

## PHYSICAL THERAPY RECOMMENDATIONS FOR INJURY PREVENTION IN ALPINE SKIING

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### ABSTRACT

**Introduction:** *Alpine skiers face high speeds, significant forces, natural and unnatural obstacles, and various environmental conditions on the slopes. Thus, they are highly exposed to certain injuries, amongst which the most common are those to the knee followed by injuries to the spine, shins, head, as well as arm and thumb injuries.*

**Purpose:** *The purpose was to systematically review the scientific literature on injuries, risk factors, and prevention in competitive alpine skiing and to provide recommendations for injury prevention in the field of physical preparation, kinesiotherapy, and/or specific exercises, and to determine which exercise program would be most appropriate for an alpine ski racer.*

**Methods:** *PubMed, Web of Science, and COBISS databases were used with PRISMA method to review the physical therapy recommendations for injury prevention in alpine skiing.*

**Results:** *10 studies were included in the final systematic review. We have not found any evidence-based prevention programs that are not older than 10 years on the topic of physical preparation for alpine ski racers. We found that most often, the literature describes prevention in terms of equipment, course preparation, course safety awareness, and the experience of the skier.*

**Conclusions:** *The recommendation for the most efficient prevention according to the current literature is to follow the above preventive measures in combination with*

*appropriate physical preparation, where we recommend relying on research evidence in other (non-contact) sports that have similar injury mechanisms as alpine ski racing.*

**Keywords:** *sports medicine, injury prevention, physiotherapy, alpine skiing*

## FIZIOTERAPEVTSKA PRIPOROČILA ZA PREPREČITEV POŠKODB PRI ALPSKEM SMUČANJU

### IZVLEČEK

**Uvod:** *Smučarji se na progah soočajo z visokimi hitrostmi, velikimi silami in različnimi okoljskimi pogoji. Posledično so izpostavljeni določenim poškodbam, med katerimi so najpogostejše poškodbe kolena; sledijo poškodbe hrbtenice, golenice, glave in poškodbe roke ter palca.*

**Cilji:** *Namen je bil sistematično pregledati znanstveno literaturo na temo poškodb, dejavnikov tveganja in preventive pri tekmovalnem alpskem smučanju in podati preventivna priporočila pred nastankom poškodb na področju telesne priprave, kinezio-terapije in/ali specifičnih vaj ter ugotoviti, kakšen program vaj bi bil najprimernejši za preventivo pred specifično poškodbo alpskega smučarja tekmovalca. Ugotavljamo pomanjkanje preventivnih programov za izboljšanje telesne pripravljenosti smučarjev saj prevladujejo izsledki o preventivi z vidika smučarske opreme, priprave proge, ozaveščenosti o varnosti na progi in izkušenj smučarja.*

**Zaključek:** *Priporočila za najučinkovitejšo preventivo glede na trenutno literaturo so upoštevanje zgoraj omenjenih napotkov v kombinaciji z ustrežno telesno pripravo, pri kateri priporočamo opiranje na dokaze raziskav v drugih (nekontaktnih) športih, ki imajo podobne mehanizme poškodb kot alpski smučarji tekmovalci.*

**Ključne besede:** *športna medicina, preprečevanje poškodb, fizioterapija, alpsko smučanje*

## INTRODUCTION

Alpine skiing as an activity was not popular before the 18th century. It took another 100 years for it to establish itself as a sport (Pfister, 2001). Today, skiing and snowboarding are among the most popular winter sports in the world and the organisation of alpine skiing competition is at the highest level (Schoenhuber, Panzeri, & Porcelli, 2018). Injury trends have been increasing in recent years, and the current incidence suggests that as many as one in three elite skiers may be injured in a single season (Tarka et al., 2019). Almost half of all injuries require the skier to be absent from training and competition for more than a month (OSTRC, 2019). As in any sport, prevention programs play an important role, preparing the skier physically to reduce the risk of injury. The team of physiotherapists and other health professionals is crucial for the physical preparation of a top alpine skier, and needs to take into account the specificities of each individual and the mechanisms of injury specific to skiing (Spörri, Kröll, Gilgien, & Müller, 2017). In addition to good physical fitness, suitable and safe ski equipment, properly prepared slopes, knowledge and experience, awareness of the skier and, above all, good psychological preparation are important for the prevention of alpine skiing injuries. In 2006, the International Ski Federation (FIS), in cooperation with the Oslo Sports Trauma Research Centre (OSTRC), developed the injury Surveillance System (ISS) to monitor injuries in different skiing disciplines and collect data for more detailed research into the causes of these injuries. The primary aim of the organization is to reduce injuries among skiers, and to propose preventive measures that have not yet been tested in clinical practice (OSTRC, 2019).

