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PhD student : ZADIC ALEXANDRU

Optimizing performance in alpine skiing through a comprehensive approach to the development of static and dynamic balance

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PROF. UNIV. DR. GROSU EMILIA FLORINA

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Introduction and Motivation for Choosing the Theme

Introduction

Skiing stands as a fundamental pillar of the Winter Olympic Games, encompassing various competitions, with a focus on alpine skiing, a discipline rooted as far back as 1924 and with a growing popularity (*International Sports Federations*, 2022). Within alpine skiing, athletes face descents on steep slopes, aiming primarily to complete the course in the shortest time, highlighting the intensity and precision of this discipline (Hébert-Losier et al., 2014). Events such as slalom, giant slalom, super-G, and downhill present distinct technical and physical requirements, each with specific characteristics (Alejo et al., 2021; Supej & Holmberg, 2019). Performance in alpine skiing is determined by a complex blend of factors, including strength, coordination, technique, and mental preparation (Gilgien et al., 2018). Although balance and postural control are essential in skiing, the literature doesn't always grant them the attention they deserve, highlighting a gap in research (Müller & Schwameder, 2003; Spörri et al., 2012).

In the context of recent technological advancements, it is imperative to re-evaluate and update research to align with the current realities of alpine skiing. Even though notable advancements have been made in ski biomechanics (Supej & Ogrin, 2019), there are aspects of performance that still await in-depth exploration, thus emphasizing the importance of continuous research (Nakazato et al., 2011).

Motivation for choosing the theme

Balance, essential in many sports, seems surprisingly under-investigated in alpine skiing. While there are studies examining the impact of balance on skiing performance, they yield varied, sometimes even contradictory results. For instance, Çamlıgüney's (2012) research and that of Cigrovski et al. (2016) suggest that snow training can enhance skiers' balance, whereas Müller et al. (2011) and Firlus (2018) counter this notion. While Hydren (2013) emphasizes the importance of balance in alpine skiing, other studies contest this connection (Male et al., 2013; Noe & Paillard, 2005). This discrepancy underscores the need for further research to clarify the role of balance in alpine skiing.

Dryland training, used in alpine skiing preparation, has been examined in several studies. The findings are mixed, with some indicating significant improvements in skiers' balance, while others yield ambiguous or insignificant results. Within the Romanian skiing context, there are constraints limiting access to on-snow training, amplifying the need for research focusing on developing general and specific dryland physical capacities.

From a technical perspective, balance is crucial for a skier's performance. A loss of balance can affect turn dynamics, resulting in inefficient descents and speed losses. This emphasizes the importance of focusing on balance development and technique refinement.

This research aims to devise a balance development protocol for skiers, focusing on two age groups: adult ski instructors and children aged 9-11. Personal motivation, combined with a scientific understanding of biomechanics and the processes involved in sports performance, led to the selection of this topic, hoping to contribute to enhancing skiers' preparation and performance.

Purpose of the Theme

The purpose of this research is to analyze the impact of dryland training, centered on improving balance, on alpine skiing performance. We specifically focus on developing dynamic and static balance, as well as anticipatory capacity, presuming these will lead to a significant increase in athletic performance.

Objective of the Theme

The main objective of the studied topic is to verify the effect of a program for developing static and dynamic balance on sports performance in adult alpine skiers and children aged 9-11. Other specific objectives of the thesis include:

- Evaluating the effectiveness of the protocol under specific alpine conditions;
- Investigating the reliability of testing equipment under varying snow conditions, ensuring accurate evaluations under real conditions;
- Implementing practical balance development methods;
- A detailed analysis of the efficiency of these methods within the context of skiing, considering its complexities and specific challenges;

- Evaluating the impact of the protocol on specific variables: static and dynamic balance, technique, trunk stability, agility, and explosive strength;
- Focusing on the 9-11 age group of children, an age deemed crucial for skill development in skiing;
- Exploring the potential of the methodology in a new context, bearing significant implications for the training of young athletes.

Theme actuality

Alpine skiing has undergone a significant evolution over the past few decades, with major transformations in equipment technology and slope infrastructure. We've witnessed the emergence of optimized snow conditions, characterized by a more uniform surface and the use of artificial snow of higher density (Ropret, 2015). Furthermore, technical innovations in skis, such as a reduced side-cut radius and enhanced torsional rigidity, have revolutionized the way skiers interact with the slope (Ropret, 2015). The introduction of "rapid gate" poles added an additional layer of speed and dynamism to the sport, profoundly impacting skiers' preparation and performance (Ropret, 2015).

In light of these technological advancements, previous studies conducted two to three decades ago, prior to these innovations, can now be seen as outdated and may no longer reflect the current realities of alpine skiing. Thus, the theme's relevance arises from the need to approach alpine skiing research with a contemporary perspective that integrates these technological advancements, ensuring the relevance and applicability of the findings in the sport's current context.

A consensus from specialized literature suggests that effective training for alpine skiers should focus on developing aerobic and anaerobic capacities, muscle strength enhancement, and refining motor skills such as balance, agility, and coordination (Andersen & Montgomery, 1991; Maffiuletti et al., 2006; Patterson et al., 2009; Platzer et al., 2009; Raschner et al., 2013).

However, the effectiveness of balance training in the context of alpine skiing remains a subject of debate. While some research indicates promising results, highlighting the benefits of an 8-9 week off-snow training program in balance development (Čillík & Rázusová, 2014; Vitale et al., 2018), other studies contradict these findings, suggesting no notable differences between groups that underwent such interventions and those that did not (Mahieu et al., 2004; Malliou et al., 2006).

In alpine skiing, on-snow training is vital for achieving top performance. However, this type of training is often constrained by variable factors, such as weather conditions, physical resources, or logistics. In this regard, off-snow training emerges as a viable alternative.

In the digital age, modern technology finds its place in researching performance in alpine skiing, offering new perspectives and analytical methods. The integration of portable wireless technologies represents a step forward in performance study. Moreover, detailed monitoring of an athlete's movements provides deep insights into the mechanisms underpinning performance, paving the way for more efficient training strategies tailored to contemporary sport demands.

Novelty elements

Our study focuses on optimizing off-snow training for skiers, aiming to enhance athletic performance. One of the primary challenges is evaluating performance under real conditions, both during training and in competitions. To address this issue, we turn to portable wireless technologies that allow real-time athlete monitoring. This innovative approach aims at integrating modern technology in assessing skiers' performance, providing an updated and detailed view of their abilities across different contexts.

The central element of originality in our thesis lies in integrating exercises and action methods provided by various training methods - proprioceptive, neuromuscular, balance training with equipment, plyometric training, for trunk stability - into a unique macrocycle focused on balance development. The thesis introduces innovation by merging training methods into one macrocycle and emphasizing children aged 9-11, aiming to develop more efficient training strategies for this age group.

