Open Access
KOSALB International Journal of Human Movements Science, Vol: 2, No: 2, 2023, p 54-62, DOI: 10.5281/zenodo.10428036 | ISSN: 2958-8332 | Published: 25.12.2023

KOSALB

Original article

The effect of ground reaction forces in different phases of the ski turn: A systematic review

Era Deva[1ABCDE] Bujar Turjaka[2ACE*]

[1]*University for Business and Technology (UBT), Faculty of Sport and Movement Science, ORCID: 0009-0009-5258-7134, eradeva8@gmail.com, Kosovo.*
[2]*University of Pristina "Hasan Prishtina", Faculty of Physical Education and Sport, ORCID: 0009-0006-4034-7027, bujar.turjaka@uni-pr.edu, Kosovo.*
**Corresponding author: bujar.turjaka@uni-pr.edu*
Authors' Contribution: A: Study design, B: Data collection, C: Data analysis, D: Manuscript preparation, E: Discussion and conclusion

ABSTRACT

Study aim(s): This study aims to analyze the specialized literature on the influence of ground reaction forces in specific phases of the ski turn.
Methods: Systematic searches on the PubMed, Web of Science and Scopus databases were conducted using the following keywords: ground reaction forces in alpine skiing. Studies included in this review address the influence of ground reaction forces in specific phases of the ski turn. This study is a systematic review model, which is based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards.
Results: In this review, various research methodologies were employed, including assessments of alpine skiers (5 studies), three-dimensional kinematic data analysis (2 studies), and systematic reviews (2 studies). Key findings include the difference of ground reaction forces in specific phases of the ski turn, the difference between feet (inside and outside), the impact of slope steepness, and discipline-specific forces.
Conclusion: Our analysis has provided valuable insights into the role of ground reaction forces in ski turns. We've observed that the peak of this force occurs during the steering phase, particularly in 'Steering 2.' The outside foot plays a crucial role in the turning process, experiencing higher ground reaction forces, while the inside foot contributes to stability. Steeper slopes amplify these forces. To optimize ski turn performance, early and smooth application of ground reaction forces is essential.

Keywords: Skiing, Force, Turn, Phase, Steepness

Open Access
KOSALB International Journal of Human Movements Science, Vol: 2, No: 2, 2023, p 54-62, DOI: 10.5281/zenodo.10428036 | ISSN: 2958-8332 | Published: 25.12.2023

KOSALB

Original article

INTRODUCTION

Alpine skiing stands as an intensely competitive and high-risk sport, drawing enthusiasts from across the globe [1]. When we contemplate the small margin that separates the winner from the runner-up, it becomes evident that every aspect of skiing must undergo comprehensive analysis to gain a strategic edge over other competitors.

To begin with, in alpine skiing, a ski run consists of turns that allow the skier to change direction (steer) and control the speed by twisting and tipping the skis to achieve the desired outcome out of the turn [2]. Analyzing a turn by splitting it into different phases is essential for gaining a deeper understanding. Yet, there's still no agreement on how many phases a turn should be divided into. Different authors suggest dividing it into two, three, or four phases, adding to the ongoing discussion. However, a more comprehensive breakdown of the turn involves four phases: Initiation (P1), Steering 1 (P2), Steering 2 (P3), and the Completion phase (P4). The initiation phase involves an edge change from the inside edge of the outside ski of the previous turn to the inside edge of the new outside ski. Meanwhile Steering 1 continues until the gate passage, with increased edging, and Steering 2 extends from the gate passage to the maximum of hip and knee flexions. Lastly, the Completion phase continues until the skis are flat, and the Initiation phase of the next turn begins [3].

By delving into the biomechanical factors influencing ski turns and their phases, we gain a profound insight into the physics underlying skiing, providing a clearer understanding of the mechanics at play in this sport. The focus of this study falls on the Ground Reaction Force – the force exerted by the ground on a body in contact with it, according to Newton's third law [4]. In skiing, the GRF is the force that provides direction and speed control, making turning possible. The GRF holds great significance, serving as both a cornerstone for gaining a fundamental understanding of skiing and a tool for deducing outcomes resulting from the technique. In its most basic form, skiing essentially entails the mastery of two fundamental aspects: the manipulation of the magnitude and direction of the force exerted by the snow upon us, and the precise positioning of our bodies to maintain equilibrium against this force [5].

