showing a significant reduction of time during the short turn ($p<.05$, Figure 2(B), Table 2).

Skiing time for the steering phase 2 was 0.19 ± 0.05 seconds during the short turn and 1.58 ± 0.24 seconds during the basic parallel turn, showing a significant reduction of time during the short turn ($p<.05$, Figure 2(C), Table 2).

2. Vertical ground reaction force

In the initiation phase, the vGRF was 0.24 ± 0.06 N/kg, 0.04 ± 0.02 N/kg, and 0.04 ± 0.03 N/kg on the forefoot, midfoot, and rearfoot, respectively during the short turn; the vGRF was 0.17 ± 0.07 N/kg, 0.12 ± 0.02 N/kg, and 0.11 ± 0.10 N/kg on the forefoot, midfoot, and rearfoot, respectively during the basic parallel turn, showing a significant reduction of vGRF on the midfoot and rearfoot during the short turn ($p<.05$, Figure 2(A), Table 3).

In steering phase 1, the vGRF was 0.58 ± 0.11 N/kg, 0.10 ± 0.03 N/kg, and 0.18 ± 0.09 N/kg on the forefoot, midfoot, and rearfoot, respectively during the short turn; the vGRF was 0.40 ± 0.08 N/kg, 0.23 ± 0.02 N/kg, and 0.18 ± 0.07 N/kg on the forefoot, midfoot, and rearfoot, respectively during the basic parallel turn, showing a significant increase in the vGRF on the forefoot and significant reduction on the midfoot during the short turn ($p<.05$, Figure 2(B), Table 3).

In steering phase 2, the vGRF was 0.55 ± 0.10 N/kg, 0.18 ± 0.03 N/kg, and 0.84 ± 0.08 N/kg on the forefoot, midfoot, and rearfoot, respectively during the short turn; the vGRF was 0.22 ± 0.04 N/kg, 0.19 ± 0.03 N/kg, and 0.71 ± 0.08 N/kg on the forefoot, midfoot, and rearfoot, respectively during the basic parallel turn, showing a significant increase in the vGRF

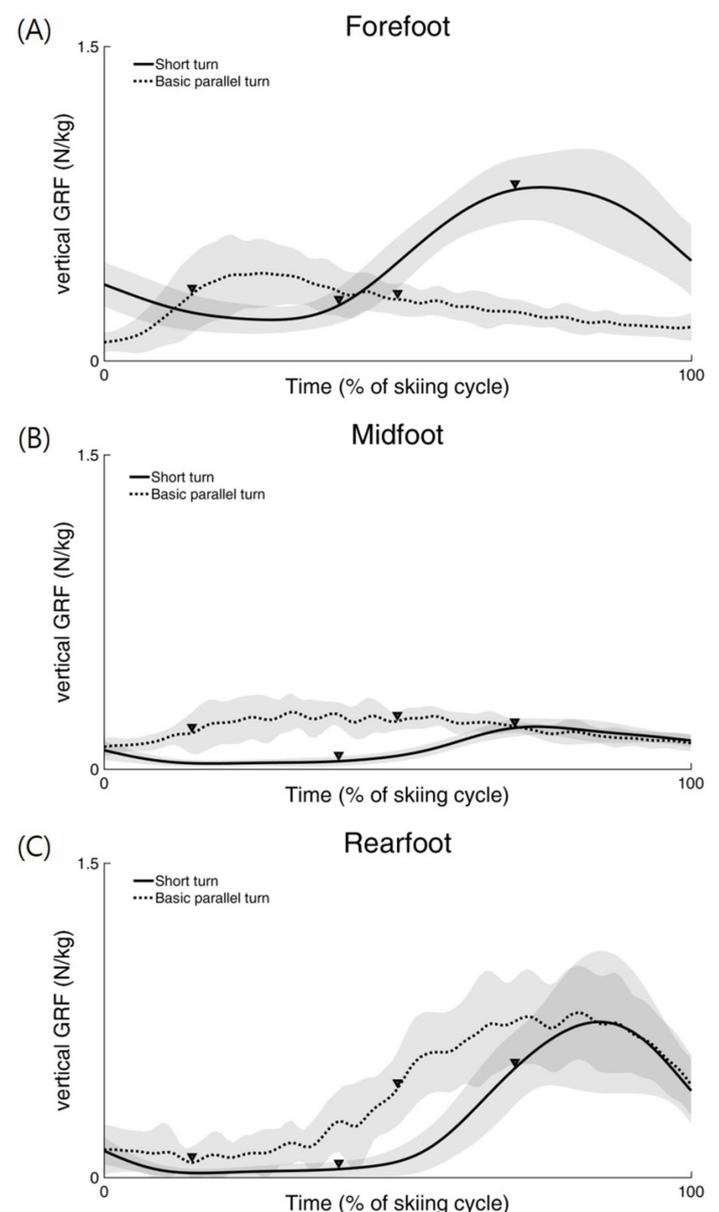


Figure 2. Mean \pm standard deviation of the vertical GRF on the forefoot (A), midfoot (B), and rearfoot (C) of the outer ski during short turns (solid line) and basic parallel turns (dot line). The ▼ symbol indicates an event between skiing phases.