PART I

THEORETICAL-SCIENTIFIC FOUNDATION OF THE WORK SYNTHESIS CHAPTER I. THEORETICAL CONCEPTUAL ELEMENTS REGARDING PERFORMANCE IN ALPINE SKIING.

Alpine skiing is characterized by a remarkable complexity in its physical, technical, and tactical aspects (Andersen & Montgomery, 1991; Gilgien et al., 2018; Hydren et al., 2013; Hébert-Losier et al., 2014). Factors such as weather conditions and the specifics of each discipline add additional layers of difficulty (Andersen & Montgomery, 1991; Turnbull et al., 2009). Performance in skiing is closely tied to physical abilities, necessitating proper training and evaluation (Pritchard, 2020; Andersen & Montgomery, 1991; Maffiuletti et al., 2006). Technical quality, combined with neurogenic activity and energetic aspects, is essential for performance (Gilgien et al., 2018; Müller & Schwameder, 2003; Szmedra et al., 2001).

Monitoring and assessing individual preparation are crucial for optimizing training (Turnbull et al., 2009; Raschner et al., 2013). Essentially, performance in alpine skiing is influenced by a combination of factors, without a single determining variable (Raschner et al., 2013; Turnbull et al., 2009).

Muscle fibers are classified as slow-twitch (ST) type I or slow fibers, and fast-twitch (FT) type II or fast fibers, with ST fibers being endurance-oriented and FT fibers being strength/power-oriented (Bottinelli & Reggiani, 2000). Elite skiers tend to recruit more slow-moving muscle fibers, while less skilled skiers use fast-moving fibers (Thorstensson et al., 1977). Tesch et al. (1978) and Nygaard et al. (1978) highlighted the types of fibers active during skiing using histochemical measurements. During the GS turn, eccentric contractions are dominant, with high intensities (Berg & Eiken, 1999; Hintermaister et al., 1997).

Elite skiers have greater muscular strength, especially in eccentric contractions (Abe et al., 1992). Ropret (2015) suggests that skiers' training should focus on eccentric contractions. Alpine skiing demands a combination of power and strength, with studies indicating a correlation between these attributes and performance (Tesch et al., 1978; Haymes & Dickinson, 1980). However, there isn't a direct proportionality between strength and World Cup ranking (Andersen & Montgomery, 1988; Neumayr et al., 2003). Alpine skiing is a high-intensity activity, with energy coming from ATP-

PCr, anaerobic glycolysis, and oxidative metabolism (Hydren et al., 2013; Saibene et al.,1985). To optimize skiing performance, both the aerobic and anaerobic systems should be the target of training (Veicsteinas et al., 1984; Saibene et al., 1985).

Alpine skiing races involve descents ranging from 45 seconds (SL) to 2.5 minutes (DH), being classified as high-intensity short-term exercises (Stöggl et al., 2018). While technical skills are vital for performance, maintaining these skills throughout a race and a competitive season requires robust physiological capacity (Turnbull et al., 2009). However, there are still unexplored aspects regarding skiing techniques, and the complexity of movements combined with challenging conditions complicates assessment with current technologies (Klous et al., 2010).

The turn in alpine skiing is a complex maneuver allowing direction change, either to the right or left (Vaverka et al., 2012). In competitions, the goal is to perform efficient turns, losing as little speed as possible. The modern carve turn, unlike previous techniques, involves almost equal weight distribution on both skis during the turn, providing better stability and control (Müller & Schwameder, 2003).

The evolution of technique in alpine skiing has gone hand in hand with the development of equipment, especially carve skis (Hirose et al., 2013). These skis have been modified to be shorter, with a wider waist, and with tailored rigidity, thus offering skiers better control and enhanced maneuverability (Müller & Schwameder, 2003).

Understanding mechanics is essential to mastering skiing techniques (LeMaster, 2010). The moving skier is influenced by a range of forces, including gravity, snow reaction forces, and aerodynamic resistance (Howe, 1983; Lind & Sanders, 1997). Contemporary skiing combines various techniques, starting with ski pivoting and culminating in a precise carve turn, minimizing speed loss and optimizing control (LeMaster, 2010; Reid, 2010).

SYNTHESIS CHAPTER II. PSYCHOMOTOR CAPACITY AND BALANCE

Grosu (2009) defines psychomotricity as the integration of motor and psychic functions. This encompasses various components, such as kinesthetic sensitivity, balance, coordination, and others. In sports, especially in alpine skiing, motor and functional skills are essential for performance (Male et al., 2013).

Balance is the ability to maintain the body's center of gravity in a stable position, whether at rest (static) or in motion (dynamic) (Ricotti, 2011). Moreover, balance relies on the integration of information from the visual, vestibular, and somatosensory systems, which coordinate neuromuscular responses for stability (Nashner, 1997). Despite its significance, research on balance, particularly among adolescent athletes, is limited. In assessing balance performance in sports, the sport's specificity plays a crucial role. Bressel (2007) observed significant differences in balance performance between athletes in football (soccer), basketball, and gymnastics. These findings are also supported by Davlin (2004). Hrysomallis (2011) emphasized that gymnasts have the best balance skills, followed by footballers (soccer players) and swimmers, while basketball players did not exhibit superior balance. Balance is governed by neuromuscular responses and sensory information from the vestibular, visual, and proprioceptive systems (Proske & Gandevia, 2012).

Trunk stability is vital for maintaining balance, and plyometric training can enhance balance and postural stability (Benis et al., 2016). In alpine skiing, balance is a vital component (Hrysomallis, 2011; Hydren et al., 2013). Skiing demands robust balance and precise coordination, especially in the "carving" technique (Raschner et al., 2012). However, research related to balance in alpine skiing is limited, with mixed results on the impact of dryland training on balance (Čillík & Rázusová, 2014; Vitale et al., 2018; Mahieu et al., 2006). In conclusion, balance plays a pivotal role in athletic performance, with significant variations depending on the sport's specificity. In alpine skiing, balance is paramount, but research in this area remains limited and calls for further exploration.

SYNTHESIS CHAPTER III. TRAINING IN ALPINE SKIING

Sport training is a specialized pedagogic process, focused on maximizing competition performance, enhancing work capacity, sporting skills, and psychological traits (Bompa, 1999; Bompa & Buzzichelli, 2015; Carrera & Bompa, 2007). Bompa (1993) outlines the general objectives of training, which encompass physical development, technical and tactical factors, psychological aspects, and theoretical knowledge. There are three essential stages in training: preparation, competitive phase, and transition period (Bompa, 1999; Harre, 1982; Matveyev, 1981; Zatsiorsky & Kraemer, 2006).