To support this, previous studies have analyzed various characteristics, including the effect of the Ground Reaction Force (GRF) in different phases of the turn, different anatomical parts of the foot, throughout the entire turning motion, and distinctions between the inside and outside feet. Nevertheless, there is a notable absence of a clear understanding regarding which specific phase experiences higher GRFs and the optimal strategies for managing these forces effectively.

Thus, considering the previous information, the main focus of this study is to analyze the current literature to conclude the clear effect of ground reaction forces in different phases of the ski turn.

METHODS

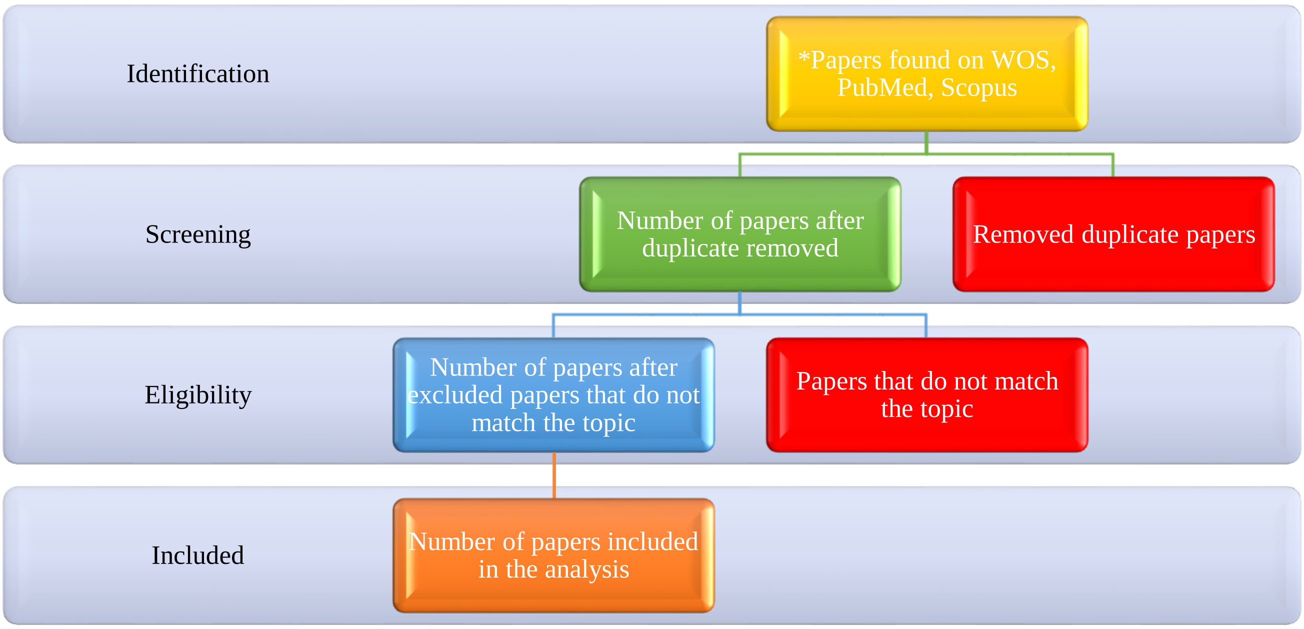
Research design

This study is a systematic review model, which is based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards and aims to deduct a new conclusion about the current literature about the effect of ground reaction forces in different phases of the ski turn [6].

