DOES THE SEQUENTIAL TEACHING OF ELEMENTS OF ALPINE SKI SCHOOL FOLLOW THE INCREASE OF PRESSURE BENEATH THE SKIER'S FOOT?

Vjekoslav Cigrovski[1], Mateja Očić[1], Ivan Bon[1], Tomislav Rupčić[1], Igor Božić[2]

[1]*University of Zagreb, Faculty of Kinesiology, Croatia*

[2]*University of Banja Luka, Faculty of Physical Education and Sport, Bosnia and Herzegovina*

Original scientific paper

Abstract

In everyday practice, it is quite common for a ski instructor to ask ski school participants to become aware of pressure under certain parts of the feet during skiing in order to improve their performance. At the same time literature is lacking concerning ground reaction forces and pressures achieved during recreational level skiing. The aim of the present study was to determine the differences between measured forces and their distribution under skiers' feet during performance of different elements of ski technique. Analysis of kinetic parameters was conducted on four elements of alpine ski school (snowplough, basic turn, parallel turn, short turn). Variable sample included 16 variables. In each element of ski technique analysed were 12 turns (6 in left and 6 in right side). Kinetic parameters were measured by insoles designed for pressure detection (Novel, Pedar). Results of our study suggest that in-boot pressure over outer leg rises as the turns become more complex (from basic to parallel turn and short turn). When pressure is compared between inner and outer leg, significantly lower pressure level was on an inner leg (in ratio 1:4) in all elements of technique except during short turn. From a ski technique standpoint, it was clear that the pressure applied with the feet was higher towards more complex elements, and this finding is in accordance with advancements of plan and program of an alpine ski school. Therefore, it is necessary for ski instructors to teach skiing beginners where, when and how to apply pressure in each phase of learning process.

***Key words**:* alpine skiing, kinetic analysis, pressure insoles

Introduction

Analysis of forces acting on a skier during the turn leads to a better understanding of relationships between time parameters and forces in different phases of a turn. To control the forces during the turn, skier needs to position the skies at a specific angle (edging angle), press them on the snow surface and rotate them (LeMaster & Supej, 2015). Skies are led to perform a turn by whole body movements, whose effects are transferred through feet and ski boots on a ski and finally snow surface (Cigrovski & Matković, 2015). To find an optimal balance position by using feet, ski shoes and skies on a snow surface, it is essential to harmonize the pressure that a skier produces during a turn as well as ground reaction forces (Falda-Buscaiot et al., 2017). While skiing, a skier copes with gravity, air resistance and snow resistance forces as well as centrifugal force acting from the centre of a turn laterally (Vaverka & Vodickova, 2010; Vaverka et al.,2012). In the literature, regarding the duration of skiers' pressure on a snow surface as well as ground reaction force, turn is usually divided into two or three phases (Lešnik & Žvan, 2010; Cigrovski & Matković, 2015). The highest measured ground force during competitive skiing is during steering phase at the point where skier shifts to an outer leg and ends when a skier at the final stage of a turn detaches from the snow surface, where the ground force equals zero (Vaverka et al., 2012). For years now, investigation of forces during skiing uses insoles that measure pressure distribution beneath the competitors' feet. Moreover, improvements in insole performance enabled gathering of additional detailed data, but investigation was primarily conducted on ski racers (Schaff et al., 1988; Falda-Buscaiot et al., 2017). Mentioned research helps our understanding which part of the feet is pressured during particular phase of a turn, and helps in determining which region of the foot contributes to the steering effect of skies during a particular phase of a turn relative to terrain steepness (Gilgien et al., 2015; Supej et al., 2015).

The question remaining is if what is determined for ski competitors is valid also for ski beginners and recreational level skiers. In everyday practice, it is quite common for a ski instructor and a coach to ask ski school participants to become aware of a pressure under certain parts of the feet during skiing in order to improve their performance. At the same time literature is lacking concerning ground reaction forces and pressures achieved during recreational level skiing. Some authors have reported on differences in the ground reaction forces between skiers of different level (expert and intermediate level) measured by pressure insoles during different skiing modes (high dynamic-carving in short radii vs low dynamic-parallel in long radii) and during different phases of a turn (Nakazato et al., 2013). For a beginner to achieve and maintain optimal balance position while going through different phases of a turn he needs to cope with different forces (Žvan et al., 2015). For a safe and efficacious alpine ski school it is essential that the demands put on a ski beginner escalate properly through the elements of alpine ski school, starting from more basic ones such as snowplough to more complex turns of parallel ski technique.