In alpine skiing, technique is paramount for performance, but it is closely tied to physical and psychological foundations (Kornexl et al., 2003). Bosco et al. (1994) and Andersen & Montgomery (1988) emphasize the role of technique and physiological factors in alpine skiing performance. The components of performance include technical, tactical, psychological, and physical aspects (Schoenhuber et al., 2018). Gilgien et al. (2018) suggest a periodization of training in alpine skiing, with two main periods: preparation and competition. During the preparation phase, skiers focus on equipment calibration and technique refinement, followed by physical conditioning and on-snow training. In the competitive phase, physical preparation aims at maintaining fitness, achieving peak form, and recovery. Plisk (1988) offers another perspective on periodization, with five distinct phases.

Furthermore, sport training is a complex pedagogic process, focused on developing and maximizing sports performance. In alpine skiing, technique and physical preparation are critical for performance, with training periodization adapted to the sport's specifics and the individual needs of athletes.

In alpine skiing, external conditions exhibit great variability, demanding technical and tactical adaptations from skiers. This mirrors open motor skill sports, where the course, terrain, snow conditions, speed, and visibility can significantly vary. Hence, technical training must consider these aspects to effectively prepare an Olympic skier (Gilgien et al., 2018).

Specialization in skiing either focuses on technical events, like slalom and giant slalom, or on speed events, such as super-g and downhill. On-snow training is influenced by this specialization, with typical training sessions lasting between 2-4 hours, varying in the number of runs and turns based on the discipline (Gilgien et al., 2018).

Technical training is constrained by physiological, psychological, and practical factors, but innovative strategies can increase training volume. For instance, reinforcing physical conditioning can enhance a skier's endurance and efficiency (Gilgien et al., 2018).

Similarly, specific on-snow training is largely determined by the discipline in which the skier chooses to specialize (Gilgien et al., 2018). A clear trend is observed among athletes, opting either for technical events like slalom (SL) and giant slalom (GS) or for speed events such as super-g (SG) and downhill (DH) (Gilgien et al., 2018).

Regarding physical preparation, alpine skiing is demanding, requiring the development of strength, power, stability, aerobic and anaerobic capacities, coordination, and balance. Physical condition tests are used for talent identification and development, but their relevance in predicting skiing performance remains debatable (Gilgien et al., 2018).

The dynamics of alpine skiing have evolved, now featuring tighter turns and much larger ground reaction forces, heightening the potential relevance of lower body peak power in skiing performance (Patterson et al., 2009; Supej & Holmberg, 2019).

Training for alpine skiing focuses on the whole-body development, especially legs and trunk, emphasizing stability and eccentric training, crucial for managing forces and impacts during turns (Ferguson, 2010; Patterson & Raschner, 2015). Coordination and motor control training are also vital, often combined with strength and power workouts (Raschner et al., 2004). Other activities, like cycling or soccer, are integrated to enhance endurance (Gilgien et al., 2018).

Regarding psychological preparation, alpine skiers must develop adaptive psychological characteristics to respond to competition stress. Perseverance and mental toughness are two of these essential traits for performance. Mental imagery, which involves generating a visual representation or a sequence of images related to the sports activity, is a technique used to optimize performance and develop psychological skills (Volgemute et al., 2016).

In conclusion, preparation in alpine skiing is intricate, involving technical, physical, and psychological training, all being essential for high-level performance (Gilgien et al., 2018).

PART II

CHAPTER IV. PRELIMINARY RESEARCH ON THE EFFECT OF BALANCE TRAINING ON SPORTS PERFORMANCE IN ALPINE SKIING AMONG SKI INSTRUCTORS

4.1 Research Background

Alpine skiing is a sport that places intense physical and mental demands on the athlete. These demands can lead to neuromuscular fatigue, affecting proprioceptive sensitivity and balance ability. As a result, skiers might lose stability during turns, leading to compensatory movements and an inefficient gliding technique. Precarious balance increases the risk of injuries, negatively impacting training volume and performance. Our research aims at optimal preparation of skiers, with a focus on developing balance, to enhance alpine skiing performance. Evaluating performance under real-world conditions is both essential and complex (Supej et al., 2020). Hence, we intend to use wearable technology to assess performance in actual competition contexts.

4.2 Purpose

The purpose of this preliminary study is to investigate the effects of balance training within the context of alpine skiing, specifically for ski instructors.

4.3 Research Objectives

The primary objective was to design a comprehensive intervention program, specifically tailored to improve both static and dynamic balance, and to examine the effect of this protocol on balance values and sports performance. This involves the creation of a set of training exercises and strategies based on empirical evidence. Another objective was to test the reliability and familiarize with the snow testing equipment.

4.4 Research Hypotheses

Within this research, several hypotheses are proposed that explore the impact of a balance training program on sports performance in alpine skiing. We formulated the following hypotheses:

H1: Implementing a balance training plan, integrated into a general plan for developing skiers' physical capacities, will result in significant improvements in both static and dynamic balance.

H2: By integrating a training program focused on balance development into the overall strategy for enhancing skiers' physical abilities, a notable improvement in the ski instructors' technique will be observed, reflected in the SKI IQ values.

H3: Integrating a program centered on balance development into the strategy for enhancing skiers' physical abilities will show notable progression in edging and pressure.

4.5 Research Methods

In our study, we implemented several scientific research methods:

- Bibliographic study: as defined by Gagea (2010), this represents a systematic process of collecting, organizing, and disseminating specialized information.
- Observation method: as emphasized by Epuran (1992), observation allows for the recording of phenomena in their natural context.
- Experimental method: Specifically, we aimed to determine if a balance-focused training program can significantly influence balance performance and lead to an overall improvement in skiing sports performance.
- Testing method: In our research, we implemented specialized tests to measure balance values, technique, pressure, and edging.
- Statistical-mathematical method: the analysis and interpretation of the data collected during our research involved the use of statistical and mathematical methods.
- Graphic method: to facilitate the interpretation of results and their communication.

4.6 Research Organization

4.6.1 Participants in the Preliminary Research

The preliminary research spanned a period of 11 months, out of which 9 weeks were dedicated to the application of the balance development intervention protocol. In the preliminary study, we had a total of 24 participants, all male. The subjects were divided into two groups: a control group and an experimental group using paired sampling.

4.6.2 Research Design

Using a two-factor experimental design, this preliminary research examines the interaction between independent variables and their effect on dependent variables. Within the scope of our study, the two independent variables are represented by the balance development training protocol and repeated measurements (pre and post-intervention).

4.6.3 Tests used in the Preliminary Research

1. Snow testing with the CARV device

Protocol:

During a descent on a giant slalom route, consisting of 20 gates spaced evenly at 20 meters apart, the Carv device recorded multiple parameters including balance, edging, edge angle, pressure exerted on the outside ski during turns, turn symmetry, and SKI IQ.

2. ISOFREE testing

Postural stability was evaluated using the ISOFREE force platform (Medical Equipment IsoFree, Tecnobody S.R.L., 2015). Using the force plate, we measured the center of pressure (COP) parameters, including standard deviations in anterior-posterior and medio-lateral directions.

