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The Effect of Balance Training Protocols on Alpine Skiing: A Systematic Review of Dry-Land and On-Snow Interventions on balance performance

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Abstract

The role of balance as a fundamental motor skill in alpine skiing is unquestionable, but the literature appears scant concerning specific studies on balance training, its outcomes, and particulars such as training intensity, duration, and frequency in relation to alpine skiing. This comprehensive review draws upon articles discovered via a systematic, computerized search of prominent databases including Science Direct, Science Citation Index, Scopus, Directory of Open Access Journals, and Academic Search Complete spanning the period 1991-2020. Given the absence of a universally accepted terminology for training encompassing balance exercises, our search incorporated articles discussing balance training, neuromuscular training, proprioceptive training, core stability training, and postural control within the context of alpine skiing, employing a Boolean search strategy. From the 437 articles found, only 10 satisfactorily met our inclusion criteria. This systematic review sought to clarify the balance training protocols, specifically those involving dry-land or on-snow interventions, which improve balance performance in healthy alpine skiers. A majority of the reviewed articles attested to a beneficial effect of balance training protocols on balance performance in alpine skiing.

Keywords: Balance training, proprioceptive training, neuromuscular training, dry-land training, on-snow training.

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Introduction

Alpine skiing, while immensely popular, is a highly challenging sport, necessitating advanced motor control and coordination skills (Hébert-Losier et al., 2014). Moreover, the skier must adapt to shifting environmental factors like alterations in snow conditions, visibility, the steepness of the slope, and uneven terrain, among others (Skilehrerverband, 2019; Komissarov, 2020).

These fitness components are refined through intensive snow and dry-land training programs, geared towards skiers at all levels. A deeper comprehension of the elements impacting performance in such a multifaceted sport could establish the foundation for superior athlete preparedness, thereby leading to significant progress in both technique and conditioning (Cross et al., 2021). It's been suggested that such comprehensive training may also serve to mitigate the risks associated with fatigue during competitive skiing, thus contributing to overall safety (Andersen & Montgomery, 1991).

Also, Raschner et al. (2013) argue that optimizing performance in alpine skiing necessitates an improvement in the quality of physical fitness and ski technique training. Moreover, they highlight the need for alpine skiers to master complex motor skills like balance, agility, and coordination – skills deemed fundamental for success in this physically demanding sport (Maffiuletti et al., 2006; Patterson et al., 2009; Raschner et al., 2012).

In addition to demanding high levels of aerobic and anaerobic capacity, alpine skiing places a premium on motor skills development. It is vital that the neuromuscular system is adequately conditioned, enabling effective engagement of balance during downhill runs and consequently preventing falls. Słomka et al. (2018) thus posit that by incorporating specific balance training into their regimen, skiers may stand to further enhance their performance. This approach underscores the significance of balance in the sport of alpine skiing and calls for more focused and nuanced training strategies.

Moreover, alpine skiing, as characterized by Hydren et al. (2013), is a sport that inherently grapples with instability, particularly when skiers interact with softer snow and rutty course conditions. This instability necessitates the enhancement of motor patterning for such unpredictable conditions, achievable through neurological adaptations fostered by balance training. By incorporating balance components into strength and plyometric training, using tools like bossu balls, balance discs, and stability balls, one can catalyze improvements in neuromuscular motor patterning (Hydren et al., 2013).

Defined as the ability to maintain the body's center of mass over the support surface, balance assumes a heightened role in alpine skiing, a concept underlined by both Cigrovski et al. (2018) and Hydren et al. (2013). Yet, despite its paramount importance, there is a noticeable

dearth of research examining the effect of balance on alpine skiing. The direct correlation between balance and skiing performance has yet to be definitively confirmed, as evinced by studies such as those by Male et al. (2013), Noe & Paillard (2005), and Raschner et al. (2012). This highlights a significant knowledge gap that necessitates a more comprehensive exploration into this vital component of alpine skiing.

Moreover, several researchers, including Brachman et al. (2017), Male et al. (2013), Noe & Paillard (2005), and Słomka et al. (2018), have underscored the scarcity of studies addressing balance improvement in alpine skiing. Compounding this research deficit, standardized tests tailored to snowy conditions are noticeably absent (Brachman et al., 2017; Zech et al., 2010), emphasizing the need for further research and the creation of standard testing protocols within the sport.