### Skiing injuries

In the World Cup, the highest level of competition, the incidence of injuries ranges from 23% to 37% in a single season. Almost half of all injuries occur during competition, *despite the majority of runs being taken during training* (Tarka et al., 2019).

According to the Oslo Sports Trauma Research Centre (OSTRC) (2019), a total of 1083 injuries were recorded in the Alpine Skiing World Cup seasons between 2006 and 2019 among the 3329 competitors interviewed. As many as 40% of the injuries were those that required the competitor to be absent from training and competition for at least 28 days. The most common type of injury was a joint or ligament injury, followed by bone fracture, muscle or tendon injury, concussion, bumps and contusions, skin injury, and various others. Injuries to the knee accounted for the largest proportion of body part injured (41.3%), followed by injuries to the hand, finger and thumb (9.7%), and injuries to the head or face (9.4%) (OSTRC, 2019). In their study Tarka et al. (2019) also cite the knee as the most commonly injured part of adult competitive skiers, followed by back and tibia injury, then head and upper limb injury. In younger skiers, the knee is also the most common place of injury, followed by the upper limb, spine and lower limb injuries. Anterior cruciate ligament (ACL) injury is cited as the most common

specific diagnosis in both adult and younger skiers. This is followed by a concussion and tibia fracture.

Most injuries occur in downhill, followed by supergiant slalom (SG), then giant slalom (GS), and the fewest injuries occur in slalom. In the World Cup, knee injuries, the most common, account for 37.7% of injuries. There are at least 5 times as many injuries in the World Cup as there are in the European Cup. There are almost 7 times more knee joint injuries in the World Cup compared to the European Cup (OSTRC, 2019).

## METHODS

This article is based on a literature review. Data were extracted from Slovenian and other sources (PubMed, Web of Science, and COBISS databases) throughout the world during the period from March 14, 2020 to July 30, 2020. The inclusion criteria for the peer-reviewed literature included ski injury and/or prevention, Slovenian or English language, and research that is less than 10 years old. The following keywords were used: alpine skiing, ski injuries, prevention of ski injuries, prevention program, risk factors in alpine skiing. The exclusion criteria were prevention measures that applied to other sports and did not include recommendations aimed at preventing injuries in alpine skiers. We also excluded studies where the full text was not available, studies with fewer than 15 subjects or where subjects withdrew from the study for various reasons, and studies with no conclusion. We reviewed the research summaries, narrowed the selection using inclusion and exclusion criteria, and critically analyzed the selected literature.

## RESULTS

The search for the keywords listed above returned 102 hits, and an additional search yielded one additional hit. By screening the titles we first eliminated duplicates and then excluded studies older than 10 years (only keeping those from the 2011–2021 period). Forty-three studies remained, from which we additionally excluded studies not related to sports injuries and/or alpine skiing by reviewing abstracts thus ultimately arriving at 16 studies for full-text review. After the content review, we excluded 6 studies that did not relate to injury prevention. 10 relevant studies were thoroughly analyzed with conclusions described in the discussion. The systematic review process is presented in Figure 1.

The characteristics of the included studies are shown in Figure 1.