4.6.4 Measuring Devices

1. Snow-specific device “CARV” The CARV device is a skiing performance monitoring tool that operates based on an inertial motion unit (IMU) principle. CARV consists of a smart insole that is placed inside the ski boot, between the boot shell and the liner. The insole is connected to a data recording and tracking device attached to the boot.
2. ISO FREE Force Plate - for measuring static and dynamic balance on dry land The base support of the force plate is a sensory platform with four load cells capable of real-time detection of the subject's ground force distribution. It is a highly sensitive stabilometric plate certified as a MEDICAL DEVICE (class I) with a ground resolution of 1 mm (Tecnobody S.R.L., 2015).

4.6.5 Balance Development Training Program

The balance program took place twice a week for 9 weeks in 2021, with 45-60 minute sessions supervised by a specialized coach. The training sessions were held in a gymnasium equipped with various tools, from Swiss balls to mini trampolines. Each session began with warm-up exercises, followed by specific activities, with one-minute breaks between them, tailored according to a well-defined protocol.

4.6.6 Intervention Plan of the Preliminary Research

In the context of alpine skiing, a sport of high complexity, we chose to implement exercises from five training methods for balance development. We selected exercises from neuromuscular training as a balance development method (Hewett et al., 1999; Mandelbaum et al., 2005; Zazulak et al., 2007). In addition, we incorporated exercises and methodological means for trunk stability (in English, core-stability training). Our program also incorporated plyometric training exercises, a method recognized for its efficacy in improving balance, neuromuscular properties, and joint awareness (Arazi & Asadi, 2011). Furthermore, exercises from proprioceptive training and specific device-aided balance development training also showed positive aspects in optimizing balance.

4.7 Preliminary Research Data Results and Statistical Processing

Statistical Analysis

We used the Skewness and Kurtosis test to verify the normality of the distribution, with results indicating a normal distribution. We employed multivariate analysis of variance (MANOVA) to examine the relationships between variables. Effect size was measured using the partial eta squared coefficient (η2). Data was processed using SPSS and visualized in Excel. The set significance level was 0.05, in accordance with standards (Pallant, 2016).

4.8 Results and Statistical Analysis of Testing with the CARV Device

After allocating the subjects into the two groups - experimental and control - using the paired samples method, we applied a multivariate analysis (MANOVA) to determine any differences between the two groups before implementing the intervention.

Table 1

MANOVA Analysis of Control-Experiment Differences Before Intervention

Dependent Variable		*Sum of Squares*	*Degrees of Freedom*	*Mean Squares*	*F*	*p.*	*η2*
	Ski IQ	115,200	1	115,200	0,613	0,444	0,033
	Balance	5,000	1	5,000	0,065	0,801	0,004
	Edging	72,200	1	72,200	1,047	0,320	0,055
	Pressure	0,200	1	0,200	0,002	0,962	0,000

From the data presented in Table 23, it can be observed that the differences between the two groups regarding the analyzed dependent variables are not statistically significant. To compare the experimental group with the control group after the intervention, **we decided to create 4 new dependent variables that are equal to the difference between post-intervention (posttest) and pre-intervention (pretest) for SKI IQ, balance, edging, and pressure.**

Table 2

Analysis of Differences Between Experimental and Control Group (Dependent Variable: Pretest-Posttest Differences) CARV

Dependent Variable	*Sum of Squares*	*Degrees of Freedom*	*Mean Squares*	*F*	*p*	*η2*
ski_iq_difference	80,000	1	80,000	34,450	**0,000**	0,657
balance_difference	105.800	1	105,800	1,965	0,178	0,098
edging _difference	51 .200	1	51 ,200	2,992	0,101	0,143
pressure_difference	168,200	1	168,200	1 ,325	0,265	0,069

In Table 25, the differences between the control and experimental group regarding the 4 dependent variables (pretest-posttest Ski IQ difference, pretest-posttest balance difference, pretest-posttest edging difference, pretest-posttest pressure difference), their statistical significance, and the effect size are presented. First and foremost, we notice a significant and very large difference regarding Ski IQ **(F (1,18) =34.45; p=0.000),** and we can assert with a 95% probability that the results obtained are not random and are the effect of the intervention protocol. Regarding the other dependent variables, the differences are not statistically significant.

4.9 Results and Statistical Analysis of Testing with the ISOFREE Device

Variables:

• Balance on two feet with eyes closed - standard deviations of COP in anterior-posterior (FB), medial-lateral (ML) = EDPOÎ

• Limits of stability = LOS

• Balance on the left foot (S) and right foot (D) - standard deviations of COP in anterior-posterior (FB), medial-lateral (ML) = EP1S/D, FB/ML

To identify any significant differences between the control group and the experimental group pre-intervention, and to validate the effectiveness of the subject allocation process, we applied a multivariate analysis of variance (MANOVA).

The differences between the two groups regarding the 7 dependent variables are not statistically significant. Thus, we can conclude that the two groups were equivalent before the intervention, indicating that the randomization was successful.

In the next step, we created 7 new dependent variables (by calculating the difference between posttest scores and pretest scores for each participant).

Table 3

Diferențe între grupul control și experiment analiză inferențială

Variable	*Sum of Squares*	*Degrees of Freedom*	*Mean Squares*	*F*	*P*	*η2*
Difference EDPOÎ FB	18,096	1	18,096	24,952	**0,000**	0,531
Difference EDPOÎ ML	1,955	1	1.955	4,891	**0,038**	0,182
Difference LOS	1,021	1	1,021	0,307	0,585	0,14
Difference EP1S FB	2,394	1	2,394	1,624	0,216	0,069
Difference EP1S ML	3,197	1	3,197	3,874	0,062	0,150
Difference EP1D FB	2,660	1	2,660	2,568	0,123	0,105
Difference EP1D ML	3,161	1	3,161	7,307	**0,013**	0,249

Based on the data presented in Table 29, for the variable Difference **EDPOÎ FB**, we observe a statistically significant difference between the groups, with an F-value of 24.952 and a significance of $p < 0.001$. The effect size, represented by η2, is 0.531, indicating a large effect size. For the variable Difference **EDPOÎ ML**, there is also a statistically significant difference, with F=4.891 and p=0.038, and a moderate effect size with η2 of 0.182. Lastly, for the **Difference EP1D ML**, the F-value is high, with F=7.307, the significance p is below the standard threshold of 0.05, at p=0.013, indicating a statistically significant difference. The effect size is moderate to large, with η2 of 0.249.

4.10 Discussions

In the preliminary research, we aimed to evaluate the impact of balance training on balance performance and alpine skiing performance among ski instructors. Moreover, another objective was to test the practicability of the testing equipment on snow.

Snow Testing

Our results indicate a significant improvement in the skier's technique, measured by the SKI IQ variable. This suggests that balance training can have a direct and positive impact on overall skiing performance.