The significance of balance is not restricted to professional skiing but extends to novice practitioners as well (Cigrovski et al., 2016; Malliou et al., 2004; Ružić et al., 2003). Modern ski techniques require a strong sense of balance in both lateral and longitudinal dimensions (Debertin et al., 2020), necessitated by the considerable inward leaning angles of the body and the shorter ski lengths (Raschner et al., 2012).

Balance, a complex process, depends on the integration of visual, kinesthetic, and vestibular inputs. The visual, vestibular, and proprioceptive systems play a crucial role in assimilating afferent data, which is indispensable for maintaining stability (Paillard, 2002; Vuillerme & Nougier, 2004). Diverse training programs incorporating proprioceptive elements have been demonstrated to enhance body composition and balance skills. Inclusion of proprioceptive elements in their training allows athletes to exhibit superior static and dynamic balance compared to non-athletes, enhancing both their performance and balance control (Perrin et al., 2002).

However, terms such as 'neuromuscular', 'balance', and 'sensorimotor' training cover a wide array of exercises and may refer to neuromuscular or sensorimotor tasks. Still, balance training appears to be the most relevant term as it primarily aims to improve balance (Taube et al., 2008). The term 'balance training' does not necessarily imply specific biological structures that might adapt to the training intervention but refers more to the enhancement of a particular skill. Given balance's central role in alpine skiing, its training is crucial for efficient descents (Müller & Schwameder, 2003).

Unfortunately, there is no universally agreed-upon terminology to describe exercises aiming to improve postural stability. Various authors utilize different terms, such as 'balance training' (Bernier & Perrin, 1998), 'sensorimotor training' (Gruber & Gollhofer, 2004), 'neuromuscular training' (Paterno et al., 2004), and 'proprioceptive training' (Wülker &

Rudert, 1999). For the purpose of clarity in this article, the term 'balance intervention' will be used to refer to these exercises, while the term 'balance performance' will refer to the outcomes of such interventions.

Similar to other sports demanding speed and strength, skiing also requires precise motor control over a restricted base of support. Highlighting postural control during training can lead to enhanced balance performance during skiing (Słomka et al., 2018).

Although balance skill is recognized as a performance factor, research into the effects of alpine skiing on balance skill or the impact of balance training on alpine skiing remains limited, and the results from available studies are inconsistent. Some research (Wojtyczek et al., 2014; Cigrovski et al., 2017) noted improved balance skills among recreational skiers who engaged in days of technical skiing. Conversely, Firlus (2018) postulated that completing ski training negatively impacted the control of the body's center of mass. Moreover, a review by Brachman et al. (2017) cited Malliou et al. (2004), who found no significant differences concerning the effect of balance training on balance between the experimental and control groups.

Given the continuing discussion about the effectiveness of balance training in enhancing balance performance for alpine skiing, this systematic review strives to address the notable research gap between balance training methodologies and balance outcomes. The independent variables under study are the different balance training protocols, encompassing both dry-land and on-snow exercises. The dependent variable, conversely, represents the resultant balance performance in alpine skiing among healthy subjects. The primary objective of this review is to establish if balance intervention protocols yield substantial enhancements in alpine skiing balance performance.

METHODS

Research Model:

Systematic review method was used in the research.

Population-Sample (Study Group):

Our systematic literature search initially yielded a total of 437 studies. However, after eliminating duplicates, we were left with 415 unique studies. Subsequent application of our inclusion and exclusion criteria further reduced this number to 6 qualifying studies.

Additionally, we conducted a thorough examination of reference lists from these articles, as well as from pertinent review articles. This process enabled us to identify 4 more studies of relevance, bringing the total number of studies included in our review to 10.

Data Collection:

The selected studies were meticulously scrutinized by two independent reviewers who carried out a detailed extraction of pertinent information. This process was facilitated by the utilization of predetermined extraction forms designed to ensure the consistent and comprehensive gathering of data.

The scope of information extracted encompassed several key aspects of each study. These included details about the study participants such as their age, gender, and physical condition, the specific balance training protocol applied in each case, the type of balance tests that were conducted as part of the study, and the balance parameters that were evaluated.

Moreover, we paid particular attention to the outcomes of the studies, specifically focusing on the reported effects of the balance training protocols on the participants' balance performance. These outcomes often included improvements in balance, agility, and proprioception, which are critical factors in alpine skiing performance.

This thorough extraction and analysis process allowed us to gain a comprehensive understanding of the methodologies and findings of each study, thereby facilitating an in-depth and insightful review of the current state of balance training in alpine skiing.