The aim of the present study was to determine the differences between measured forces and their distribution under skiers' feet during performance of different elements of ski technique.

Methods

Participants: Analysis of kinetic parameters was conducted on four elements of alpine ski school (snowplough, basic turn, parallel turn, short turn). They were performed by a female 25 years old ski instructor (height 165 cm, weight 56 kg). Prior to study start participant was in detail informed about study aims and voluntarily agreed to participate.

Variables: Variable sample included 16 variables. In each element of ski technique analysed were 12 turns (6 in left and 6 in right side). Pressure distribution of inner and outer ski boot on snow surface with respect to axis of turn rotation was analysed. For every turn data were collected on overall foot pressure on surface, distribution of pressure on medial and lateral part of a foot and on heel. Results are shown in newton (N).

Protocol of investigation: Kinetic parameters were measured by insoles designed for pressure detection, Novel, Pedar. For the purposes of this investigation they were set at 100Hz. The optimal insole size was selected and inserted into inner ski boots. Insoles were thin and light, so had minimal influence on skier's performance during the investigation. This is especially important during more dynamic skiing, i.e. performance of advanced elements of ski technique. Standard calibration according to manufacturers' advice was performed (Novel GmBh, Munich, Germany). Kinetic parameters for all four elements were measured on selected part of terrain, taking into consideration characteristics of specific element, in previously defined corridor of 25 m width in case of basic and parallel turn and 10 m wide corridor in case of snowplough and short turn. Before turns were measured, participant received detailed information on turn characteristics she was to perform. Study was performed during morning hours in order to secure better snow conditions. Participant had the same skiing equipment (slalom skis and boots) during demonstration of the four elements of ski technique.

Methods: For the statistical analysis program „Statistica“ version 13.5 was used. Calculated were basic descriptive parameters for all 16 variables. For the detection of differences between the elements multivariate analysis of variance (MANOVA) was used, and Tukey post-hoc test was used to determine differences between elements. Results were considered significant in case of $p<0.05$.

Results and Discussion

Table 1 Results of MANOVA for four elements of alpine ski school.

	Test	Lambda value	F	p
criteria	Wilks	0,00	14,76	0,00*

Results shown in Table 1 show statistically significant difference between four elements of ski technique (F= 14,76; p=0,00).

Table 2 Basic descriptive statistical parameters and ANOVA for variables snowplough, basic turn, parallel turn, and short turn.

Variable	snowplough	basic turn	parallel turn	short turn	F	p
Max_R_o	608,36±89,76	704,09±71,05	854,29±69,69	922,02±94,16	18,09	0,00*
Med_R_o	366,67±74,07	397,38±53,45	546,92±59,60	380,41±88,81	8,49	0,00*
Lat_R_o	231,82±40,98	306,07±45,07	284,18±18,76	207,68±51,69	7,38	0,00*
Heel_R_o	9,87±24,18	0,64±1,57	23,19±36,44	333,93±80,27	75,00	0,00*
Max_L_i	42,43±53,12	32,34±29,03	21,07±13,82	273,33±70,33	39,93	0,00*
Med_L_i	18,33±21,60	2,46±4,16	14,27±10,12	73,90±51,14	7,59	0,00*
Lat_L_i	20,79±37,09	26,59±30,17	5,98±5,81	41,45±20,51	1,89	0,16
Heel_L_i	3,30±8,08	3,28±6,02	0,82±2,01	157,99±103,74	13,36	0,00*
Max_L_o	672,83±79,47	770,30±42,90	913,54±73,21	906,39±73,13	17,08	0,00*
Med_L_o	334,00±67,17	428,33±10,33	566,61±82,65	390,78±64,09	15,13	0,00*
Lat_L_o	298,67±35,20	339,15±41,95	314,65±35,08	225,74±22,69	12,05	0,00*
Heel_L_o	40,15±26,47	2,81±5,38	32,27±38,70	289,88±78,28	51,09	0,00*
Max_R_i	4,16±4,91	18,99±23,22	15,82±4,51	364,96±90,97	84,01	0,00*
Med_R_i	0,00±0,00	4,15±7,98	6,99±6,76	105,50±44,03	30,45	0,00*
Lat_R_i	4,16±4,91	5,82±7,35	8,83±6,59	101,38±34,36	41,75	0,00*
Heel_R_i	0,00±0,00	9,03±14,05	0,00±0,00	158,08±41,48	75,44	0,00*