Scheme of the reduction of papers found in the current literature:

Open Access
KOSALB International Journal of Human Movements Science, Vol: 2, No: 2, 2023, p 54-62, DOI: 10.5281/zenodo.10428036 | ISSN: 2958-8332 | Published: 25.12.2023

Original article



**There were no exclusion criteria for quality because the searching criteria were limited to WOS, PubMed, and Scopus*

Table 1. Number of papers in the current literature that are related to the effect of ground reaction forces in skiing.

Papers	PubMed	Web of Science	Scopus	Total
Found papers	37	38	41	116
Matching topics	2	3	4	9
Papers that have conclusions about the ground reaction force in the ski turn	2	3	4	9

While the total number of found papers is 116, just 9 papers cover the topic, and just 9 papers have a conclusion about the effect of ground reaction forces in Skiing. This also means a lack of research related to ground reaction forces in specific phases of the ski turn.

RESULTS

Table 2. Papers related to the effect of ground reaction forces in skiing found in PubMed.

Authors	Sample	Measured characteristics (topic)	Conclusion	Published in
Thomas Falda-Buscaiot, Frédérique Hintzy, Patrice	Eleven alpine skiers participated in the study (seven boys and four girls) with 105 ± 37 FIS points	Influence of slope steepness, foot position, and turn phase on plantar pressure distribution	Results indicated that the total foot surface differed significantly depending on the slope (higher in steep sections vs. flat sections), and the turn phase (higher during steering2 vs. three other phases),	PubMed, 2017, France [3]

Rougier, Patrick Lacouture, Nicolas Coulmy		during giant slalom alpine ski racing	although such modifications were observable only on the outside foot. These results suggest a differentiated role played by each foot in alpine skiing turns: the outside foot has an active role in the turning process, while the inside foot may only play a role in stability.	
Matej Supej, Kim Hébert-Losier, Hans-Christer Holmberg	The authors collected 3-dimensional kinematic data during a World Cup race from 10 male slalom skiers	Impact of the steepness of the slope on the biomechanics of World Cup slalom skiers	Examining the time-course behaviors of variables during turn cycles indicated that steeper slopes were associated with slower velocities but greater accelerations during turn initiation, narrower turns with peak GRFs concentrated at the midpoint of steering, more pronounced lateral angulations of the knees and hips at the start of steering that later became less pronounced, and overall slower turns that involved deceleration at completion.	PubMed, 2015, Slovenia [7]

Table 2 displays a selection of papers retrieved from PubMed that feature relevant conclusions.

Table 3. Papers related to the effect of ground reaction forces in skiing found in Web of Science.

Authors	Sample	Measured characteristics (topic)	Conclusion	Published in
Matej Supej, Jan Ogrin, Nejc Šarabon, Hans-Christer Holmberg	Nine elite skiers completed a 20-gate slalom course	Asymmetries in the Technique and Ground Reaction Forces of Elite Alpine Skiers Influence Their Slalom Performance	Although slalom skiers were found to move their bodies in a quite symmetrical fashion, asymmetry in their skiing technique and GRF influenced variables related to asymmetries in performance.	Web of Science, 2020, Slovenia [8]
Kim Hebert-Losier, Matej Supej, Hans-Christer Holmberg	Systematic review of scientific literature	Biomechanical Factors Influencing the Performance of Elite Alpine Ski Racers	In the case of slalom and giant slalom events, performance could be enhanced by steering the skis in such a manner as to reduce the ski-snow friction and thereby energy dissipated. This was accomplished by earlier initiation of turns, longer path length and trajectory, earlier and smoother application of ground reaction forces, and carving (rather than skidding).	Web of Science, 2014, Sweden [11]

Jörg Spörri, Josef Kröll, Benedikt Fasel, Kamiar Aminian, Erich Müller.	Ten top-level athletes were divided into GS and SL groups. Both groups performed a total of 240 GS and 240 SL turns at 2 different course settings.	A Kinematic and Kinetic Study of Giant Slalom and Slalom	In SL, ground-reaction force peaks were significantly lower when the gate offset was increased, while in GS, no differences between course settings were observed. SL was characterized by shorter turns, lower frontal and lateral bending angles after gate passage, and a trend toward greater total ground-reaction force peaks compared with GS.	Web of Science, 2016, Austria [10]

Table 3 displays a selection of papers retrieved from the Web of Science that feature relevant conclusions.