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Additionally, we conducted a thorough examination of reference lists from these articles, as well as from pertinent review articles. This process enabled us to identify 4 more studies of relevance, bringing the total number of studies included in our review to 10. This comprehensive approach ensured we amassed a robust collection of research to inform our understanding the effects of balance training protocols on balance performance in alpine skiing.

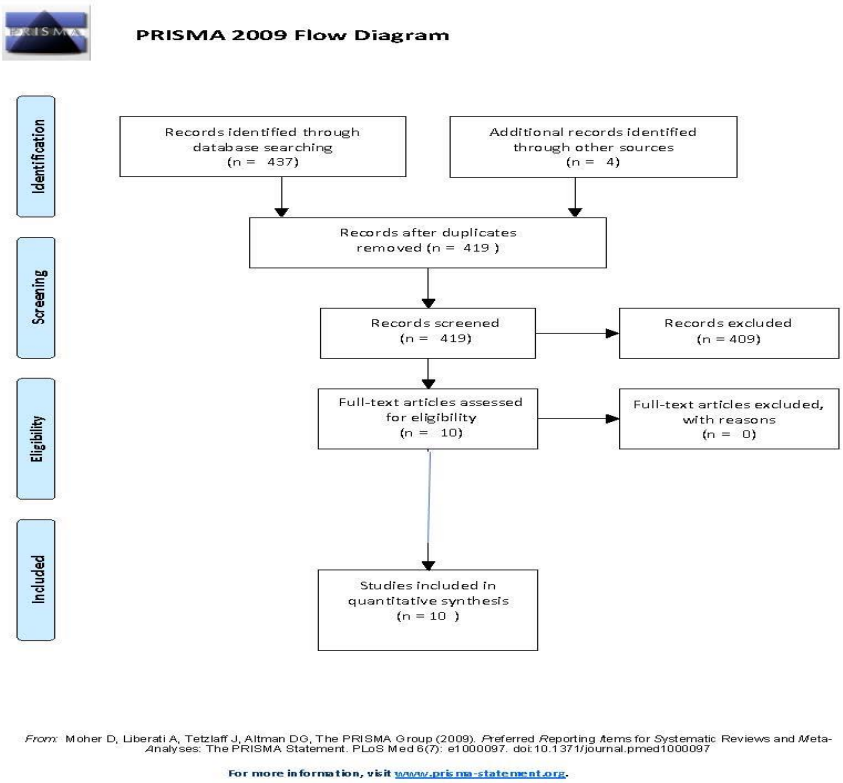

Figure 1. *Prisma flow chart showing - Balance training protocols – Study selection for Review (Moher et al. 2009).*

Figure 1 visually displays the journey from the initial 437 studies identified through our systematic search to the final 10 studies included in our review. The chart highlights key stages in this process, including the removal of duplicates, the application of inclusion and exclusion criteria, and the supplementary search of other sources such as reference lists and review articles. This comprehensive flow diagram allows for a clear understanding of the rigorous methodology adopted for study selection in our review of balance training protocols in alpine skiing.

Overview of Balance Training Protocols

The intervention strategies employed in the reviewed studies were diverse, focusing primarily on balance exercises performed on stable or unstable platforms for dry-land training (DLT) as well as technical exercises during on-snow training (OST). The selected methodologies for dry-land training included a spectrum of balance-enhancing exercise programs such as inline skating, balance drills using non-specific equipment (Čillík & Rázusová, 2014), and whole-body vibration training, incorporating squats, calf raises, skiing movements, and jumps onto a vibrating plate (Mahieu et al., 2006).

Additionally, core stability and plyometric balance exercises were introduced to the regimen (Słomka et al., 2018). Certain studies implemented a neuromuscular warm-up protocol

comprising of a circuit of ten exercises performed in stable and unstable positions (Vitale et al., 2018). In some instances, indoor balance training was conducted on balance boards, focusing on standing on a single leg with or without the aid of a ski pole (Malliou et al., 2004).

On the other hand, the on-snow training methods embraced exercise programs tailored towards enhancing balance, incorporating basic ski training exercises. For example, techniques like snowplow turns, side slipping, navigating through moguls, stem turns, and herringbone climbing were utilized (Camliguney et al., 2012; Camliguney, 2013; Firlus, 2018; Malliou et al., 2004; Staniszewski et al., 2016).