Results of univariate analysis of variance are shown in Table 2 and suggest statistically significant differences in 15 variables (p=0.00) between all four elements of ski technique.

Table 3 Tukey post-hoc results in each measured variable in right turn for every element of ski technique (1 - snowplough, 2 - basic turn, 3 - parallel turn, 4 - short turn).

Max_L_o					**Med_L_o**				
Group	1(672,83)	2(770,30)	3(913,54)	4(906,39)	group	1(334,00)	2(428,33)	3(566,61)	4(390,78)
1		0,10	0,00*	0,00*	1		0,07	0,00*	0,41
2	0,10		0,01*	0,01*	2	0,07		0,01*	0,73
3	0,00*	0,01*		1,00	3	0,00*	0,01*		0,00*
4	0,00*	0,01*	1,00		4	0,41	0,73	0,00*	
Lat_L_o					**Heel_L_o**				
Group	1(298,67)	2(339,15)	3(314,65)	4(225,74)	group	1(40,15)	2(2,81)	3(32,27)	4(289,88)
1		0,21	0,85	0,01*	1		0,51	0,99	0,00*
2	0,21		0,61	0,00*	2	0,51		0,68	0,00*
3	0,85	0,61		0,00*	3	0,99	0,68		0,00*
4	0,01*	0,00*	0,00*		4	0,00*	0,00*	0,00*	
Max_R_i					**Med_R_i**				
Group	1(4,16)	2(18,99)	3(15,82)	4(364,96)	group	1(0,00)	2(4,15)	3(6,99)	4(105,50)
1		0,95	0,97	0,00*	1		0,99	0,95	0,00*
2	0,95		1,00	0,00*	2	0,99		1,00	0,00*
3	0,97	1,00		0,00*	3	0,95	1,00		0,00*
4	0,00*	0,00*	0,00*		4	0,00*	0,00*	0,00*	
Lat_R_i					**Heel_R_i**				
Group	1(4,16)	2(5,82)	3(8,83)	4(101,38)	group	1(0,00)	2(9,03)	3(0,00)	4(158,08)
1		1,00	0,97	0,00*	1		0,89	1,00	0,00*
2	1,00		0,99	0,00*	2	0,89		0,89	0,00*
3	0,97	0,99		0,00*	3	1,00	0,89		0,00*
4	0,00*	0,00*	0,00*		4	0,00*	0,00*	0,00*	

Overall average force during the turn performed by the outer (left) leg is progressively increasing towards the more complex elements and is almost the same during parallel turn and short turn. When compared to research of Lafontaine and coauthors (1999), and taking into account limitations of the equipment at the time, similar findings in terms of pressure detection were also reported and explained by the turn dynamics, which is faster in case of short turns. The highest forces during all elements of technique were measured above the medial part of the foot, and it progressively increased towards the more complex elements. The forces over lateral part of the foot were increasing during basic turn, and were then falling towards short turn, during which the force was smaller than in snowplough turn. The force measured over heel was small except during performance of a short turn, when it was significantly higher compared to other turns. Overall average force during the turn on the inner (right) leg was small, except during short turn, when it was significantly higher compared to other types of turns. Forces over medial part of a foot were small, except measured during short turn, when the force was significantly more pronounced compared to other turn types. Similarly, forces over lateral part of the inner foot were also small, except during performance of a short turn, where forces were also significantly higher over the heel than during other turns.

Table 4 Tukey post-hoc results in each measured variable in left turn for every element of ski technique (1 - snowplough, 2 - basic turn, 3 - parallel turn, 4 - short turn).