Table 4. Papers related to the effect of ground reaction forces in skiing found in Scopus.

Authors	**Sample**	**Measured characteristics (topic)**	**Conclusion**	**Published in**
Wu Jinping, Zhao Liang, Sun Dong	The biomechanical research and the latest papers related to competitive performance were systematically analyzed to determine biomechanical factors affecting competitive performance of alpine skiers	Influence Factors for Competitive Performance of Alpine Skiers in the View of Biomechanics	In the case of slalom and giant slalom events, the earlier initiation of turns, longer path length, and trajectory, earlier and smoother application of GRF, and carbene technique carving to reduce the ski-snow friction and thereby dissipate energy should be used to improve sports performance.	Scopus, 2021, China [12]
Matthias Gilgien, Jörg Spörri, Josef Kröll, Philip Crivelli, Erich Müller	During seven giant slalom, four super-G, and five downhill WC competitions, mechanical characteristics of a forerunner were captured using differential global navigation satellite technology and a precise terrain surface model	A comparison between the competition disciplines in men's World Cup alpine skiing	Turn ground reaction forces were largest for giant slalom, followed by super-G and downhill.	Scopus, 2013, Norway [13]
Matej Supej, Ronald Kipp, Hans-Christer Holmberg	Eighteen elite skiers were recorded with three-dimensional kinematical measurements	Mechanical parameters as predictors of performance in alpine World Cup slalom racing	We suggest that the shortest R AMS and the highest GRFs should be reduced in elite slalom to increase performance.	Scopus, 2011, Slovenia [14]

Open Access
KOSALB International Journal of Human Movements Science, Vol: 2, No: 2, 2023, p 54-62, DOI: 10.5281/zenodo.10428036 | ISSN: 2958-8332 | Published: 25.12.2023

KOSALB

Original article

Sona Jandova, Frantisek Vaverka	The investigation was carried out on a group of 6 skiers (3 racers and 3 ski teachers)	Ground reaction forces measurement based on strain gauges in alpine skiing	We realized that during a carving turn the strongest ground reaction forces occur during the steering phase after the fall line and during the initiation phase skis are alleviated and edging is changed. A comparison of measured left carving turn and comparison of right carving turn showed a very similar cycle.	Scopus, 2008 Czechia [9]

Table 4 displays a selection of papers retrieved from Scopus that feature relevant conclusions.

DISCUSSION

This study's primary objective was to conduct an in-depth analysis of existing literature concerning the impact of ground reaction force in the ski turn, with specific attention to its influence on the identified phases of the turn: Initiation (P1), Steering 1 (P2), Steering 2 (P3), and the Completion phase (P4). The studies encompassed in this review have furnished valuable insights into the findings related to ground reaction force measurement, which we will break down below.

Broadly, the studies incorporated in this paper encompass a diverse spectrum of research methodologies; assessments of alpine skiers (5 studies), acquisition of three-dimensional kinematic data from past races (2 studies), and systematic reviews of current literature (2 studies). Notably, when looking at the studies involving athlete testing, a common trend emerges – they often featured relatively small sample sizes, ranging from 6 to 18 skiers [3,8,9,10,14]. Among the 54 participants in these tests, the majority, 51 individuals, were ski racers, while the remaining three were ski instructors. Additionally, the kinematic data analyzed was sourced from World Cup races in Slalom, Giant Slalom, Super G, and Downhill [7,13].

To begin, in a study led by Thomas Falda-Buscaiot et al., eleven skiers participated in a giant slalom course while wearing pressure insoles beneath their feet. Upon analyzing the plantar pressure data, the researchers made several significant conclusions. They found that the impact of ground reaction forces beneath the foot surface was closely tied to the slope's steepness; steeper slopes resulted in higher ground reaction forces. Additionally, they observed that the outside foot of the skier experienced greater ground reaction forces compared to the inside ski, suggesting that the outside ski plays a role in the turning process, while the inside ski contributes to stability. Notably, when examining the phases of the turn, it became evident that the highest ground reaction forces were most pronounced during the second part of the steering phase (Steering 2) in comparison to the other three phases [3].