Ballance assessment

The dynamic and static balance were measured using a combination of laboratory, clinical, and field tests by various researchers. These balance tests were performed before and after the intervention protocol. Some studies additionally evaluated other parameters such as technical skills, strength, aerobic endurance, and agility (Camliguney, 2013; Malliou et al., 2004).

Dynamic balance was typically assessed using advanced tools like the Sport Expert MEDSP300 balance platform (Camliguney et al., 2013), the Biodex Stability System (Malliou et al., 2004), and the Optojump Next System (Słomka et al., 2018). Other methodologies included the Y-Balance Test as well as certain field tests, for example, slalom tests and running over a bench with three turnabouts (Camliguney, 2013; Čillík & Rázusová, 2014).

In terms of static balance, simpler tests like the Flamingo Test (Čillík & Rázusová, 2014) were utilized, and more complex evaluations were performed on force plates. These advanced tools are capable of tracking the movement of the center of pressure (COP) (Firlus, 2018; Staniszewski et al., 2016), the center of mass (COG) (Čillík & Rázusová, 2014; Mahieu et al., 2006), and carrying out postural sway assessments. For instance, devices like the MFT S3 Check were employed to measure symmetry and stability index, providing a thorough analysis of balance performance.

FINDINGS

Table 1. *The Effects of Balance Training Protocols on Balance Performance*

Reference	Balance training protocol	Balance Parameter	Outcome
(Camliguney et al., 2012.)	OST; ski education module/training; 4h/day ST for a week.	Disequilibrium Distance Slalom Keeping knee flexion of 135-150 degrees.	Increase the static and dynamic balance of leg power of male athletes compared with female athletes.
(Camliguney, 2013.)	OST; ski training; 4h/day ST for a week	Dynamic balance (M/L) Dynamic balance (A/P).	Improvement in DB in M/L, negatively affected in A/P plane.
(Čillík & Rázusová, 2014)	EG: DLT 9-week specialized training program focused on balance (e.g. inline skating, balance skills on non-specific tools) 3x/w, 30 min each session CG: general focused training on physical abilities.	1. number of errors 2. Center of mass (COG).	EG: improved SB and DB
(Mahieu et al., 2006.)	DLT: WBV training: squatting, deep squatting, wide-stance squatting.	COG.	No convincing results in postural control after WBV training.
(Malliou et al., 2004)	EG&CG- OST: basic ski lessons 2w, 5d/w, 2-4h/d EG: + DLT on balance boards 4x/w, 20min/d.	Stability indices - Deviation from horizontal plane A/P, M/L.	Stability indices of balance improve for both legs on both groups.
(Słomka et al., 2018)	DLT: core stability, plyometric, balance, and stretching exercises 2x/w x 8w	Average displacement of the Jumping point during jumps in the ML and AP direction on both legs	Significant improvements in the jump height, flight time, and area for the left leg and area for right leg.
(Staniszewski et al., 2016)	OST:nine-day ski training camp 5h/day for 9 days	EO, EC, barefoot and in ski boots. A/P, M/L sway indicators were calculated, also the sway path of the COP.	In both groups, a statistically significant improvement in stability was observed after the training camp only while standing in ski boots

(Vitale et al., 2018)	DLT: neuromuscular warm-up protocol, 2x/w for 8 w, 30 min per session for EG	A, PM, PL directions, and composite score of YBT	Comparisons of the pre-and post-intervention YBT showed significant improvement in the EG compared to the CG.
(Firlus, 2018.)	OST: 5 days of ski	EO/EC barefoot and with ski boots M/L, A/P plane, COP	Negative effect
(Wojtyczek et al., 2014)	OST: 7 days of ski	Symmetry index +stability index = balance ability	Improved balance. performance in Polish students regardless of sex or skiing experience.

Note. EG = experimental group; CG = control group; OST = on-snow training; SB= static balance; DB = dynamic balance; EO = eyes open; EC = eyes closed; M/L = medial/lateral; A/P = anterior/posterior; DLT = dry-land training; COG = center of gravity; WBV = whole-body vibration; NR = not reported; COP = center of pressure; YBT = Y-Balance test; N = number;

Balance outcome

Research indicates varied effects of skiing on balance performance. Some studies have reported positive effects on the experimental groups (EG), with improvements in both static and dynamic balance (Camliguney, 2012), as well as in stability index values (Staniszewski et al., 2016; Wojtyczek et al., 2014). Conversely, a study by Firlus (2018) found no notable improvements in balance performance after on-snow training (OST) or a ski education module. The relationship between balance performance and different variables like anterior-posterior (A/P) medial-lateral (M/L) values has been analyzed under various conditions - both eyes open (EO) and eyes closed (EC), with or without ski boots.