Dry Land

Testing Regarding dry land testing, we observed significant improvements in two-legged balance with eyes closed in antero-posterior and mediolateral directions, as well as in one-legged balance on the right foot in the mediolateral plane. These results are consistent with previous studies (Vitale et al., 2018; Myer et al., 2006; Słomka et al., 2018).

Practicability of the Testing Equipment on Snow

By optimizing the snow testing process, we aimed to eliminate any variables that might influence the results. This involved making adjustments and improvements to the testing process, as well as verifying the accuracy and reliability of the testing devices used. Additionally, we deemed it essential for both the skiers and the researchers to familiarize themselves with the testing equipment.

Balance Development Protocol

The exercises for balance development were adapted from five different methods, based on previous studies that showed benefits in improving balance and postural stability. These methods include neuromuscular training, core stability, equipment-based training, plyometrics, and others. While previous studies, such as those by Vitale et al. (2018) and Čillík & Rázusová (2014), have highlighted improvements in skiers' balance, their methods varied. Furthermore, although balance is crucial for skiing performance, there is a lack of research focusing solely on this aspect, with most studies focusing on strength and power development. Thus, continuing research in this area is essential.

Thus, through our research, we attempted to bring new data to a little-studied branch of alpine skiing, with controversial results.

4.11 Preliminary Research Conclusions

Our results highlighted significant improvements in skiers' performance, especially regarding SKI IQ, a value derived from balance, edging, and pressure, as well as positive results of dryland testing. This suggests that balance training can positively impact overall skiing performance. Regarding the proposed hypotheses:

- **H1** was partially confirmed, indicating that balance development training can significantly improve certain dimensions of skiers' static balance. Thus, the Difference EDPOÎ FB showed a statistically significant difference between groups **(F=24,952; p<0,001; η2=0,531).** The Difference EDPOÎ ML also showed a statistically significant difference **(F=4,891; p=0,038; η2=0,182)**. Finally, for the Difference EP1D ML, we identified a statistically significant difference **(F=7,307; p=0,013; η2=0,249).** The preliminary research results suggest an increase from pretest to posttest in the Balance variable from the snow testing, but this is not statistically significant.
- **H2** was confirmed, with SKI IQ serving as a representative measure of skiers' technique, showing significant improvements following the balance development protocol.
- **H3**, although showing positive trends, requires further research to be fully confirmed regarding weighing and pressure.

In conclusion, we identified significant improvements in balance on both feet with eyes closed, indicated by lower standard deviation values from the center of pressure (COP) in the antero-posterior and mediolateral planes. Similarly, we observed progress in balance on the right foot in the mediolateral plane and the overall performance of skiers (SKI IQ). These advancements are attributed to the balance-focused intervention protocol implemented over nine weeks.

4.11.1 Limitations and Future Directions for Research

Within our preliminary research on alpine skiing, we analyzed the impact of balance development on performance. However, the study encountered several limitations, including a reduced sample size due to COVID-19 restrictions and uncertainties concerning the reliability of snow tests and the CARV device. The variability of testing conditions and the lack of information about the control group's activities made interpreting the results more complex. For future endeavors, it is crucial to expand the sample size, validate the snow tests, and integrate more advanced technologies into the evaluations. Additionally, it would be beneficial to closely monitor the control group and investigate the methods' applicability across various categories of skiers. Adopting these measures will enhance the quality and relevance of research in the field of alpine skiing.

CHAPTER V. FUNDAMENTAL RESEARCH - EFFECTS OF A 10-WEEK ON-LAND BALANCE DEVELOPMENT PROGRAM ON THE SPORTS PERFORMANCE OF 9-11 YEAR OLD ALPINE SKIERS

5.1 Research background

Alpine skiing is a dynamic and intricate sport where balance plays a pivotal role in performance. Despite its significance in skiing, research regarding balance training for young skiers remains limited and often ambiguous. Balance, an essential component in skiing, requires continuous adjustments due to rapid changes in terrain, speed, and snow conditions. Losing balance can compromise technique and speed, increasing injury risk. Proper training can also prevent fatigue and enhance a skier's adaptability to various conditions. With recent technological advancements in skiing, it's imperative to update research to reflect the sport's current realities. Performance evaluation in real conditions is critical, and wearable technologies like CARV can provide valuable insights. In conclusion, optimizing performance in alpine skiing essentially requires understanding and training balance, considering the latest technologies and preparation methods.

5.2 Research purpose

This research aims to assess the impact of various exercises and intervention tools from multiple training methods to enhance balance and technique in alpine skiing for skiers aged 9 to 11.

5.3 Research objectives

The fundamental research goal is to gauge the effect of a balance development protocol, utilizing intervention tools and exercises selected from various balance development methods. These focus on enhancing dynamic balance performance, static balance, trunk stability, and explosive strength in skiers aged 9 to 11. Furthermore, our study aims to:

• Assess this protocol's impact on dynamic balance in dynamic skiing situations;

• Investigate if this protocol advances static balance and trunk stability;

• Examine the protocol's efficacy in developing explosive strength;

• Another objective is to optimize snow testing methods;

• The research's final objective is to determine a positive link between a skier's balance and their alpine skiing technique.

5.4 Research hypotheses

This research seeks to explore several interconnected hypotheses:

H_1 : We hypothesize that the balance development protocol positively affects dynamic balance values and the technique of skiers aged 9 to 11, represented by the dependent variable SKI IQ;

H_2 : We posit a positive relationship between balance and alpine skiing technique;

H_3 : We assume that using wearable technology could offer distinct insights into junior alpine skiers' performance and technique. We believe that these immediate and accurate data can enhance traditional training strategies, promoting more personalized training methodologies and, consequently, optimizing athlete performance;

H_4 (4.1.): We hypothesize that the balance development protocol positively impacts static balance values;

H_4 (4.2.): We assume that the balance development protocol can increase trunk strength;

H_4 (4.3.): We believe that the balance development protocol can lead to the enhancement of explosive strength;

H_4 (4.4.): We assume that the balance development protocol can lead to agility development;

H_5 : We theorize that improving balance through our training protocol might lead to alterations in canting angles, which could positively impact control and speed during descent;

In essence, this research integrates these hypotheses, aiming to validate a multidimensional approach combining motor, psychomotor, and biomechanical variables for a profound understanding of the balance development protocol's effect.

5.5 Research Methods

The fundamental study employs the same methods as the preliminary study. The methods are similar, and we utilized:

- Experimental method;
- Testing method;
- Statistical-mathematical method;

5.6 Organization of the Fundamental Research

5.6.1 Subjects of the Fundamental Research

The subjects for the fundamental research were chosen based on their availability to participate in the study and were selected from two sports clubs in Cluj-Napoca: A.C.S. Cubs Cluj-Napoca and PC Cluj Napoca. The study included a group of 30 participants aged between 9 and 11 years (n=26 boys, n=4 girls).

