MOST EFFECTIVE TRAINING METHOD FOR INJURY PREVENTION IN ALPINE SKIING

LITERATURE REVIEW

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Preface

The thesis that lies in front of you is entitled "Most effective training method for injury prevention in alpine skiing" and was written by Mirjam Talen. This thesis was written as a graduation assignment for the physical therapy study at Hanze University of applied Sciences. The aim of this assignment was to write a literature review in order to find training methods for reducing the risk of injury during alpine skiing.

The subject for this research became clear during my first internship in Austria, when I saw how many patients came into the clinic with ski-related injuries. Compared to the Netherlands, skiing is a popular sport in Austria and this, together with my experiences in practice, attracted my interest in this subject. Research often focuses on what the best treatment method is, but I wanted to find an answer on how to prevent an injury. With this curiosity, I started my research and searched for literature to answer my research question.

First of all, I would like to thank my thesis supervisor from the Hanze University of Applied Sciences, Cornill Blauw-Hospers, for her helpful guidance during the thesis. Secondly, I would also like to thank Hanze University of Applied Sciences and its employees for giving me the opportunity to do both my internships and my graduation assignment in Austria. I learned a lot during this time, developed myself as a physiotherapist and gained many new insights.

Innsbruck, June 11th 2023,

Mirjam Talen

Abstract

Objective: The aim of this study is to do research into the most effective training method in relation to injury prevention in alpine skiing.

Methodology: In this literature review, the databases Pubmed, Pedro, SPORTDiscus, Cinahl, and Google Scholar were systematically searched with the pre-defined search string. The results of this search were stepwise narrowed down using various relevant pre-defined filters along with the inclusion and exclusion criteria. Methodological quality was tested by using the AMSTAR 2. Data extraction was performed in which only the most relevant data, appropriate for this topic, was selected and used in this study.

Results: After performing the search and data selection, 6 articles were included in this study. The collected data from these studies was divided into four different themes: prevention, physical aspects, equipment aspects and environmental aspects. Within the theme of prevention, statements were made mainly about methods for preventing ACL injury involving equipment such as ski boots, bindings and skis. As a physical aspect, core stability was found to be the most important factor in preventing skiing injuries. Long and wide skis have been confirmed to have a negative effect on injury.

Conclusion: This study reveals that no definitive statement can be made on the best training method for injury prevention in alpine skiing as very little is known about this subject in the current literature. On the other hand, several risk factors have been found to have an impact on injury risk. The main findings of this study show that both long and wide skis, along with a lack of core stability, increase the risk of injury. This also applies to changing snow conditions in the same descent while skiing at high speed.

Keywords: Alpine skiing, Prevention, Training method, Injury

Contents

1. Introduction

Alpine skiing and snowboarding are really popular winter sports. People from all over the world are participating in this sport, from kids to elderly people with a big variation in skill level. More than 40 million skiers travel to one of the 300 alpine resorts located in the world's major mountain chains, in approximately 40 different countries (3). In the last decade the popularity of snowboarding has been increasing. In the year 2000 snowboarding increased to 21% in comparison to skiing which decreased 4% that year according to the Canadian ski council (3). Not only are people participating in this sport recreational, but alpine skiing has also been an Olympic winter sport since 1936. Within alpine skiing there are four major disciplines, known as: downhill, super giant slalom, giant slalom, and slalom. Besides those disciplines there are also some others, known as/for example moguls and snowboarding (2). As well as in competitive alpine skiing as in recreational alpine skiing there happens to be a high risk of injury during participation in this sport.

The most common anatomical location in terms of ski injury is the knee, with about one third of all ski injuries. A rupture of the ACL is one of the most diagnosed injuries in recreational alpine skiers regarding 15-21% of all the injuries (7). The second most common ski injury is head injury with up to 20% of all injuries on the ski slopes (7). However, the risk of head injury can be significantly reduced by the use of a ski helmet (7). In addition to the developments of wearing a helmet, the developments of ski bindings are also of positive importance when it comes to injury prevention. In particular, the number of tibial fractures and minor knee strains has decreased in recent years due to developments in ski bindings (1).

On the slopes, in addition to adults, many children can often be seen. They too are at risk of sustaining an injury while skiing. In the study of Sahlin, (1990) they did specific research on injuries during sport activities among children (8). It was a one-year study which included children between the age of five and fourteen, who were treated at Trondheim Regional and University Hospital for their injuries incurred during sports. Among them, 53% were boys and 47% were girls, with a total of 2841 children who were included. The sport that caused the most injuries was soccer. Alpine skiing and horse riding were the sports which caused the most severe injuries. The most common type of injury reported in alpine skiing was with a number of 29, bone fractures, followed by 27 cases of dislocations and 26 contusions (8).

To identify risk factors for injuries, it is necessary to look at the variety of aspects that affect people during alpine skiing. One can divide them into physical factors, personal factors, environmental factors and external factors. When it comes to physical factors, age, gender, general health, strength, coordination, and ski experience are to be considered. Examples of personal factors may include the amount of risk taking, potential fear or uncertainty, overestimation of one's own skiing abilities. For environmental factors, refer to the quality of the slopes, weather conditions, state of clear visibility, obstacles both on and surrounding the slopes. External factors can include other people on the slopes, the equipment used and the wearing of protective gear. Not all of the above factors can be controlled by the skier himself. However, there are factors that one can influence yourself and thereby reduce the risk of getting injured.