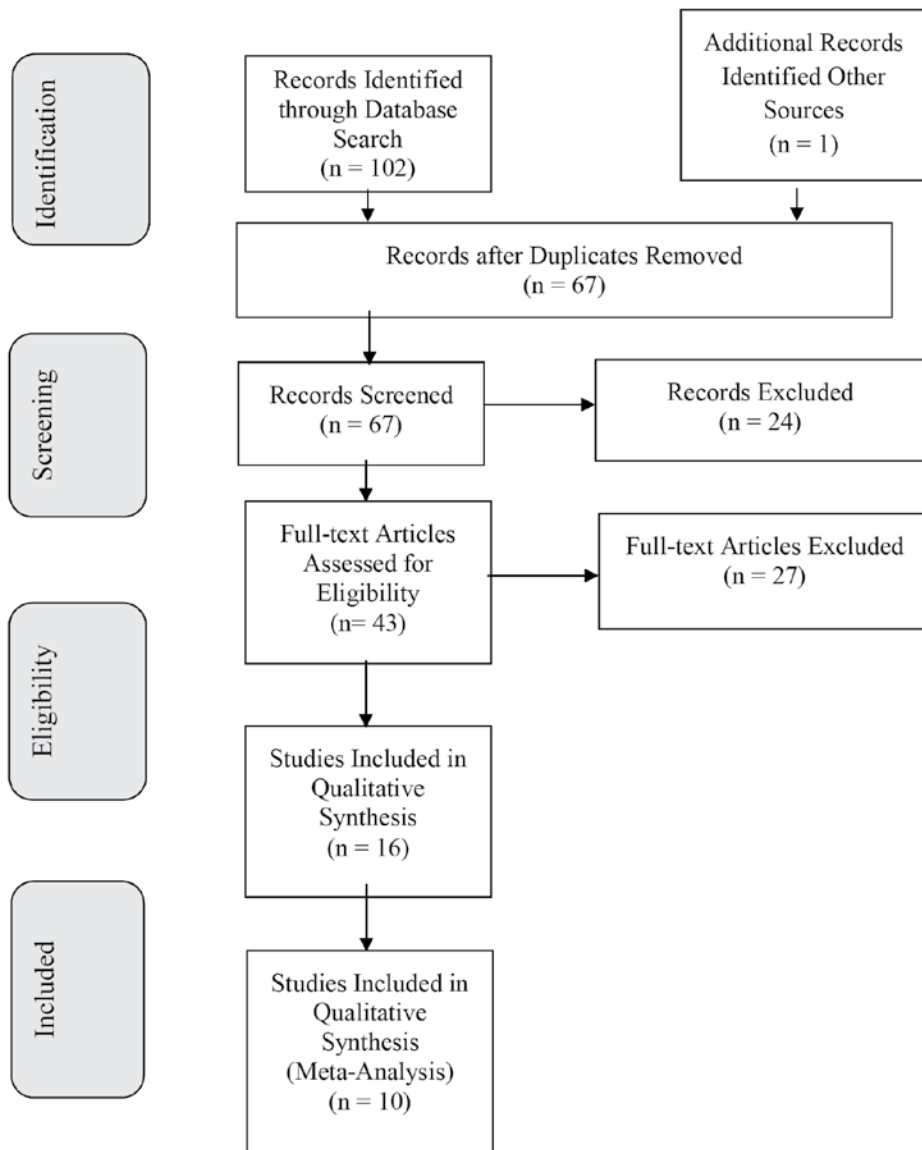


Figure 1.: The characteristics of the included studies (PRISMA flow diagram).

## DISCUSSION

The incidence of sports injuries, especially in team sports, can generally be reduced through fitness training and prevention programs. On this basis, we hypothesized that there are evidence-based prevention interventions based on pre-injury fitness level in alpine ski racers and derived prevention programs that could be incorporated into the training process of competitive skiers.