They were divided into two groups: the experimental group (EG) with an average age of 9.86 years (SD=0.83) and the control group (CG) with an average age of 9.66 years (SD=0.61). Subjects were allocated to the experimental and control groups using the matched samples method, based on the SKI IQ score obtained from initial snow tests.

5.6.2 Experimental Design

In our study, we utilized a two-factor experimental design involving the use of an experimental group and a control group. The two-factor factorial design allowed us to examine the differences between these two independent groups, while simultaneously conducting repeated measurements within each group at two different points in time.

5.6.3 Research Variables

Independent Variables

The first independent variable involved the implementation of a specialized training program designed to enhance static and dynamic balance within the experimental group, while the control group did not receive this training.

The second independent variable was represented by repeated measurements.

Dependent Variables:

- Static balance assessed using the BTS P-walk pressure plate;
- Explosive force assessed using the BTS G-walk;
- Agility;

- Trunk stability;
- Dynamic balance assessed with the CARV device (giant slalom track);
- Edging assessed with the CARV device;
- Edging angle;
- Pressure assessed with the CARV device;
- SKI IQ assessed with the CARV device.

5.6.4 Protocols and Tests used in Fundamental Research

5.6.3.1 Initial and Final Snow Testing Protocol with the CARV Device

To assess the performance of the athletes in the experimental study, we chose to use a giant slalom track with 20 gates and a distance of 18 meters between the gates for initial and final snow testing. The tests took place between 14:00 and 19:00 on the blue slope in the Mărișel ski area, Romania. Before testing, athletes performed a dry warm-up and did a reconnaissance descent of the route.

5.6.4.2 Pressure Plate Testing Protocol

Using a balance plate that measures and records the parameters of the pressure center, along with the average position of this center in the anterior-posterior and mediolateral directions, we analyzed the following aspects, based on a testing protocol similar to that used in other alpine skiing research but on different balance plates (Staniszewski et al., 2016):

- Unipodal balance, either on the right foot or on the left foot
- Bipodal balance with eyes closed and open (Figure 20).

The testing protocol for bipedal balance with eyes closed is identical to the one used in the pilot study.

5.6.4.3 **Counter Movement Jump (CMJ) Test and Protocol** – *for measuring explosive strength*

For the evaluation of explosive strength, we used the G-walk system with which we measured jump height. The Counter Movement Jump (CMJ) test involves an initial eccentric phase, during which the extensor muscles of the legs stretch through a preparatory contraction movement, followed by a concentric phase where there's an explosive extension in the opposite direction. The testing protocol includes 15 consecutive jumps (CMJ), and the G-walk device presents an average of these 15 jumps.

5.6.4.4 Agility Test

Within this research, we utilized the agility test among obstacles as described by Gonaus and Müller (2012).

5.6.4.5 Trunk Stability Testing

In this study, we selected the physical fitness test "plank up", described by Badau et al. (2021), which examines the overall function of the trunk muscles, with a particular emphasis on balance, endurance, and muscular strength. This test involves maintaining the "up plank" position on an unstable spherical surface.

5.6.4.6 TANITA Measurements

The TANITA device was used to determine body composition. Measurements with the Tanita BC-320 (Tanita Corp., Tokyo, Japan) were taken at a frequency of 50 Hz using standard settings after manually entering the height, gender, and age of the subject.

5.6.5 Devices used for testing and evaluating dependent variables

BTS G-walk

According to the device manual (G-walk User Manual, 2016), G-WALK (BTS Bioengineering S.p.A., Garbagnate Milanese, Italy) is the ideal solution for a quick and objective assessment of walking, running, and jumping parameters. The system consists of an inertial sensor named G-SENSOR, the G-Studio software, and a set of protocols for analyzing specific movements (G-walk User Manual, 2016). This system uses a technology called Inertial Measurement Unit (IMU) that measures linear acceleration and angular rotation of the object it's attached to. It is typically attached using a belt at the sacral (L5) level of the subject to obtain an objective view of body movement. The G-Walk system for movement analysis in healthy subjects has been documented to be reliable for all measured spatio-temporal parameters (De Ridder et al., 2019). In our research, we used BTS G-WALK to assess performance in vertical jumps (Counter Movement Jump - CMJ).

BTS P-WALK

BTS P-WALK *(P-Walk FM12050 BTS-Bioengineering, Milan, Italy)* este un sistem de analiză a mersului produs de compania BTS Bioengineering. Dar, folosind un singur modul, P-walk permite evaluarea echilibrului prin generarea datelor a centrului de presiune (COP).

Stabilometric Analysis

BTS P-WALK (P-Walk FM12050 BTS-Bioengineering, Milan, Italy) is a gait analysis system produced by BTS Bioengineering. Using a single module, P-walk allows for balance assessment by generating Center of Pressure (COP) data.

Variabilele pe care le-am măsurat pentru fiecare dintre protocoalele de testare pentru echilibrul unipodal și echilibrul pe doua picioare cu ochii închiși și deschiși:

- **Distance traveled by COP:** Defines the total length of the path marked by COP; the sum of distances between COP locations constitutes the path length (Krawczyk-Suszek et al., 2022).
- **Average COP position on the X-axis:** represents the COP oscillations from the center of the trajectory in the anteroposterior plane, measured in millimeters.
- **Average COP position on the Y-axis:** represents the COP oscillations from the center of the trajectory in the medial-lateral plane, measured in millimeters.

5.6.4.7 Carv system

CARV is a UMI device that attaches between the ski boot and the ski boot liner and can measure a range of performance-relevant parameters, including the force applied during turns, balance, pressure on skis, and other factors. Through a mobile Bluetooth app, CARV can provide real-time information on the skier's performance.

5.6.6 Balance development protocol for skiers aged 9-11

Considering that balance is crucial for alpine skiing performance, we propose a dedicated protocol to enhance balance in children aged 9 to 11. In our research, we decided to focus on various balance development techniques, including exercises and actionable means from neuromuscular training, core and upper body stabilization training, proprioceptive training, equipment-assisted balance training, and plyometric training. These techniques were chosen based on prior studies that highlighted notable improvements in dynamic alignment of the lower limbs, postural stability, and injury prevention.

5.6.4.8 Duration, Location, and Timing of the Study

Balance development training took place twice a week for 10 weeks, from September to December 2022. Each training session lasted 30-40 minutes. The balance development protocol was conducted in a fitness room, and subjects from the experimental group were divided into two groups: the first group attended training from 5 pm to 6 pm, while the second group participated from 6 pm to 7 pm on Mondays and Wednesdays due to organizational reasons.