As mentioned earlier, when it comes to reducing head injuries, wearing a helmet has a very significant impact (7). However, wearing a helmet also has other effects on skiers. "According to the so-called risk compensation hypothesis, people adjust their behavior in accordance to their perceived level of risk (7)." This may cause people to take more risk, ski with increased speed and aggressiveness (7). Which in return can lead to an increased risk of getting injured. And for that

reason, it makes risk taking behavior an important aspect in research related to injury prevention (9).

Over the years there has been a lot of research on injury epidemiology, injury etiology, and potential prevention (10). The study by Spörri, *et al.,* (2017) reported 38 injury risk factors (10). However, of those 38 factors, only 5 of the 38 factors showed a direct relationship to injury risk. Namely insufficient core strength/core strength imbalance, sex (depending on type of injury), high skill level, unfavorable genetic predisposition, and the combination of highly shaped, short and wide skies. Until now, only the combination of less shaped and longer skis with reduced profile width has shown a positive effect on injury risk (10). This indicates that there is still a considerable amount of room to research other factors that may have an impact on reducing injury risk.

In this literature review, research will be conducted to determine the most effective training method to reduce the risk of injury in alpine skiers. Training methods and prevention tools will be included in this study to arrive at the fullest possible answer appropriate to the problem statement.

2. Methodology

2.1 Research design

The design of this study is a literature review which examines the most effective training methods for injury prevention in alpine skiing. Commissioned by the Hanze University of Groningen, this literature review was conducted during the period from February 2023 to June 2023 to answer the research question.

2.2 Databases and search strategies

In this study, articles were collected by using the following databases: PubMed, Pedro, SPORTDiscus, Cinahl, and Google Scholar. Several databases were selected so that all the different professions could be inoculated allowing a wide range of possible data availability for this study. Pubmed was selected because it is one of the largest databases in the field of medicine and peripheral areas with more than 35 million citations and abstracts of biomedical literature. In order to have not only a medical but also a physiotherapy incidence in this study, it was chosen to use the Pedro database as well. This database also has a large reach with more than 38 thousand randomized trials, systematic reviews and clinical practice guidelines in physiotherapy. Since this study focuses primarily on skiing, and skiing is considered a sport, the selection of the SPORTDiscus database is explicable. The Cinahl database was searched because it contains articles related to the field of nursing, paramedic professions, dietetics, speech therapy, physical therapy. Thereby providing a wide range of different professions memorialized within the healthcare industry. The final database used in this study was Google Scholar. This database was chosen because it can easily be searched for scientific information and references for full-text articles. Unfortunately, it is not a library database, the database contains gray data (data that cannot be traced back to its origin) and also the option for specific search is limited. This is something to keep in mind when potentially selecting items from this database.

After selecting the databases, a search string was formulated that could be used to perform targeted searches in those databases to arrive at relevant articles. The search string was set up by using multiple synonyms so that there would be as many results as possible in the same search area. In order to create the search string, several Boolean operators were used. For the purpose of connecting search terms, the operator OR was used. To exclude search terms, the operator NOT, has been used. The search string that was used in the different databases when performing the search is shown in Table 1.

Table 1: Search string used in the different databases

Database	Search string
Pubmed, SPORTDiscus, Cinahl, Google Scholar	(((((((Training alpine skiing) OR (ski injury)) OR (injury prevention ski)) OR (ski specific training)) OR (training method ski)) OR (ski training)) OR (prevention skiing)) NOT (cross country)
Pedro	Training in alpine skiing

2.3 Selection process

For the selection of articles, the process began by entering the search string, shown in table 1, in all the selected databases. In order to arrive at the most recent articles, the decision was made to filter it by articles published in 2010 or more recently. One of the inclusion criteria is that the articles must be available in full text. For this reason, it was decided to select full text articles only. This was followed by the selection of reviews. Only review or systematic reviews were included in this study. This was chosen because it allows the data found to be made easily comparable and reviewed. Something that stood out was that many of the articles did not focus specifically on skiing but, however, it was mentioned somewhere in the article. By this reason, it was decided to filter for articles that in fact focused on skiing. This was accomplished by filtering in PubMed, SPORTDiscus and Cinahl on the search string for just the titles of the articles. There was no possibility to apply this filter in Google scholar and Pedro. Therefore, a similar screening was performed in Pedro and Google scholar by the researcher. The screening was executed using the inclusion and exclusion criteria which can be found in Table 2. As a final step, it was chosen to perform a screening of the remaining articles through reading and critically reviewing the abstract. In this step, also, the inclusion and exclusion criteria were incorporated.