Spörri et al. (2017) in their literature review presented injury prevention for elite alpine skiers through a four-stage model, according to the epidemiology and aetiology of the injury. Based on these, they formulated an idea for preventive measures, followed by a test of the effectiveness of the preventive measure or program. They found that the risk factors directly associated with injury were insufficient lower trunk stabilization, gender, skiing difficulty, genetic predisposition and the combination of longer, narrower skis with a smaller radius. Otherwise, the review did not provide any specific recommendations related to physical fitness, exercise program, training or kinesiotherapy as parts of an injury prevention program. Of all the studies included, this was the only one that linked skiing injury to the strength of insufficient trunk stabilization and not only to equipment, skills and behavior on the slopes. In contrast, Audet et al. (2019) described risk factors for injury in skiers in terrain parks, where injuries to skiers and snowboarders occur mainly due to factors such as the level of difficulty of the skiing, listening to music during the sport, previous injury, temperatures between  $-10^{\circ}\text{C}$  and  $0^{\circ}\text{C}$ , night skiing and snowboarding, and performing more demanding maneuvers. Both studies found that risk factors differed according to the type of skiing but were consistent with the level of difficulty of the skiing, i.e., a higher level of difficulty was associated with a higher risk of injury in terrain park skiing or a competition slope. Hébert-Losier and Holmberg (2013) traced more than 80 methods for preventing musculoskeletal injuries and divided them into five groups - equipment, education and knowledge, caution and behavior, experience, and other factors. They found that most of the recommendations related to ski equipment or other factors, while none related to physical fitness, exercise, or training. They also highlighted the problem of this under-researched area. Audet et al. (2019) found that skiing and snowboarding carry a high risk of head, neck and back injury. Cusimano and Kwok (2010) found a 15% to 60% reduction in head injuries and a drastic reduction in concussions owing to helmet use. However, they did not associate helmet use with a reduction in the neck or cervical spine injuries. Also, Bailly et al. (2017) later found that the majority of injured skiers did not use a helmet. In more than half of the cases, the mechanism of injury was a fall. This was followed by, in order of frequency, collision with another skier, a jump, and collision with an obstacle, which also caused serious concussions. Sulheim, Ekeland, Holme, & Bahr (2017) found that despite increased helmet use among skiers and boarders, the incidence of head injuries decreased by only 2.2 per cent. They suggest as a possible reason for this the dramatic change in alpine skiing over the last decade due to new, faster and thus more dangerous ski designs, and unsafe slope layout in ski parks. According to the findings of Cusimano, Luong, Faress, Leroux, & Russell (2013), it could be suggested that the use

of a video with instructions and recommendations for safe skiing on the slopes could contribute to safety. Contrary to Sulheim et al. (2017), Haaland, Steenstrup, Bere, Bahr, and Nordsletten (2016), who studied the effects of newly introduced rules in skiing and ski equipment on the severity and type of injuries, found that the number of injuries per 100 skiers in a season decreased from 36 to 27 in the period after the new rules were introduced. Upper limb injuries decreased for women, while upper and lower limb injuries decreased for men. The most important contributor to the reduction in injuries was the introduction of the rule to combine longer and narrower skis with a smaller radius. Ruedl et al. (2011) found that injury onset was independent of average skiing time before the injury, and that injured men were taller, heavier, and skied at higher levels than uninjured men. The main conclusion of this study was that there are no significant gender differences in the mechanisms of anterior cruciate ligament (ACL) injury.

After a systematic review, we conclude that the best-researched areas for injury prevention are equipment, education (awareness rising) and knowledge, as well as caution and behavior on the ski slope. The results of our systematic review indicate a lack of evidence and, in particular, a lack of research into physical fitness as injury prevention for alpine skiers, as well as a lack of research on prevention programs. The topic of physical fitness as injury prevention for competitive alpine skiers has been poorly researched and even somewhat forgotten (overlooked), as we have not seen any research addressing this type of prevention in alpine skiing in the last two years.

Based on a systematic review, we found that there are evidence-based injury prevention measures for alpine ski racers that relate to equipment, skills, and experience in critical or unpredictable situations on the ski slope. In this respect, reference can also be made to Hébert-Losier and Holmberg (2013), who found that preventive measures related to equipment dominate instead of prevention in the form of physical training. More than half of the included studies concerned the choice and use of ski helmets. The importance of the role of equipment in injury prevention in alpine skiers is particularly clear when viewed from a sports biomechanics perspective. With the development of alpine skiing, athletes are exposed to greater forces and reaching higher speeds, which require increasing improvement and modernization, even in adapted equipment. With the advancement of technology and materials, there is more sophisticated, aggressive and higher quality ski equipment on the market. The advertising of extremely high-quality equipment can be deceptive, leading the recreational skier to exceed his/her technical abilities and consequently putting him/her at a greater risk of injury. In addition to the use of protective equipment, dealing with critical situations on the slopes, attending ski courses and training, developing skiing skills and experience in order to be able to react more appropriately to unpredictable events play a major role in prevention.