Table 2. Mean (standard deviations) of the skiing time and paired *t*-test results between turn types (unit: sec)

Turn phase	Basic parallel turn	Short turn	<i>t</i> -value	<i>p</i> -value
Initiation phase	0.50±0.16	0.26±0.05	4.243	.002*
Steering phase 1	1.14±0.40	0.19±0.08	11.058	.000*
Steering phase 2	1.58±0.24	0.19±0.05	18.512	.000*

Note. The * symbol indicates a significant difference between the basic parallel turn and short turn at $p < .05$.

Table 3. Mean (standard deviations) of the vertical GRF and paired *t*-test results between turn types (unit: N/kg)

Turn phase	Plantar regions	Basic parallel turn	Short turn	<i>t</i> -value	<i>p</i> -value
Initiation phase	Forefoot	0.17±0.07	0.24±0.06	-2.040	.069
	Midfoot	0.12±0.02	0.04±0.02	8.669	.000*
	Rearfoot	0.11±0.10	0.04±0.03	2.401	.037*
Steering phase 1	Forefoot	0.40±0.08	0.58±0.11	-3.448	.006*
	Midfoot	0.23±0.02	0.10±0.03	9.974	.000*
	Rearfoot	0.18±0.07	0.18±0.09	-.028	.978
Steering phase 2	Forefoot	0.22±0.04	0.55±0.10	-9.901	.000*
	Midfoot	0.19±0.03	0.18±0.03	.467	.651
	Rearfoot	0.71±0.08	0.84±0.08	-4.761	.001*

Note. The * symbol indicates a significant difference between the basic parallel turn and short turn at $p < .05$.

on the forefoot and rearfoot during the short turn ($p < .05$, Figure 2(C), Table 3).

DISCUSSION

After learning the basic techniques, recreational alpine skiers learn how to descend with their skis aligned in parallel by learning basic parallel turns. During this process, skiers learn how to control the center of mass, weight loading, and edging angles through joint and segment movements, after which they selectively learn carved turns that enable rapid gliding and short turns with short radii to become more advanced skiers (Kim et al., 2014; Kim et al., 2014). Alpine skiing involves a heavier use of the outer ski than the inner ski with reference to the direction of the turn (Hintermeister et al., 1997; Kröll, Wakeling, Seifert & Müller, 2010; Stricker, Scheibera, Lindenhofera & Müllera, 2010; Vaverka et al., 2012). The vGRF patterns in the forefoot, midfoot, and rearfoot varies widely according to the type and phase of turn (Kim et al., 2014; Nakazato et al., 2013). Because short turns have the shortest radii among all types of turns performed by skiers, they must be performed in a shorter amount of time with a relatively large centripetal force. Therefore, this study analyzed the skiing time and vGRFs shown during basic parallel turns and short turns.

The first thing that recreational skiers who are learning short turns practice is turns with short rhythms. According to our findings, the duration of the initiation phase, steering phase 1, and steering phase 2 were significantly lower by 48.00%, 83.33%, and 87.97%, respectively,

in the short turns compared to those in the basic parallel turns. In terms of skiing time in relation to type of turn, basic parallel turns showed a relatively longer duration of steering phases, with times spent on initiation phase, steering phase 1, and steering phase 2 at 15.53%, 35.40%, and 40.63%, respectively, while short turns showed relatively longer duration of the initiation (transition) phase, at 40.63%, 29.69%, and 29.69%, respectively. Thus, intermediate skiers should not only shorten the overall duration of all phases but also focus on performing turns with relatively shorter steering phases and longer initiation phases to generate GRF.