Table 2: In- and exclusion criteria

Inclusion criteria	Exclusion criteria
Articles from 2010 and more recently	Articles older than 2010
Articles available in full text for free	Articles that are not available full text
Reviews of systematic review	RCT, clinical trials, Meta-analysis, Book
Articles in English	Articles in languages other than English
Focusing on alpine skiing	Focus op cross country skiing
Title must include the components Skiing + training or prevention	Articles that already appeared or been selected in another database

2.4 Assessment of methodological quality

In order to assess the methodological quality of the articles, the measurement tool AMSTAR 2 (A MeaSurement Tool to Assess systematic Reviews) has been used (11). Its purpose is to assess the methodological quality of a review. This is based upon a checklist which consists of 16 questions, all of which cover the components expected in a review. The AMSTAR 2 is proven to be easy to use with each review requiring 14.9 (95% CI: 17.0, 12.8) minutes to conduct. This in comparison to the OQAQ (28) tool which takes an average of 20.3 (95% CI: 22.5, 18.0) minutes to perform, and the Sacks (29) instrument which takes an average of 34.4 (95% CI: 37.3, 31.6) minutes to administer the test. When it comes to validity, the AMSTAR 2 also shows a good performance. Compared to the other measuring instruments, the AMSTAR 2 had an ICC of 0.66 (95% CI: 0.28, 0.84) compared to the OQAO and 0.83 (95% CI: 0.64, 0.92) compared to the Sacks instrument (27).

Due to the fact that the AMSTAR 2 tool does not include a scoring scale to rank the performed measurements, the researcher independently decided to only use the tool to create an overview of

the quality of the articles. There are no requirements for the articles with the aim of achieving a predetermined score on the AMSTAR 2.

2.5 Data extraction

All of the studies that were included underwent a methodological quality assessment. From all articles, the required and most relevant information has been extracted. When creating the data extraction table, general information was collected such as the name of the article and authors and the year of publication. To be able to extract and present the more specific data in an organized manner, it was chosen to describe the key points, method, results and conclusion from the articles. The outcomes of the data extraction can be found in Table 3.

3. Results

3.1 Selection process

The search for this study was conducted on May 8, 2023, by entering the search string, shown in Table 1, into the selected databases. The selected databases including PubMed, Pedro, SPORTDiscus, Cinahl, and Google Scholar. A total of 10284 results were obtained from this initial search. This number was reduced by the use of multiple selection steps to come to the most relevant articles. For example, the first selection step was to exclude articles published before 2010. Performing this step resulted in 5601 articles. However, this step was not performed in the Pedro database due to not being able to apply this filter. The selection by full text only or free full text was the next step in the selection process. After this step, a total of 4774 articles remained. Not all databases could accommodate this step either, this time it involved Pedro and Google Scholar. The third selection step was to exclude articles that were not a review. This step could not be performed in Pedro, SPORTDiscus and Cinahl. A total of 364 articles remained after performing this selection step. The next selection step was to apply the filter to show only articles that have the search string, or parts thereof, in the title. This filter could be applied in the Pubmed, SPORTDiscus and Cinahl databases. A total of 46 articles remained after applying this selection step. A hand search was applied in the databases Pedro and Google Scholar to achieve the same step. The outcome of this selection step was a total of 29 articles. In the final step of the selection process, the remaining articles were screened for the abstract, assessing the relevance of the articles. As a final result, 6 articles were included in this study. All the different steps and their outcomes are clearly organized in the flowchart below (Figure 1).