Given the underresearched area, there is still the possibility that well-designed research focused on the question presented could also lead to important conclusions in the intended direction. In this respect, we hope to build on the research of Spörri et al. (2017), which highlights, among other things, the insufficient strength of trunk stabilization and genetic predisposition as risk factors for injury. However, we could also refer in part to the research of Langran and Selvaraj (2002) and McKenna and Hammond

(2007) on an individual's level of fitness, which found that skiing (and snowboarding) ability, skill level, and experience are important for injury prevention. Furthermore, Hébert-Losier and Holmberg (2013) focused their study on the mechanism of injury to the ACL. In most cases, it is a backward or forward fall combined with the rotation of the tibia on the femur. As early as 1995, studies by Ettlinger, Johnson, and Shealy had developed a method of interactive training which included a video, an instructor, and group and individual training dedicated to backward falls in combination with the rotational mechanism, and the link between the mechanism and the knee injury. The effectiveness of this method was successfully demonstrated, with a 62% reduction in the number of serious knee injuries. Three years later, Jørgensen, Fredensborg, Haraszuk, and Crone (1998) showed that the number of injuries was reduced by 30% in cross-country skiers who watched a ski instruction video. A study by Cusimano et al. (2013), however, did not show that watching a safety instruction video reduced the number of injuries. Still, it did show that skiers were more aware of safety on the slopes, highlighting another very important preventive measure. The research by Ettlinger et al. (1995), Langran and Selvaraj (2002), McKenna and Hammond (2007) show that the central role in prevention is not only occupied by equipment, but also by strategies related to other domains, which may include, in part, specific exercises and physical training programs. In 1987, Morrissey, Seto, Brewster, and Kerlan proposed a series of specific movements, stretches and cardiovascular training to reduce the risk of many musculoskeletal injuries in alpine skiers. Their proposals are based on the physiological and biomechanical forces experienced by alpine skiers during skiing. For example, knee flexion and extension against resistance, internal rotation of the tibia, stretching of the posterior thigh and calf muscles have been suggested as exercises to prevent knee joint injuries. These exercises are still useful in practice today, even though the nature of alpine skiing has changed considerably since 1987, especially in terms of speed, forces, slopes, conditions, and equipment. For this reason, modern recommendations on training are adapted to the new developments in field, according to Koehle, Lloyd-Smith, and Taunton (2002). This can be seen when comparing the shape and length of skis. In the 1980s, skis with a side bow were not used. At that time, the most common mechanism of injury to the ACL was a backward fall with knee rotation (Natri, Beynnon, Ettlinger, Johnson, & Shealy, 1999; Beynnon, Ettlinger, & Johnson, 2007). However, as the use of carving skis became more widespread, and forward fall with rotation became the most common mechanism for ACL injury (Ruedl et al., 2009; Ruedl et al., 2011). With advances in skiing, equipment, and technology, understanding of human physiology and its response to sport and exercise has also evolved. In parallel, exercise methodology and concepts have evolved. Over the last two decades, deep trunk stabilization exercises have become a predominant component of training programs for a wide variety of sports. According to McGill (2010), the effective activation of the transversus abdominis, the paraspinal muscles, and the pelvic floor muscles is considered to be the key component for effective sports performance and injury prevention. In addition, neuromuscular activation training has also been identified as effective in preventing knee joint injuries in non-contact sports (Hewett, Lindenfeld, Riccobene, &



Noyes, 1999; Sugimoto et al., 2012a). The inclusion of a physiotherapeutic program of exercises for the neuromuscular junction is recommended for recreational alpine skiers, particularly in this direction, as different forces and variations have different effects on the recruitment patterns of the quadriceps femoris muscle (Kröll, Wakeling, Seifert, & Mueller, 2010; Kröll, Müller, Seifert, & Wakeling, 2011).