5.7 Obtained Results and Statistical Data Processing

5.7.1 Statistical Analysis

To perform the analysis of our data, we used the Multivariate Analysis of Variance (MANOVA). To measure the effect size, we employed the partial eta squared (η2) as the measure of effect size in our MANOVA model. For the visual representation of our data, we utilized Excel software (Microsoft Office 2020) and SPSS (version 1.0.0.1275; SPSS Inc, Chicago, IL). In our statistical analysis, the first assumption we investigated was that of normality. To assess this assumption, we applied the Kolmogorov-Smirnov test. In addition to the Kolmogorov-Smirnov test, we examined the skewness and kurtosis of our data. Regarding the assumption of homogeneity of variances, this assumption was validated using the Levene's test (Levene, 1960).

5.7.2 Prelucrarea statistică

Prelucrarea statistică a datelor noastre a fost realizată folosind software-ul Statistical Package for the Social Sciences (SPSS) (versiunea 1.0.0.1275; SPSS Inc, Chicago, IL).

5.7.3 Results

5.7.2.1 Anthropometric measurements of the subjects

We analyzed parameters such as age, weight, muscle mass, body fat percentage, and height. This was done as a precautionary measure, to check if there were significant differences between groups before the implementation of the GE balance development protocol that could influence our study. Through the results of the t-test, we conclude that there are no significant differences between the two groups in terms of the parameters examined. Subsequently, we conducted a MANOVA analysis. Based on the outcomes of our analysis, we found no statistically significant differences between the control group and the experimental group concerning these variables on pre-test.

5.7.3.2 Testing the assumptions of the variables for snow testing

In our process of verifying the assumption of normality, we chose to use the Kolmogorov-Smirnov test. Our observations from applying this test revealed that one value proved to be statistically significant. However, a notable aspect is the resilience of the MANOVA analysis to violations of normality. MANOVA remains robust even when normality is moderately or slightly violated, as was demonstrated in Cohen's (2008) paper. Additionally, we also considered measures of skewness and kurtosis. We found that the calculated values for both, skewness and kurtosis, fall within acceptable limits.

5.7.3.3 Differences between the pretest and posttest of the control and experimental groups

Next, we used a multivariate analysis of variance (MANOVA) to analyze the potential differences between the control and experimental groups regarding variables such as SKI IQ, balance, canting, and pressure. The dependent variable was established by calculating the difference between post-test and pre-test scores.

After conducting this analysis, a significant difference was identified between the control and experimental groups regarding SKI IQ ($F=13.239$; $p=0.001$, $\eta 2=0.321$). Furthermore, the effect size ($\eta 2=0.321$) suggests a large effect magnitude.

We also observed statistically significant differences in the balance value ($F=4.800$; $p=0.037$; $\eta 2=0.146$). The effect size indicates a moderate to large effect magnitude. For the Pressure difference variable, an F value of 8.084 was noted, with a significance of 0.008, indicating a significant difference between groups. The effect size is $\eta 2=0.224$, suggesting a large effect magnitude.

Further, we analyzed a derived variable of edgeing, specifically the canting angle. Data analysis revealed a contrast between the control group, which showed a decrease, and the experimental group, which showed an increase. However, the obtained F test statistic is 3.31, with a p-value of 0.079.

5.7.3.4 Correlations between posttest and pretest variables

From the data, all correlations stand out as statistically significant. It's evident that the pre-test SKI IQ showcases a robust positive correlation with post-test edging ($r = 0.872$, $p < 0.001$). Additionally, SKI IQ holds noteworthy associations with Balance ($r = 0.524$, $p = 0.003$) and Pressure (r = 0.515, p = 0.004), highlighting a profound relationship between these variables. Post-test Balance displays significant ties with all other variables, with the most potent being with Weighing (r = 0.556, p = 0.001). The post-test Pressure reveals a meaningful association with SKI IQ (r = 0.515, p = 0.004), Balance (r = 0.479, p = 0.007), and Weighing (r = 0.385, p = 0.035), indicating a moderate interrelation amongst these facets.

These insights are pivotal as they denote that the intervention produced a comprehensive impact on the participants. It suggests that honing one skill, such as SKI IQ, might be intrinsically tied to enhancements in other capabilities, like balance.

5.7.4 Dryland Testing Results and Analysis

5.7.4.1 Differences between Pre-test and Post-test of Control and Experimental Groups in Dryland Testing Variables

We utilized the t-test to assess potential disparities between the two groups. The outcomes of the t-tests hint that both groups were on a similar footing at the commencement of the research across all four measurements, as no significant differences surfaced between them.

Subsequently, we incorporated the MANOVA test to delve into the variations between the control group and the experimental group, focusing on several pertinent variables. The dependent variable was pinpointed by calculating the gap between the final score and the starting one. Therefore, the three OD2P variables were amalgamated into the same analysis. Again, the dependent variable was ascertained by determining the difference between post-test and pre-test scores.

Upon reviewing the statistical analysis for the variables OD2P_AP, OD2P_ML, and OD2P_COP, several conclusions can be drawn. For the OD2P_AP variable, an F-value of 1.584 was observed with a significance level of p=0.219. The associated effect size, indicated by η^2, is 0.054, suggesting a small effect. In contrast, the analysis for the OD2P_ML variable revealed an F-value of 4.304, signaling a significant difference with a p-value of 0.047. The effect size for this variable, represented by η^2, is 0.133, pointing to a medium effect. For the OD2P_COP variable, the F-value stands at 5.212, indicating a statistically significant difference between groups since the p-value is less than 0.05 (p=0.030). The effect size for this variable, denoted by η^2, is 0.157, suggesting a medium to large effect.

After analyzing the results for balance on both feet with eyes closed, it can be discerned that for the dependent variable "OI2P_AP_difference", the statistical F-value is significant at 14.249. This is accompanied by an exceptionally small p-value of 0.001. Additionally, the partial η^2 coefficient is 0.337, indicating a large effect size.

5.7.4.2 Analysis of the Results of the One-Footed Balance Test / Right Foot

When looking at the dependent variable "SP1PD_ML_difference," our statistical analysis indicates an F-value of 8.966. This is associated with a significant p-value of 0.006, highlighting a pronounced difference between the groups for this specific variable. The magnitude of the effect, as represented by the partial η^2, is 0.243, which suggests a moderate to large effect size.

For the "SP1PD_COP_difference" dependent variable, the analysis yields an F-value of 4.344. This result is accompanied by a p-value of 0.046, denoting a significant difference between the groups for this variable since it is below the conventional 0.05 threshold. The effect size for this variable, represented by the partial η^2, stands at 0.134, pointing to a moderate effect.

5.7.4.3 Analysis of the Results of the One-Footed Balance Test / Left Foot

Examining the statistical results, we note that for the dependent variable "SP1PS_ML_difference", the F-value is 6.396, with a significant p-value of 0.017. This indicates a significant difference between the groups for this variable. The partial η2 is 0.186, which is considered to be a moderate effect size. The difference in other variables is statistically insignificant.