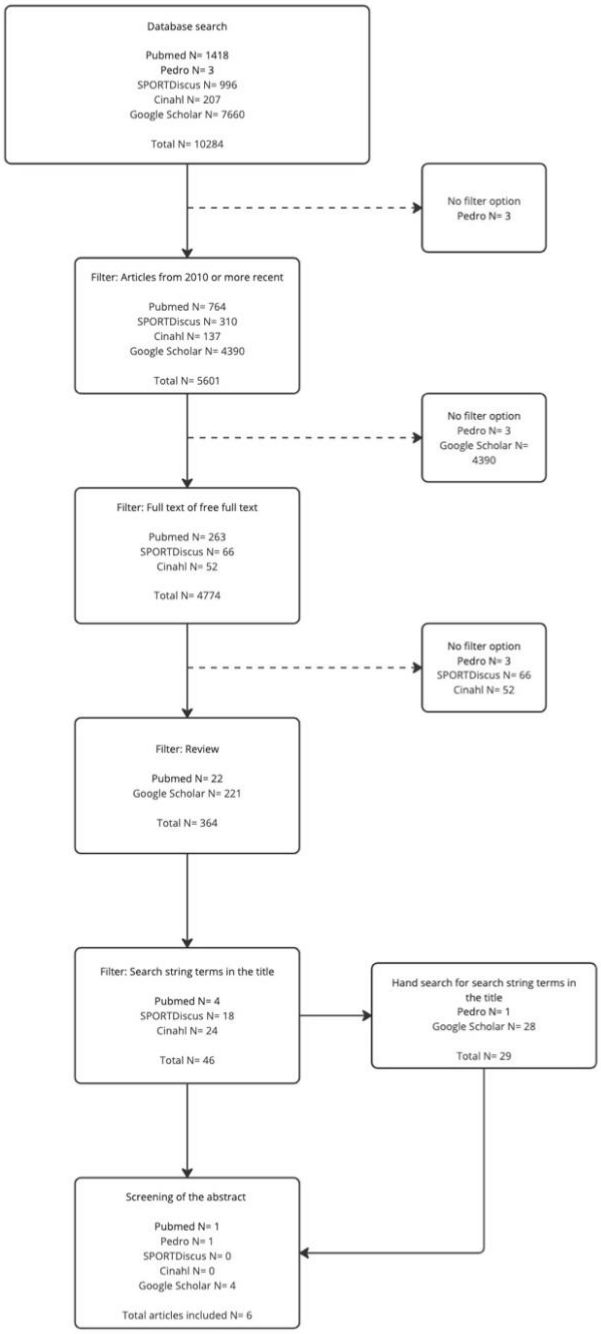

Figure 1: Flowchart

Table 3: Data extraction

Article	Key points/main focus	Methodology	Results	Conclusion
Spörri et al, 2016	To provide an overview of all knowledge related to alpine skiing, using the 4-step model of injury prevention research by Mechelen et al (12), and also to identify potential perspectives for future research.	Three databases (PubMed, MEDLINE and Web of Science - accessed 31 January 2016) were searched to identify relevant studies. The key search term used was 'alpine skiing' and the main focus was on injury-related articles related to alpine skiing (10).	The most important results of this article are that, by using the 4-step method of Mechelen et al (12), the researchers were able to link different risk factors to the prevention options that are appropriate for each factor. However, using the Mechelen et al model (12), only one article successfully completed all 4 steps.	In terms of injury etiology, only five statistically proven (i.e. proven to be directly related to injury risk) risk factors have been identified: 'insufficient core strength/core strength imbalance' (13); 'female/male sex' (13,14,15,16,17); 'high skill level' (18); 'unfavourable genetic predisposition' (19); and the combination of highly shaped, short and wide skis (10,20).
Hébert-Losier and Holmberg, 2013	To systematically review the literature for recommendations to prevent injuries specific to recreational alpine skiing and snowboarding. The focus was on the identification of recommendations that were directed at physical fitness, exercise and/or training for the prevention of musculoskeletal injuries in these two sports (21).	Relevant MeSH terms and key words were searched in 14 electronic databases in October 2011. Articles were included if they dealt with injury prevention, recreational skiers and snowboarders, and the musculoskeletal injuries (21).	A total of 80 recommendations for the prevention of musculoskeletal injuries in recreational alpine skiers and snowboarders were found and categorised into the following five main categories: equipment (n = 24), education and knowledge (n = 11), awareness and behaviour (n = 15), experience (n = 10) and third party involvement (n = 20). There were no recommendations on physical fitness, exercise and/or training per se or their role in injury prevention (21).	The dominance of equipment-related interventions in the injury prevention literature may be rationalised from a sports biomechanics perspective. These activities involve high velocities and impact forces. However, this also points to the need for appropriate levels of strength, endurance and conditioning to meet the technical demands of these sports (21).
Jordan et al, 2017	1) To review the current understanding of the epidemiology, aetiology, risk factors and methods of preventing ACL injuries in alpine ski racing. 2) To provide an overview of what is known about ACL reinjury and return to sport after ACL injury in alpine ski racing (22).	For this study, the databases PubMed, SPORTDiscus and MEDLINE were searched for all relevant scientific articles using the search term "alpine skiing AND ACL". A second search was conducted using the key words 'downhill skiing AND knee injury' to ensure that the most relevant articles had been retrieved. Articles were included if they were published in English from 1991 onwards.	Three primary mechanisms of ACL injury were found, involving internal rotation of the tibia and anterior shear forces from ski equipment and the environment. While trunk muscle strength imbalance and genetics were found to be predictive of ACL injury in developmental skiers, there was limited scientific data on ACL injury risk factors in elite skiers (22). To date, no studies have evaluated the effectiveness of ACL injury prevention training programmes in elite alpine skiers, and only one study has evaluated the effect of ski design modifications on injury reduction (23).	There are significant gaps in the scientific research regarding modifiable neuromuscular risk factors for ACL injury, and to date there are no research studies that have conducted ACL injury prevention training programmes in an alpine race skier population. Reinjury to the ACL is also a common occurrence in alpine ski racing, and alpine ski racers appear to have a disproportionately high rate of success in returning to the sport when compared to other athlete populations (22).
Leppänen et al, 2013	To summarise the effects of interventions to prevent sports injuries.	Search conducted in September 2013 using the following databases: PubMed, MEDLINE, SPORTDiscus, Cochrane Central Register of Controlled Trials, CINAHL, PEDro and Web of Science. Key words used in the search: sports injury/ies, athletic injury/ies, prevention, preventive.	Sixty-eight randomised controlled trials were included in the systematic review and 60 trials were included in the meta-analysis from 5580 articles retrieved after searching the databases and relevant bibliographies. Insoles (OR 0.51, 95 % CI 0.32-0.81), external joint supports (OR 0.40, 95 % CI 0.30-0.53) and specific training programmes (OR 0.55, 95 % CI 0.46-0.66) appeared to be effective in reducing the risk of sports injuries. Stretching (OR 0.92, 95 % CI 0.80-1.06), modified shoes (OR 1.23, 95 % CI 0.81-1.87) and preventive videos (OR 0.86, 95 % CI 0.44-1.68) did not seem to be effective (24).	The implications of the findings are that sports injuries can be prevented, at least to some extent, by the use of injury and sport-specific methods, and that the implementation of such preventive measures in practice can be of great benefit. As sport injuries are detrimental to an athlete's career and health and have a high cost to society, it is essential to promote evidence-based prevention methods (24).
Gatterer et al, 2021	To summarise the currently existing knowledge specifically related to the effects of cold exposure on physiology, in an attempt to provide practitioners and coaches alike with practical suggestions to minimise potential negative effects on performance, mitigate health issues and optimise the preparation of athletes in different sport disciplines (25).	No method was described in the article.	A review of the selected literature on the various influences on sports performance in a cold environment was carried out using different themes. Recommendations were made in different areas related to sport and cold environment based on the results of the research.	This review provides an overview of the current literature available on the preparation of active individuals and athletes who are specifically competing or exercising in cold environments and adverse weather conditions. Where appropriate, practical recommendations have been provided for both endurance and speed/power sports. Consideration has also been given to the management of short and long term health issues. It should be noted that some specific sports may require specific recommendations that cannot be provided in this review (25).
Leppänen, 2013	Update and summarise the results of randomised controlled trials on sports injury prevention. The following research questions will be answered by the study (26): 1. Is it possible to prevent sports injuries? 2. And if it is, how can sports injuries be prevented?	Relevant studies were searched using the following databases in November 2012: PubMed, MEDLINE, SPORTDiscus, the Cochrane Central Register of Controlled Trials, CINAHL, PEDro and Web of Science.The following key words were used in the search: sports injury(s), sports injury(s), prevention, prevention, randomised, controlled trial and randomised controlled trial. Different combinations of key words were used (26).	The meta-analysis included 59 studies with 65 comparisons. Insoles (OR 0.51, 95%CI 0.32- 0.81), external supports (OR 0.40, 95%CI 0.30-0.53) and training programmes (OR 0.55, 95%CI 0.46-0.66) appeared to be effective in reducing the risk of sports injuries. Stretching (OR 0.92, 95%CI 0.80-1.06), modified shoes (OR 1.23, 95%CI 0.81-1.87) and preventive videos (OR 0.94, 95%CI 0.43-2.04) were not efficient.	The systematic review and meta-analysis of 67 RCT showed evidence that different treatments, such as insoles, external joint supports and training programmes, appear to be effective in reducing the risk of sports injuries (26).