Likewise, Matej Supej et al. reached a similar conclusion regarding the impact of slope steepness on mechanical skiing variables, specifically focusing on the concentration of ground reaction forces during the midpoint of the Steering phase [7]. It's crucial to highlight that in this study, the turning process was divided into three distinct phases, where Steering 1 and Steering 2 comprised a single phase, in contrast to the previously mentioned study. This insight emerged from their analysis of three-dimensional kinematic data collected during a Slalom World Cup race [7]. In another study by the same author, the examination centered on whether asymmetries in a racer's technique

Open Access
KOSALB International Journal of Human Movements Science, Vol: 2, No: 2, 2023, p 54-62, DOI: 10.5281/zenodo.10428036 | ISSN: 2958-8332 | Published: 25.12.2023

KOSALB

Original article

affected their performance. To investigate this, nine elite alpine skiers were closely monitored on a 20-gate slalom course using a global navigation satellite system (GNSS) and pressure insoles. Interestingly, the skiers exhibited highly symmetrical techniques. However, the study's key finding pointed to the ground reaction force (GRF) as a significant influencer on variables related to the asymmetries observed in their performance [8].

Furthermore, Sona Jandova et al. devised a specialized measuring device capable of quantifying forces in three dimensions and their corresponding torsional moments around these three axes. This innovative system underwent testing with a group comprising six individuals, consisting of three racers and three ski instructors. The collected data revealed that, during a carving turn, the most robust ground reaction forces again manifest themselves during the steering phase [9].

On the contrary, Jörg Spörri et al. delved into a comprehensive study, examining the kinematics and kinetics of Giant Slalom and Slalom skiing, all while considering various course configurations aimed at preventing injuries. The measurement of ground reaction forces was facilitated once more through the use of pressure insoles. The findings revealed that in the case of Slalom, larger gate offsets were associated with reduced ground reaction forces, whereas in Giant Slalom, no significant differences were observed across different course settings [10].

In a distinct approach, Kim Hebert-Losier et al. directed their attention toward the biomechanical aspects that impact elite athletes' performance. Their findings suggested that optimizing performance could be accomplished by skillfully manipulating the interaction between skis and snow to minimize friction. This could be achieved through actions such as initiating turns earlier, covering a longer path, executing precise carving, and fluidly applying ground reaction forces [11]. This viewpoint finds support in the work of Wu J et al., as evidenced in their systematic review of biomechanical factors influencing competitive skiing performance [12].

Regarding ground reaction forces in various skiing disciplines, in a study by M. Gilgien et al., it was found that the highest ground reaction forces were observed in Giant Slalom, followed by Super G and Downhill disciplines [13]. It's important to note that this study did not include data for the Slalom discipline. However, when Slalom is considered, Jörg Spörri et al. reached a different conclusion, indicating that Slalom exhibited even greater total ground reaction force peaks compared to Giant Slalom [10].

CONCLUSION

Our analysis has revealed significant insights into the dynamics of ground reaction forces during ski turns. The peak of this force occurs notably during the Steering phase, with particular emphasis on the latter part, commonly known as 'Steering 2.' Furthermore, the findings indicate that, during the turn, the outside foot - responsible for the turning process - experiences notably higher ground reaction forces, while the inside foot predominantly contributes to stability. Additionally, we've concluded that steeper slopes correlate with increased ground reaction forces. In light of these discoveries, it becomes evident that optimizing performance in ski turns hinges on the early and smooth application of ground reaction forces. This knowledge equips skiers and coaches with valuable insights to refine their technique and enhance their skiing experience. However, a notable limitation of our study is the relatively small number of research papers supporting our findings. While we've made efforts to provide a comprehensive analysis based on existing literature, this limited pool of studies on the topic may introduce bias and uncertainty to our conclusions. Future research with a larger dataset could enhance the reliability and precision of our understanding of ground reaction forces during ski turns. It is essential to note that as you expand beyond the databases mentioned, the quantity of papers on this topic may increase, but the overall quality of the papers is likely to diminish.