5.7.4.4 Analysis of the Results for Explosive power

Using the ANOVA analysis for the counter-movement jump (CMJ) height values, the test value is statistically significant **(F=6.08, p=0.02).**

5.7.4.5 Analysis of the Results for the Agility Test and Trunk Stability

Analyzing the statistical results, we note that for the dependent variable "ST_difference" **(F=4.305, p=0.047, η2=0.133)**, the F statistic value is 4.305, accompanied by a p-value of 0.047. This indicates a significant difference between groups for this variable.

5.7.4.6 Testing Assumptions for Dry-land Testing Variables

We converted scores to z-scores to identify any outliers. A few scores exceeded the set threshold, but their exclusion did not significantly alter the results. Preliminary analyses confirmed the homogeneity of variances, and although there were deviations from normality due to extreme scores, they do not compromise the validity of our analysis. The results can be interpreted with confidence.

5.8 Discussions

The primary objective of the study was to examine the effect of a balance development protocol on the performance of skiers aged 9-11 years. While many studies highlight the importance of dry-land training for skiers, few focus on the role of balance in alpine skiing. Previous research provided mixed outcomes regarding the impact of balance training on performance, with some studies revealing significant improvements in static and dynamic balance, while others reported no notable differences.

In our study, we employed various balance development methods, encompassing exercises and modalities from neuromuscular training, trunk stability training, proprioceptive skill development training, equipment-assisted balance development training, and plyometric training. The balance development exercises were selected and tailored from a range of studies that displayed positive effects from various training modalities, such as proprioceptive training, plyometric training, trunk stability training, equipment-assisted balance training, and neuromuscular training, adapted to suit our participants' needs.

Regarding the analysis conducted on the snow-testing variables within this study, it emphasizes that the experimental group, which underwent a 10-week balance development training program, showed significant improvements compared to the control group. These advancements were validated by statistically significant differences in three key variables: SKI IQ ($F=13.239$, $p=0.001$, $\eta2=0.321$), balance ($F=4.800$; $p=0.037$; $\eta2=0.146$), and pressure ($F=8.084$; $p=0.08$).

Further, examining the dry-land test results, we can assert that the balance development protocol positively impacted static balance values and trunk stability. The analysis highlighted significant differences between groups for variables like OD2P_ML, OD2P_COP, "OI2P_AP_difference", indicating the protocol's substantial impact on these variables.

The variable "SP1PD_ML_difference" showed a statistically significant difference between groups. For the "SP1PD_COP_difference" variable and the "SP1PS_ML_difference" variable, our findings point to a notable difference between groups. Similarly, for the "ST_difference", we also discerned a significant difference between groups. Additionally, a statistically significant difference in explosive strength performance (F=6.08, p=0.02) was observed.

However, considering the sport's complexity and multidimensional nature, further research is still required to optimize these strategies and to delve into other potential approaches that could effectively enhance balance.

5.9 Conclusions

Our research results support the significance of balance training for young skiers, an area inconsistently represented in previous studies. Our findings, which highlight significant improvements in SKI IQ, balance, pressure, and variables tested with the pressure board in the experimental group that underwent a 10-week balance development training program, underscore the effectiveness of such an intervention. These results are statistically significant and align with outcomes from other existing studies that have examined this skill and yielded a positive impact.

Based on the data analysis, we have drawn the following conclusions concerning our research objectives:

- ✓ In the context of hypothesis H1, the statistical analysis confirmed our assumption that the balance development protocol has a positive effect on dynamic balance values (F=4.800; p=0.037; η^2=0.146) and SKI IQ (F=13.239, p=0.001, η^2=0.321).
- ✓ Regarding hypothesis H2, our statistical analysis revealed a significant positive correlation between dynamic balance and technique (SKI IQ) in alpine skiing (r = 0.524, p = 0.003).
- ✓ In terms of hypothesis H3, data analysis using wearable technology affirmed that it can indeed offer unique insights into the performance and techniques of junior alpine skiers.
- ✓ Pertaining to hypothesis H4(4.1), our statistical analysis highlighted significant results for certain variables representing static balance.
- ✓ Furthermore, our analysis confirmed hypothesis H4(4.2) concerning the development of trunk stability.
- ✓ Continuing on hypothesis H4(4.3), it stands validated, with the balance development protocol across various methods enhancing explosive strength (F=6.08, p=0.02).
- ✓ Conversely, we note that the 'Agility' variable doesn't show statistically significant differences.

- ✓ Lastly, hypothesis H5 is not confirmed. Although there's an increase in the canting angle from pretest to posttest in the experimental group, the values are not statistically significant.

5.10 Limitations and Future Research Directions

Our study provides valuable insights into the performance of alpine skiers; however, there are several limitations that need to be considered. Among them are the sample size, which is relatively small, challenges with wearable technology that may introduce measurement errors, variability in snow and temperature conditions between tests, lack of information about the control group's activities, and potential uncontrolled variables that may influence the results. Nevertheless, for the future, we recommend the continued integration of wearable technology in training and testing, conducting longitudinal studies, validating on-snow tests, dry-land training that simulates on-slope conditions, and considering testing in indoor ski centers for stricter control over variables.

5.11 Personal Contributions and Limitations of the Doctoral Thesis

While our research has made significant contributions to the existing literature, it is essential to acknowledge certain limitations that may influence the interpretation and applicability of the results.

Firstly, the sample size is highlighted. The relatively small size of the sample might limit the generalization of the results to broader populations. With a smaller sample, the statistical power of our tests is reduced, meaning there is a higher risk of not detecting a genuine effect if it exists (Type II error) (Cohen, 1988). Thus, the findings obtained from such a sample might be specific only to the studied group and cannot be confidently generalized to a broader population (Babbie, 2010). Also, using convenience samples in both studies of this thesis can introduce bias in the results since the subjects might have specific characteristics that are not representative of the general population (Field, 2013).

Moreover, we point out the absence of standardized snow testing methods. Snow testing, without standardized methods, raises doubts about the validity and reproducibility of the results. The fluctuations in snow and temperature conditions complicate data interpretation and assessment of the intervention's impact.

In the field of alpine skiing, where snow training is often constrained by external factors, we identified a pressing need to optimize dry-land training. Thus, our research primarily aimed to deepen the understanding of the effectiveness of dry-land training, focusing on maximizing performance in the absence of ideal snow conditions.

The unique elements of the presented thesis bring significant contributions to the alpine skiing field and are highlighted through the following aspects:

- ✓ Useing wireless portable technology for evaluating skier performance on snow, marking an evolution from traditional methods.
- ✓ Development of an innovative macrocycle for balance improvement, integrating various training methods, providing a holistic perspective on alpine skiing.
- ✓ Research focus on the age group 9-11, thereby addressing a gap in the existing literature and offering strategies tailored to this category.
- ✓ Conducting a comprehensive analysis of balance, encompassing both static and dynamic balance testing, for an in-depth understanding of balance in skiing.

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