3.2 Methodological quality

The quality of the selected articles was scored using AMSTAR 2. A summary of all questions and corresponding answers for each study can be found in Appendix 1. An overview of the scores is shown in Table 4.

Table 4: AMSTAR 2 scores

Article	AMSTAR 2 score
How to Prevent Injuries in Alpine Ski Racing: What Do We Know and Where Do We Go from Here?(10)	8,5
What are the Exercise-Based Injury Prevention Recommendations for Recreational Alpine Skiing and Snowboarding? (21)	14,5
Anterior cruciate ligament injury/reinjury in alpine ski racing: a narrative review (22)	9,5
Interventions to Prevent Sports Related Injuries: A Systematic Review and Meta-Analysis of Randomised Controlled Trials (24)	14,5
Practicing Sport in Cold Environments: Practical Recommendations to Improve Sport Performance and Reduce Negative Health Outcomes (25)	3
PREVENTION OF SPORTS INJURIES Systematic review and meta-analysis of randomized controlled trials (26)	12,5

The included articles achieved a score ranging from 3 to 14,5. The article of Gatterer, *et al*., (2021) brought down the average score, because the methodology was not described in this article (25). Also, the articles of Hébert-Losier, *et al*., (2013) and Leppänen, *et al*., (2013) both achieved an identical score of 14.5 (21,24). Out of all the articles that were analyzed, they received the highest score.

3.3 Findings on training methods to reduce injury risk in skiing

In the articles that were included in this study, much was written about both risk factors of getting an injury while skiing, and prevention methods. None of the included studies described something about ski-specific training prevention programs. Information on other options to reduce injury risk was therefore added to the scope of this review. A clear overview of the extracted data from the articles that were included in this review can be found in Table 3. The first paragraph will represent what was mainly found in terms of prevention methods. In the following paragraphs, the focus will be more on showing the results related to different risk factors, which are divided into three themes: physical aspects, equipment aspects and environmental aspects.

3.4 Prevention

In several studies, the subject of ACL injury is mentioned, which is explainable because it is one of the most common injuries in alpine skiing (7). None of the included studies described something about ski-specific prevention programs when it comes to the prevention of an ACL injury. The studies indicated that there were no studies on this topic yet. Due to this fact, the studies looked further into what is known about ACL prevention in other sports. For example, the study by Spörri, *et al.,* (2017)

described that the ACL injury mechanism in alpine skiing is similar to the mechanisms in team sports (10). Given this information as background, Spörri, *et al.,* (2017) indicates that because of this, the proposed jump landing screening test could be a good test to predict the risk of ACL injury in competitive alpine skiers (10). Also, the article indicates that because in alpine skiing ACL injuries are often caused by asymmetric load distribution between the outside and inside leg (during turning), the sidestep cutting-based methods might also be a meaningful screening tool (10). Finally, the screening method measuring the hamstring to quadriceps (H/Q) ratio is recommended as an injury prevention tool (10). In addition, both Spörri, *et al.,* (2017) and Jordan, *et al*., (2017) indicate that neuromuscular training programs have a positive effect on reducing the risk of ACL injury (10,22).