Max_R_o					**Med_R_o**				
Group	1(608,36	2(704,09	3(854,29	4(922,02	group	1(366,67	2(397,38	3(546,92	4(380,41
1		0,21	0,00*	0,00*	1		0,87	0,00*	0,99
2	0,21		0,02*	0,00*	2	0,87		0,01*	0,97
3	0,00*	0,02		0,49	3	0,00*	0,01*		0,00*
4	0,00*	0,00*	0,49		4	0,99	0,97	0,00*	
Lat_R_o					**Heel_R_o**				
Group	1(231,82	2(306,07	3(284,18	4(207,68	group	1(9,87)	2(0,64)	3(23,19)	4(333,93
1		0,02*	0,15	0,74	1		0,98	0,96	0,00*
2	0,02*		0,79	0,00*	2	0,98		0,83	0,00*
3	0,15	0,79		0,02*	3	0,96	0,83		0,00*
4	0,74	0,00*	0,02*		4	0,00*	0,00*	0,00*	
Max_L_i					**Med_L_i**				
Group	1(42,43)	2(32,34)	3(21,07)	4(273,33	group	1(18,33)	2(2,46)	3(14,27)	4(73,90)
1		0,98	0,86	0,00*	1		0,77	0,99	0,01*
2	0,98		0,98	0,00*	2	0,77		0,89	0,00*
3	0,86	0,98		0,00*	3	0,99	0,89		0,01*
4	0,00*	0,00*	0,00*		4	0,01*	0,00*	0,01*	

Lat_L_i					**Heel_L_i**				
Group	1(20,79)	2(26,59)	3(5,98)	4(41,45)	group	1(3,30)	2(3,28)	3(0,82)	4(157,99
1		0,98	0,76	0,53	1		1,00	1,00	0,00*
2	0,98		0,54	0,76	2	1,00		1,00	0,00*
3	0,76	0,54		0,12	3	1,00	1,00		0,00*
4	0,53	0,76	0,12		4	0,00	0,00*	0,00*	

When forces are analysed over the outer (right) leg overall average forces were subsequently increasing as the turns became more and more complex. During all elements, forces were highest over medial part of the foot and they increased further as the elements were increasing in their complexity. Forces over lateral part of the foot were rising during basic turn, and then falling through short turn where they were smaller than during snowplough turn. Forces over the heel were small except during performance of a short turn. Forces measured over inner leg (left) were overall small, except during short turn. Similarly, distribution of forces over medial and lateral part of the foot was small, except during the short turns, where forces measured over the heel were also higher than measured during all other turns performed.

Results of our study suggest that in-boot pressure over outer leg rises over medial part of the foot as the turns become more complex (from basic to parallel turn and short turn). Forces over lateral parts of the feet descend from complex to simpler turns and are highest during snowplough turn. Forces above the heel are small, except measured during short turn, where the force was higher compared to all other elements of ski technique. When inner leg is in focus, then overall pressure measured on heel is small, except for element short turn. Similarly, higher pressure was detected over medial and lateral parts of the feet, as well as over heel during performance of a short turn. Similar distribution pattern of pressure as well as magnitude of pressure was detected in both turns and on left and right leg. When pressure is compared between inner and outer leg, significantly lower pressure level was on an inner leg (in ratio 1:4) in all elements of technique except during short turn. When pressure over outer leg is analysed, then highest pressure was over medial part of the foot, regardless of the element of ski technique. In case of a short turn, additionally higher pressure was detected over the heel.