CONFLICT OF INTERESTS

The authors reported no potential conflict of interest.

REFERENCES

1. Koehle MS, Lloyd-Smith R, Taunton JE. *Alpine ski injuries and their prevention.* Sports Med. 2002; 32(12):785-793. doi:10.2165/00007256-200232120-00003\
2. Todd L. *Ski Turns: An Expert Guide To Ski Turn Types And Techniques.* Get Carv. 2019 December 13. Available from: https://getcarv.com/blog/ski-turns-an-expert-guide-to-ski-turn-types-and-techniques
3. Falda-Buscaiot T, Hintzy F, Rougier P, Lacouture P, Coulmy N. *Influence of slope steepness, foot position, and turn phase on plantar pressure distribution during giant slalom alpine ski racing.* PLoS One. 2017;12(5):e0176975. Published 2017 May 4. doi:10.1371/journal.pone.0176975.
4. Britannica T. Editors of Encyclopaedia (2023, March 27). *Newton's laws of motion.* Encyclopedia Britannica. https://www.britannica.com/science/Newtons-laws-of-motion.
5. Sedgwick M, Topp J. *Physics of Skiing*. 2021 December Available from: CSIA snowpro.
6. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Moher D. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. International journal of surgery, 2021; 88: 105906.
7. Supej M, Hébert-Losier K, Holmberg HC. *Impact of the steepness of the slope on the biomechanics of World Cup slalom skiers*. Int J Sports Physiol Perform, 2015;10(3):361-368. doi:10.1123/ijspp.2014-0200.
8. Supej M, Ogrin J, Šarabon N, Holmberg H-C. *Asymmetries in the Technique and Ground Reaction Forces of Elite Alpine Skiers Influence Their Slalom Performance.* Applied Sciences. 2020; 10(20):7288.
9. Jandova Sona, Vaverka Frantisek. *Ground Reaction Forces Measurement Based on Strain Gauges in Alpine Skiing,*2008;819-823. 10.1201/9781439828427.ch119.
10. Spörri Jörg, Kröll Josef, Fasel Benedikt, Aminian Kamiar, Müller Erich. *Course Setting as a Prevention Measure for Overuse Injuries of the Back in Alpine Ski Racing - A Kinematic and Kinetic Study of Giant Slalom and Slalom.* The Orthopaedic Journal of Sports Medicine. 2016; 4. 2325967116630719. 10.1177/2325967116630719.
11. Hébert-Losier K, Supej M, Holmberg HC. *Biomechanical factors influencing the performance of elite Alpine ski racers.* Sports Med. 2014;44(4):519-533. doi:10.1007/s40279-013-0132-z.
12. Wu Jinping, Zhao Liang, Sun Dong, et al. *Influence factors for competitive performance of Alpine skiers in the view of biomechanics.* Journal of Medical Biomechanics, 2021; 36(4):502-509 (in Chinese).
13. Gilgien M, Spörri J, Kröll J, Crivelli P, Müller E. *Mechanics of turning and jumping and skier speed are associated with injury risk in men's World Cup alpine skiing: a comparison between the competition disciplines.* Br J Sports Med. 2014;48(9):742-747. doi:10.1136/bjsports-2013-092994.
14. Supej M, Kipp R, Holmberg HC. *Mechanical parameters as predictors of performance in alpine World Cup slalom racing*. Scand J Med Sci Sports. 2011;21(6):e72-e81.doi:10.1111/j.1600-0838.2010.01159.x

FOR CITATION

Deva et al. The effect of ground reaction forces in different phases of the ski turn: A systematic review. KOSALB International Journal of Human Movements Science, Vol: 2(2), 2023, p 54-62, DOI: ***10.5281/zenodo.10428036***.