Besides prevention methods for ACL injuries, articles have also examined prevention methods that focus on other factors of injury. The study by Spörri, *et al.,* (2017) describes that systemic training of tactical decisions along with exercises to improve trunk control during jump landings are a suggestion for prevention (10). The article by Hébert-Losier, *et al*., (2013) also makes statements about knowledge and behavior of skiers and how this affects injuries (21). In their study, they looked at how often recommendations for prevention were made per category in the articles they used. The results were: equipment (n = 24, 30 %), education and knowledge (n = 11, 13.8 %), awareness and behavior (n = 15, 18.8 %), experience (n = 10, 12.5 %), and third-party involvement (n = 20, 25 %). None of the included studies recommended specific physical training or exercises to prevent musculoskeletal injuries in recreational skiing or snowboarding. Similarly, the recognition and awareness of potentially dangerous situations and conditions (n = 9, 8.1 %), skill and ability level of individuals (n = 9, 8.1 %), participation in courses (n = 9, 8.1 %), and initiatives from third parties such as ski resorts, ski patrollers and sports retailers (n = 9, 8.1 %), were recommended as important factors for injury prevention (21). The studies of Leppänen, *et al*., (2013) and Leppänen (2013) looked at prevention through training only, not specifically focused on alpine skiing (24,26). Both studies found that balance board training significantly reduced sports injuries compared to the control group. Eccentric strength training was also found to significantly reduce the risk of hamstring injuries among football players.

The study by Ettlinger, *et al*., (1995) shows that by implementing an educational approach, by means of a video about injuries, awareness is created among ski patrollers and instructors about the technical and tactical factors of an injury, resulting in a 62% reduction in the risk of a knee injury (4). Interestingly, this study is mentioned in both the article of Spörri, *et al.,* (2017) as well as the article of Jordan, *et al*., (2017) (10,22). The studies of Leppänen, *et al*., (2013) and Leppänen (2013) also referred to studies in which an injury prevention video has been used (24,26). The study of Jørgensen, *et al.,* (1998) showed that the instructional video reduced the injury risk in downhill skiing (5). Where the study by Cusimano, *et al*., (2013) shows no effective reduction in injuries among school-aged children with their tested ski and snowboard prevention program, which included a video and brochures (34).

3.5 Physical aspects

In two studies, which specifically focused on skiing, it was found that core strength plays an essential role when it comes to injury risk (10,22). The study of Spörri, *et al.,* (2017) described that statistical evidence was found for four athlete-related risk factors (10). In other words, for these four risk factors a direct relationship was found between the risk factor and the likelihood of getting an injury. The four factors are insufficient core strength/core strength imbalance, female/male sex, high skill level and unfavorable genetic predisposition. A correlation between physical fitness and the risk of ACL injury was found in the study of Jordan, *et al*., (2017) (22). This study described that core strength was a significant predictor of the occurrence of an ACL injury. When it comes to the gender

factor, according to Spörri, *et al.,* (2017) (10), three studies indicate that the risk of getting an ACL injury is higher for women (10). Similarly, the study by Jordan, *et al*., (2017) describes that young woman in alpine skiing have a higher risk of an ACL injury in comparison with male athletes (22). Both the study of Spörri, *et al.,* (2017) and Jordan, *et al*., (2017) indicate that fatigue is also one of the physically related risk factors (10,22). Whereas the studies of Spörri, *et al.,* (2010) focus more on suspected fatigue due to a busy schedule or jet lag, the study of Spörri, *et al.,* (2012) focuses more on suspected fatigue at the end of a descent (30,31)

3.6 Equipment aspects

One of the topics mentioned in several studies is the influence of skis and bindings on the incidence of injury. Also, the influence of equipment on knee injuries, specifically ACL injuries, is often described. For example, Jordan, *et al*., (2017) writes that one of its included studies describes that expert ski coaches identify the aggressiveness of skis and ski boots and the inability of ski racers to control their equipment as the main cause of ACL injuries (22). This study also describes that the high stiffness of a ski boot is related to the forces that are exerted on the ACL when landing on skis where the weight is placed on the back of the ski, combined with the tightening of the quadriceps, and is therefore related to ACL injuries (22). One thing that has been particularly described about skis is that the length and shape of the skis affect the occurrence of (knee) injuries. For example, the researchers of two articles state that a short radius (turning radius) of the skis is one of the major reasons for increasing the risk of (knee) injury while skiing (10,22). Therefore, when the ski side cut radius decreases and the self-steering effect of the skis increases then it results in less controllable skis in an injury situation (22).

3.7 Environmental aspects

Risk factors attributable to environmental factors have been described in several studies. In the studies of Spörri, *et al.,* (2017) and Jordan, *et al*., (2017), high speed skiing is seen as one of the major risk factors for injuries (10,22). In particular, high speed is considered a risk factor for injury due to the fact that the impact of the crash is higher due to the increased kinetic energy caused by skiing at higher speed (33). Also, the combination of high-speed skiing together with varying terrain conditions is considered a course-related risk factor in the study (10). In addition to varying terrain and high-speed skiing, Spörri, *et al.,* (2017) and Jordan, *et al*., (2017) describe that snow condition also plays a role in acquiring an injury while skiing (10,22). In the study of Spörri, *et al.,* (2017) several snow conditions were found in the used literature to be risk factors for injury (10). These are "aggressive snow conditions", "changing snow conditions", "too bumpy/too smooth snow surface", and "water-injected/non-injected snow" (10). The same study shows that changing snow conditions in the same descent also exposes the skier to higher risk. As they must adjust their technique and equipment to the changing snow conditions (10). In addition to speed and snow, cold weather conditions are also risk factors. The study by Gatterer, *et al*., (2021) describes that passive exposure, of 60 minutes, to colder temperatures (20°C, 15°C and 10°C) in a climatic chamber leads to a significant decrease in drop jump performance (25). This decrease in performance was already observed at a temperature of 20°C. Also, the performance of the vertical jump decreased significantly in the group that was passively exposed to a temperature of 6.1°C for 15 minutes compared to the control group that was exposed to a temperature of 17.2°C (25).