When it comes to dry-land training (DLT), a notable enhancement in the level of balance performance (including static and dynamic balance, symmetry and stability index, and postural sway) has been observed between the initial and final testing of experimental groups. Čillík and Rázusová (2014) have suggested that after a 9-week training program specifically focused on balance, the experimental group demonstrated improved static balance (SB) and dynamic balance (DB) values. Furthermore, a study by Vitale et al. (2018) indicated improved balance performance following an 8-week neuromuscular warm-up protocol.

Another study conducted by Malliou et al. (2004) found that both the experimental group (EG) and control group (CG) showed similar improvements in balance performance. However, the experimental group performed significantly better on the downhill-slalom agility test, implying that specific indoor balance training aids in enhancing agility.

Contrarily, Mahieu et al. (2012) did not find any significant improvements in postural control following whole-body vibration (WBV) training, indicating that the impact of different training methods on balance performance can vary. This highlights the complexity

of this field and the need for further research to establish the most effective training interventions for improving balance in alpine skiing.

DISCUSSION AND CONCLUSION

This systematic review was conducted with the primary intention to identify balance training protocols that augment balance performance in alpine skiing. Our collective analysis from various studies revealed that most balance training strategies, irrespective of being executed on dry-land (DLT) or on-snow (OST), seem to enhance balance performance in healthy subjects. A majority of the research articles we reviewed echo this conclusion, despite a few contrary findings (Firlus, 2018; Mahieu et al., 2006; Malliou et al., 2004).

Nonetheless, our analysis also sheds light on the inherent inconsistencies present in the field. One significant inconsistency we found is the varied terminology employed across different studies to describe balance exercises. This variance in nomenclature, with terms such as 'sensorimotor training' (Gruber & Gollhofer 2004), 'neuromuscular training' (Paterno et al. 2004), or 'proprioceptive training' (Wulker & Rudert 1999) being used interchangeably, hampers the ability to draw definitive conclusions. Despite these discrepancies in terms, it's worth emphasizing the general consensus in the literature that balance training exercises significantly contribute to balance performance.

Another finding pertains to the structure and duration of balance training programs. According to our review, DLT programs of about 8 weeks' duration, with a frequency of two training sessions per week, tend to be most effective (Čillík & Rázusová, 2014; Słomka et al., 2018; Vitale et al., 2018). Meanwhile, OST programs lasting at least a week have been reported to demonstrate noticeable improvements in balance performance (Camliguney et al., 2012; Camliguney, 2013; Staniszewski et al., 2016; Wojtyczek et al., 2014). Intriguingly, one study reported a negative impact on balance performance following 5 days of ski training (Firlus, 2018), pointing to the need for further research into optimal training durations and frequencies.

An additional challenge encountered during the review was the heterogeneity in balance parameters utilized across studies. Different balance parameters, such as medial-lateral (M/L), anterior-posterior (A/P), center of mass (COM), center of gravity (COG), center of pressure (COP), stability, and symmetry values, make it difficult to compare results across studies. Further, a lack of explicit descriptions regarding the intervention or the dosages used in many studies intensifies this difficulty.

Finally, while our systematic review underscores that balance training protocols generally enhance balance performance in alpine skiing, the lack of universally accepted standards in this field complicates the drawing of definitive conclusions (Brachman et al., 2017; Zech et al.,

2010). Nevertheless, the significance of including balance training in the training regimen of alpine skiers is unequivocal. The challenge for future research lies in refining and standardizing balance training protocols to better comprehend their impact on this exacting sport.

In summary, the review revealed that balance training, both on dry land and snow, generally improves balance performance in alpine skiing. Despite inconsistencies in terminology and varying measurements of balance across studies, the positive influence of balance exercises on performance was notable. Effective training protocols appear to be dry-land training sessions of 8 weeks' duration with a frequency of two sessions per week, and on-snow training lasting at least 7 days. However, the lack of a universally accepted standard in this field makes it challenging to draw definitive conclusions. Despite the complexities, the available literature supports the inclusion of balance training in the training regimen of alpine skiers. Further research is needed to refine and standardize balance training protocols for this demanding sport.

Conflict of Interest: There is no conflict of interest between the authors.

Statement of Contribution of Researchers:

1.Author: %50

2.Author: %25

3.Author: %25

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