Alpine skiing is reported to exhibit a sequential movement of the center of pressure (COP) from the forefoot to the rearfoot in the steering phase and again to the forefoot in the initiation phase (Kim et al., 2014; Nakazato et al., 2013). The initiation phase is a phase marking the end of the previous turn and beginning of the next turn; that is, it is a phase in which the surface touching the snow shifts from the uphill edge to the downhill edge. This phase is defined as a linear phase with no turns as well as a phase in which the skis become horizontal with the snow surface with equal GRF on both feet. Further, this is also a phase in which a neutral position is assumed, where the GRF that was focused on the rearfoot at the end of the turn is again moved to the forefoot, and one in which unweighting occurs as a result from the elasticity caused by the restoration of the camber (Kim et al., 2014; LeMaster, 2010; Müller et al., 1998). In our study, the vGRF on the midfoot and rearfoot were significantly lower during a short turn. In general, more bending of the ski is required with smaller radius turns; thus, un-

weighting in the initiation phase leads to a large rebound caused by elasticity (Federolf, Roos, Lüthi & Dual, 2010; Yoneyama, Scott, Kagawa & Osada, 2008). Therefore, the lower vGRF on the midfoot and rearfoot during a short turn is speculated to be due to a greater rebound compared to that in a basic parallel turn.

In turns wherein the centripetal force is generated by using friction from skidding, such as basic parallel turns and short turns, steering phase 1 is the phase that marks the beginning of a turn using the attack angle and edging angle (Hirano, 2006; Mössner et al., 2014; Müller et al., 1998). Compared to intermediate skiers, advanced skiers induce a more drastic turn by increasing the reaction force between the tip of the ski and snow surface by using their forefoot more (Kim et al., 2014). In the present study, the vGRF resulting from a short turn significantly increased on the forefoot while it significantly decreased on the midfoot. This may be attributable to the fact that skiers have to return the skis to the fall line 83.33% quicker in a short turn than in a basic parallel turn; therefore, the vGRF on the forefoot is increased—by minimizing the distribution of the vGRF to the midfoot—to induce a stronger reaction force between the tip of the ski and snow surface.

Steering phase 2 refers to the phase in which a turn is completed by ensuring that excessive skidding does not occur by increasing the edging angle. According to Müller et al. (1998), advanced skiers enter the linear phase in a position in which skidding is minimized by increasing the edging angle using a counter rotation position, whereas intermediate skiers perform an excessive turn. The counter rotation position increases the slope of the center of mass and hip angulation to increase the edging angle, which in turn increases the reaction force between the snow surface and ski (Mössner et al., 2014; Yoon et al., 2017). This reaction force is classified as a shear force that acts horizontally to the penetration force created by the edge as it vertically penetrates the snow surface. Particularly, the penetration force increases with an increasing edging angle, suggesting that the edging angle has a direct impact on penetration depth (Federolf et al., 2014). Skidding of the ski is determined by this penetration depth, where the deeper the penetration, the lower the skidding occurs. In our results, the vGRF on the forefoot and rearfoot were significantly higher in a short turn than those in a basic parallel turn. This is speculated to be because a short turn must be completed 87.97% quicker than a basic parallel turn with minimal skidding, thereby promoting motions (such as the counter rotation position) that increase vGRF on the forefoot and rearfoot to increase the depth of ski penetration.

This study analyzed phase-specific skiing time and vGRF on the forefoot, midfoot, and rearfoot using a foot pressure detector system in order to investigate the differences of skiing time and vGRF between basic parallel turns and short turns. However, the insole-type foot pressure detector systems used for alpine ski boots tend to underestimate vGRF due to a loss of force at the support for the lower leg (Stricker et al., 2010). Thus, future studies should address the loss of force at the lower leg or perform kinematic analyses using GRF detection systems that may be installed on skis. This will contribute to improving recreational skiers' technical skills and developing a quantitative guideline that is needed to devise improved methods of teaching recreational skiers.

CONCLUSION

This study compared skiing time and vGRF during a basic parallel turn and short turn in alpine skiing. To this end, 11 ski instructors affiliated with the Korean Ski Instructor Association (KSIA) participated, and data were collected using an insole foot pressure detector system in a 16° groomed slope. The skiing time was significantly shorter for a short turn compared to that for a basic parallel turn. Further, the vGRF on the midfoot and rearfoot were significantly lower in the initiation phase while the vGRF on the forefoot was significantly higher and that on the midfoot was significantly lower in steering phase 1 for short turns. In steering phase 2, the vGRF on the forefoot and rearfoot was significantly greater. These results suggest that skiers learning short turns should take shorter steering phases than initiation phases and take positions that increase the vGRF on the forefoot and rearfoot in order to adequately perform a turn within a short period of time. Future studies should address the issue of underestimation of GRF and employ kinematic analyses to quantify the current pool of empirical knowledge, with the ultimate goal of improving the technical skills of recreational skiers.

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