4. Discussion

4.1 Reflection on the results

The aim of this study was to find the best training method for alpine skiing in order to prevent injuries. While processing the results, it quickly became apparent that many literature studies made

statements about prevention in terms of equipment. In particular, they talk about the type of skis, adjustment of bindings and wearing a helmet to prevent injuries. When it came to skis and bindings, all studies actually shared the same opinion, namely that a short radius (turning radius) of the skis is one of the major reasons for increasing the risk of (knee) injury while skiing (10,22). This statement is supported by many different articles (20, 30, 31, 36, 37, 39, 40, 41,42, 43, 44) which ensures that we can assume that this statement is very plausible. Also, the statement that both articles make about the side cut radius and the self-steering effect of the skis can also be considered very plausible because this statement is also supported by many different sources (22,30, 36, 45, 46, 47, 48). While there were many sources confirming the above statements regarding skis, only two sources confirmed the statement regarding the effect of stiff ski boots on getting an ACL injury. It should be noted that this statement involved both the stiffness of the ski shoe, landing with the weight on the back of the ski, and the tightening of the quadriceps, which has a relationship with getting an ACL injury. Therefore, this is a very specific situation of different factors on which a statement is made so that only McConkey, (1986) and Bere, *et al*., (2011) can validate this statement (37, 38).

Prevention by means of training is often rarely described in the studies selected for this review. It seems somewhat forgotten. In almost all studies the need for more research on this topic is mentioned. There were only two studies that made a statement on this (10,22). Both studies indicate that good core stability is an essential factor to lower injury risk. Another factor that might have an effect on injury risk is gender. This result is confirmed by several other authors (13,14,15,16,17). However, there are also other studies that indicate the opposite (6,18). Thus, to be able to draw a conclusion for this topic with absolute certainty is difficult because outcomes of various studies do not correspond. The statement by Spörri, et al., (2017) and Jordan, et al., (2017) regarding the positive effect of neuromuscular training on reducing the risk of ACL injury can be supported by more literature (10,22). This statement has in fact already been proven in other sports (34,49,50). The topic of fatigue is also raised in the studies of Spörri, *et al.,* (2017) and Jordan, *et al*., (2017) (10,22). Whereas the study by Spörri, *et al.,* (2012) mainly examined fatigue at the end of the descent (30). The results of this study are applicable to recreational skiers. While the studies by Spörri, *et al.,* (2010) focus more on professional athletes by including factors such as travel schedule and jet lag in their research on fatigue (31).

Something that was not according to expectations, but is certainly very interesting, was the view on the behavior of the skier and what influence this together with risk taking has on injury risk. Something that has been investigated as a means of prevention is giving instructions or offering an educational video. In the study of Ettlinger, *et al*., (1995) this was found to be a successful method of reducing injuries (4). Noteworthy was that this study was named in two included articles (24,26). Not in all included studies were always found many similarities. However, the studies of Spörri, *et al.,* (2017) and Jordan, *et al*., (2017) have found several commonalities when analyzing the data collected (10,22). From this, it can be determined that they mostly looked at their results with the same focus and made some similar choices. Returning to the study by Ettlinger, *et al*., (1995) showing that video education has a positive impact on reducing injuries, the study by Cusimano, *et al*., (2013) on the other hand, indicates that a similar study found no positive effect (4,34). The biggest distinction between these two studies is the target population. The study of Ettlinger, *et al*., (1995) focused on ski patrollers and instructors, where the study of Cusimano, *et al*., (2013) focused on school-aged children. This might possibly be a reason for the effectiveness of this prevention tool (4,34).

Much research has been done on injury epidemiology in alpine skiing. In addition to physical and equipment aspects, there has also been much research on environmental factors while skiing. These mainly include snow quality, snow conditions, trail conditions and weather. These factors were also

found to have a significantly high influence on injury risk. Combining these environmental factors with high speed creates even more risk (10,22,30,31). Not only will the risk of sustaining an injury increase, the severity of the injury will also be higher. This is explainable because at higher speeds, the impact of the crash is also higher due to kinetic energy (33). Thus, to reduce the risk of injury, skiers could adjust their speed. Besides speed, adjusting technique is also important, especially when snow conditions change in the same downhill run. This change in the snow conditions in the same downhill run also seems to be a risk factor in terms of getting injured (30,31,32).

4.2 Strength and weaknesses

This study was conducted by one researcher, which automatically means that all actions were performed by only one person. This can be seen as a weakness of this study. However, the method is described in such a way that this research is easily reproducible, which increases the reliability/validity of this research. Something that also positively influences the reliability of this research and especially of the results is the fact that the researcher has looked widely at the subject and has searched in several databases. Also in the selection process, all steps were carefully gone through by the researcher and there was always a critical eye when it came to selecting the right articles for this study. Another possible limitation of this study is the exclusion of studies older than 10 years. This raises the possibility that articles that could be of value were not included in the selection process.