Musculoskeletal training and deep trunk stabilization training are included in most preventive kinesiotherapy programs for different types of injuries (Wilk, Macrina, Cain, Dugas, & Andrews, 2012). In addition to strength, flexibility is also important to reduce the risk of injury. A prevention program should also include stretching. Stretching has the effect of lengthening muscles and reducing muscle tension, resulting in corrected pelvic and spinal positioning, which reduces lumbar back pain (Coburn & Malek, 2012). However, mobility has not always been one of the most important components of lumbar prevention programs. In 1984, Biering-Sørensen found that lumbar mobility can also worsen current lumbar conditions or pain. Hewett, Ford, Hoogenboom, & Myer (2010) found that prevention programs that include strength training have the greatest effect on reducing the number of ACL injuries. Sugimoto, Myer, McKeon, & Hewett (2012b) demonstrate a lower risk of developing an ACL injury if the athlete adheres to a prevention program more than 66% of the time. In theory, the simultaneous development of the biomechanics of sport and the understanding of human physiology should be used in favor of designing specific exercises aimed at injury prevention. This would require updating programs developed more than 30 years ago by scientists such as Morrissey et al. (1987) and defining new recommendations for recreational and competitive alpine skiers. For example, in 2010, Kiani, Hellquist, Ahlqvist, Gedeberg, & Byberg investigated the effectiveness of an injury prevention program for female football players aged between thirteen and nineteen years, that included motor skills, control and activation training. The result showed a 77% reduction in the incidence of knee injuries in the group that underwent the injury prevention training program compared to a control group that did not undergo the same training program. Even if the percentage reduction in incidence in alpine skiers using a similar program would be much lower, it would have the potential to significantly reduce the health system costs and morbidity associated with participation in winter sports. Boden and Prior (2005), however, attribute a different role on the slopes to fatigue, which can lead to serious injuries and even fatalities; and the effects of endurance training on injury prevention in alpine skiers should also be investigated. For example, in recreational skiers, a significant decrease in glycogen stores and an increase in blood lactate could lead to negative effects such as fatigue, inflammatory processes, and reduced neuromuscular function leading to injury (Boden & Prior, 2005). Endurance training can be used to better utilize glycogen stores, reduce lactate production and increase circulating anti-inflammatory cytokines at a given intensity (Walsh et al., 2011). In addition to neuromuscular training, trunk stabilization training and endurance training, plyometric training, which focuses on correct joint performance and mechanics, is also mentioned in the literature (Pfeiffer, Shea, Roberts, Grandstrand, & Bond, 2006). A preventive exercise program that includes several different correctly dosed and graded training components is more

effective than a program that includes only one training component, such as strength or stabilization training alone (Grimm, Jacobs Jr, Kim, Denney, & Shea, 2014; Sugimoto, Myer, Foss, & Hewett, 2014).

Our literature review revealed that the area of prevention in terms of fitness and as a risk factor for injury in alpine skiing is poorly/under researched. Many studies have been written on the mechanisms of injury, which, although providing a good starting point for the design of prevention programs, did not follow through in this vein, nor could we find any that did. Among recommendations for injury prevention in alpine skiing prevails the use of appropriate ski equipment. Although sports medicine experts encourage prevention programs that include sport-specific exercises, none of the studies reviewed put forward specific recommendations that could be highlighted.

The incidence of injuries in competitive alpine skiing estimated by Tarka et al. (2019) is extremely high. In competitive alpine skiing in addition to a head coach, assistant coaches and a fitness coach, a well-structured team of medical professionals is essential to provide athletes with injury prevention and treatment before, during and after the season. This team consists of a physiotherapist, an orthopaedic specialist or traumatologist, a psychologist, a sports nutritionist, a kinesiologist, and others, among whom close professional collaboration is highly desirable. The role of the physiotherapist, which is essential at this level, is to provide high-quality physiotherapy treatments and knowledge-based rehabilitation at the onset of injury and to provide preventive kinesiotherapy measures. In sports practice, prevention is most often carried out through individually tailored pre-injury prevention programs, based on training to improve fitness levels, which athletes can incorporate into their training process.

## CONCLUSIONS

Conclusions can be drawn regarding preventive measures and recommendations, including the use of appropriate ski equipment - especially suitable helmets, skill and experience in critical or unpredictable situations on the ski slope, and the use of evidence-based preventive training programs from other non-contact sports with similar injury mechanisms. At the same time, we can highlight an area that we have identified as problematic, but for which there exist no evidence-based solutions yet. We would like to encourage researchers to conduct research into risk factors and injury prevention measures in alpine skiing, focusing on the two factors already mentioned (trunk stabilization and genetic predisposition) and definitively confirm or reject them. Otherwise, they should be guided by the desire to determine findings that would serve to design prevention programs for the most common injuries to alpine ski racers. As the area of causes and mechanisms of injury is more researched than the area of prevention, the latter should be a prerequisite for more extensive research. Further research should investigate the role and effects of targeted prescribed exercises to improve fitness that would reduce the incidence and complexity of musculoskeletal injuries. Research to demonstrate the effectiveness of prevention programs at the highest level of skiing is

complex, requiring a large number of subjects, and accurate recording and analysis of data, as well as accurate identification and consideration of other factors that may influence the occurrence of injuries, regardless of an athlete's fitness level. The findings are relevant to alpine skiers, physiotherapists, other health professionals, coaches and anyone else involved in the competition or preparation of alpine skiers.

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