These results are logical and have been confirmed in similar studies (Lafontaine et al., 1999; Nakazato et al., 2011). When more complex turns, such as parallel and short turn (short turn right-906,39; left- 922,02) are performed, the skis are bent more rapidly than during simpler turns, which results in higher forces detected (snowplough right turn-672,83; left turn-608,36). Moreover, shorter, more complex turns despite the efforts are not executed in a completely “smooth” fashion. Mentioned results in the higher forces applied to the snow, which are then sent back up through the ski boots. According to current research (Falda-Buscaiot et al., 2017; Nakazato et al., 2011; Lafontaine et al., 1999), not only the type of a turn, but possibly characteristics of the terrain and skiing level (professional vs intermediate) and ski equipment can be the possible factors influencing forces and plantar pressures. In this study, unlike in previous ones, the equipment was controlled, i.e. the participant used the same skies and ski boots during the whole investigation, so mentioned could not affect in-boot pressure measurements. Relevant investigation shows that for the turn to be optimally performed, a skier needs to have adequate speed at the turn initiation as well as body position, which are accomplished through an optimal pressures and forces (Supej et al., 2011). Discussion about where and when to apply pressure while teaching recreational level alpine skiers is still vivid. Therefore, when using pressure insoles, it is possible to determine pressure distribution throughout performance of each element of alpine ski school. The methodology applied in this research confirms and justifies systematical order of teaching process according to forces that occur.

Conclusion

From a ski technique standpoint, it was clear that the pressure applied with the feet was higher towards more complex elements, and this finding is in accordance with advancements of plan and program of an alpine ski school. Therefore, it is necessary for ski instructors to teach skiing beginners where, when and how to apply pressure during each phase of a ski learning process.

Acknowledgements

The authors are grateful to the Laboratory for sports games from Faculty of Kinesiology (University of Zagreb) for supporting the measurements and their contributions to this research.

References

Cigrovski, V., Matković, B. (2015). Skiing technique-carving. Zagreb: Faculty of Kinesiology University of Zagreb.

Falda-Buscaiot, T., Hintzy, F., Rougier, P., Lacouture, P., Coulmy, N. (2017). Influence of slope steepness, foot position and turn phase on plantar pressure distribution during giant slalom alpine ski racing. PLoS ONE, 12(5).

Gilgien, M., Crivelli, P., Sporri, J., Kroll, J., Muller, E. (2015). Characterization of course and terrain and their effect on skier speed in world cup alpine ski racing. PLoS One, 10.

Lafontaine, D., Lamontagne, M., Diallo, B., Dupuis, D. (1999). Plantar pressure distribution measured during alpine ski turns. Clinical Biomechanics, 14, 558.

LeMaster, R., Supej, M. (2015). Systematic use of the inside ski in carved turns. In: 6th international congress on Science and skiing. (Muller E, Kroll J, Lindinger S, Pfusterschmied J, Stoggl T) pp. 196-199. London: Meyer & Meyer Sport.
Lešnik, B., Žvan, M. (2010). A turn to move on, theory and methodology of alpine skiing. Ljubljana: University of Ljubljana, Faculty of Sport.
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 Science and Medicine, 10, 754-762.
Nakazato, K., Scheiber. P., Muller, 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. Sport Eng, 16, 297–307.
Schaff, P., Kulot, M., Hauser, W., Rosemeyer, B. (1988). Factors affecting the pressure distribution underneath the foot sole in ski boots. Sportverletz Sportschaden. 2, 4, 164-171.
Supej, M., Kipp, R., Holmberg, H.-C. (2011). Mechanical parameters as predictors of performance in alpine World Cup slalom racing. Scandinavian Journal of Medicine & Science in Sports, 21(6):e72-81.
Supej, M., Hebert-Losier, K., Holmberg, H.C. (2015). Impact of the steepness of the slope on the biomechanics of World Cup slalom skiers. Int J Sport Physiol Perform, 10, 361–368.
Vaverka, F., Vodickova, S., Elfmark, M., (2012). Kinetic analysis of ski turns based on measured ground reaction forces. Journal of applied biomechanics, 28(1), 41-47.
Vaverka F., Vodickova S. (2010). Laterality of the lower limbs and carving turn. Biology of Sport, 27, 129–134.
Žvan, M., Lešnik, B., Supej, M. (2015). Progressive increase in velocity, ground reaction forces and energy dissipation on Alpine ski school elements. In: 6th international congress on Science and skiing. (Muller E, Kroll J, Lindinger S, Pfusterschmied J, Stoggl T) pp. 354-355. London: Meyer & Meyer Sport.

Corresponding information:

Received:14.07.2020.
Accepted:06.08.2020.
Correspondence to: Vjekoslav Cigrovski
University: University of Zagreb
Faculty: Faculty of Kinesiology
E-mail: vjekoslav.cigrovski@kif.unizg.hr