As the searches revealed that little or nothing is known specifically about training methods for injury prevention in alpine skiing, the researcher looked a little wider and also selected articles that the researcher felt could make a positive contribution to this article, but were not 100% specific to alpine skiing. Similarly, one article was included which focused primarily on prevention is sport in general, with no specific focus on skiing. Also, an article was included in this study that focused primarily on sports in cold conditions, which also had a remarkably lower score on the AMSTAR 2 than other included articles. Both articles were considered relevant to this topic and therefore included in the selection.

4.3 Recommendations

From doing this research, the question arises as to how the ski sports federations currently deal with prevention in their sport, because with the sources used, very little can be found specific on training for prevention in alpine skiing. The sport of skiing is large and a lot of athletes are actively participating in this sport at a professional level, it is to be expected that something will still be done about injury prevention. However, professional athletes are only a small part of the total number of people who participate in this sport. For these people, it is just as important to have information about prevention. Especially when looking at the current figures regarding injuries on the slopes. If it could be made evident that with specific exercises or a specific training program injuries could be significantly reduced, this would be of great benefit to skiing. Therefore, one of the recommendations is to conduct proper research both in the professional setting and in the recreational branch of the sport into which interventions can prevent injuries. It is important that the results of the studies are made available in an easily interpretable way to the people who need them. This could take the form of a training program, possibly in cooperation with the ski federations. Also, we could look into the possibility of developing a ski specific screening tool that could be used to predict the risk of getting an injury. With the knowledge gathered about the influence of changing snow conditions in the same downhill run, a suggestion can also be made to show the current snow conditions in ski resorts in more detail (30,31,32). Education on how to deal with these changing conditions and how to adapt skiing technique may also have a positive impact on injury prevention.

4.4 Relevance

The knowledge gained from this study can make a good contribution to follow-up research. In this way, researchers can start where this thesis ended and work from there. The most recent data within this theme is clearly organized in this thesis through its division into various subcategories. Many professionals are interested in the results of this thesis because the risk factors do not only relate to the physical aspect but also address issues such as human behavior and equipment. Due to the fact that all articles focus on the different risk factors that are involved in ski injuries, prevention should also focus on the various risk factors. Thereby, the physical factor would be within the profession of the physiotherapist. With the knowledge of physiotherapists, screening methods could be developed to identify physical risk factors. Subsequently, these risk factors could be addressed by an appropriate training method or physiotherapeutic techniques. In this way, besides the treatment of injuries, physiotherapists could also have a contribution in injury prevention.

5. Conclusion

This study reveals that no definitive statement can be made on the best training method for injury prevention in alpine skiing. The reason for this is the lack of specific research on training methods for injury prevention in alpine skiing. However, it has been determined that there are several factors that affect injury in alpine skiing. These factors include physical factors, equipment factors and environmental factors. In terms of physical factors, core stability has been identified as an important factor in injury risk, especially in ACL injuries. When it comes to equipment, the length and shape of the ski were found to be the most important factors that have an impact on (knee) injuries. A short ski is recommended to reduce the risk of injury. Changing snow conditions along with high-speed skiing appear to be the major risk factors when it comes to environmental factors. So, in order to make a statement about the most effective method for injury prevention in alpine skiing, the various factors must be taken into consideration. Before making a statement specifically about training methods, it is important that more and specific research is conducted on this.

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7. Appendix

7.1 AMSTAR 2 questions and answers

Appendix 1: AMSTAR 2 questions and answers

AMSTAR 2 questions	Article 1	Article 2	Article 3	Article 4	Article 5	Article 6
1. Did the research questions and inclusion criteria for the review include the components of PICO?	Yes	Yes	Yes	Yes	Yes	Yes
2. Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?	Yes	Yes	Yes	Yes	No	Yes
3. Did the review authors explain their selection of the study designs for inclusion in the review?	Yes	Yes	Yes	Yes	No	Yes
4. Did the review authors use a comprehensive literature search strategy?	Yes	Yes	Yes	Yes	No	Yes
5. Did the review authors perform study selection in duplicate?	No	No	No	Yes	No	Yes
6. Did the review authors perform data extraction in duplicate?	No	Yes	Yes	No	No	No
7. Did the review authors provide a list of excluded studies and justify the exclusions?	Partial yes	Partial yes	Partial yes	Partial yes	No	Partial yes
8. Did the review authors describe the included studies in adequate detail?	Yes	Yes	Yes	Yes	No	Yes
9. Did the review authors use a satisfactory technique for assessing the risk of bias (RoB) in individual studies that were included in the review?	No	Yes	No	Yes	No	Yes
10. Did the review authors report on the sources of funding for the studies included in the review?	Yes	Yes	Yes	Yes	Yes	No
11. If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?	No meta-analysis	Yes	No meta-analysis	Yes	No meta-analysis	Yes
12. If meta-analysis was performed, did the review authors assess the potential impact of RoB in individual studies on the results of the meta-analysis or other evidence synthesis?	No meta-analysis	Yes	No meta-analysis	Yes	No meta-analysis	Yes
13. Did the review authors account for RoB in individual studies when interpreting/ discussing the results of the review?	No	Yes	No	Yes	No	Yes
14. Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?	Yes	Yes	Yes	Yes	No	Yes
15. If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?	No	Yes	No	Yes	No	Yes
16. Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?	Yes	Yes	Yes	Yes	Yes	No
Total score	**8,5**	**14,5**	**9,5**	**14,5**	**3**	**12,5**