





'Every turn can be the last one I do' - Perceptions of injury risk in high-performance snow sports and its implication for injury prevention

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ABSTRACT

Objectives High-performance snow sports (HPSS) athletes compete in a performance-driven context with a high risk of injury. While there is a lack of evidence on effective prevention measures in snow sports, this study explored the perspectives and perceptions of HPSS stakeholders on sports injury prevention.

Methods We conducted an exploratory qualitative study based on the grounded theory principles through 11 semistructured interviews with athletes, coaches and healthcare providers from different national teams about sports injury prevention. The interviews were inductively analysed through constant comparative data analysis.

Results Participants defined risk management as a central concept in which they approached injury prevention by assessing, managing and sometimes accepting risks. Many factors, such as athlete-related and external factors, are considered in this process, ultimately influencing their decision-making. Participants acknowledged the value of experience when managing and dealing with risks, a key aspect of their learning process and career development. Within this context, open and trustworthy communication and shared responsibilities among all stakeholders influenced and shaped injury prevention strategies and behaviours. Understanding and balancing out speed and risks was considered pivotal in their daily practice. Therefore, injury prevention awareness, ownership, communication, teamwork and shared responsibilities may contribute to the success of sports injury prevention in HPSS.

Conclusion These findings substantiate the significance of such contextual factors in sports injury prevention. Considering the high-risk nature of HPSS, injury prevention suggests a shift towards risk management strategies, with a strong emphasis on contextual factors and their interactions. Young athletes might benefit from educational interventions centred on developing skills to assess and manage risks.

INTRODUCTION

Injury prevention in 'high-performance snow sports' (HPSS; including alpine skiing, snowboarding and freestyle skiing) faces many challenges, especially in elite alpine skiing. On the one hand, injury prevention research has overlooked the wide range of factors influencing injury and involving injury prevention in such a context. On the other hand, the current literature is still hampered by small sample sizes, methodological issues and the constant evolution of injury factors with equipment

WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Elite alpine skiing, snowboarding and freestyle skiing athletes compete in a performance-driven context with a high risk of injury.
- ⇒ Despite several injury risk factors and prevention strategies being suggested, there is a lack of evidence on effective prevention measures in high-performance snow sports.
- ⇒ Identifying stakeholders' perspectives and perceptions on sports injury prevention may lead to the adoption of additional injury prevention strategies and context-driven prevention measures.

WHAT THIS STUDY ADDS

- ⇒ Participants provided insights into better understanding the high-performance snow sports and the influence and guidance towards preventive behaviours.
- ⇒ Injury risk management represents the endpoint of a decision-making process vastly influenced by experience, communication and shared responsibilities among all stakeholders.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ Given the inherent high risks of alpine skiing, snowboarding and freestyle skiing, injury prevention demands a change towards a risk management approach, with a pivotal role of the contextual factors and their interactions.
- ⇒ Integrating perceptions, behaviours, preferences and experiences from athletes and interdisciplinary stakeholders can shape and improve the implementation process by embracing the complexity of injury prevention.
- ⇒ Listening to athletes' and all the interdisciplinary stakeholders' voices may help to understand the practicalities of sports and reinforce a multilevel injury prevention approach based on a context-driven approach that may contribute to developing more comprehensive injury prevention measures.

and competitive rule regulations.^{1,2} Hence, there is a lack of acknowledgement and understanding of the HPSS context and how it can influence and lead to preventive behaviours. Although various potential injury risk factors and prevention measures have been suggested, few effective strategies exist.³

In HPSS, athletes compete with one another in a performance-driven environment in which the primary aim is to increase sports performance. Moreover, such HPSS context is well known for its high risk of injury.^{4,5} Both the performance-driven and the high-risk environments can directly impact an athlete's ability to perform.⁶ In 2006, the International Ski and Snowboard Federation (FIS) established an injury surveillance system to provide data on injury trends in international elite skiing and snowboarding to reduce injury risk.⁷ However, despite the efforts and changes made throughout the last decade to improve alpine skiers' safety,^{3,8} injury rates are still high.²⁻⁴

Injury should be regarded as complex and multifactorial,^{1,5,9,10} where injury prevention demands a deep understanding of the underlying injury mechanisms and situations leading to an injury.^{4,9,10} Nevertheless, the current literature on alpine skiing has only focused on single factors, such as athletes' physical condition, equipment, course setting and snow conditions.^{4,9} For instance, when they are on slopes, these athletes must deal with such factors, their interactions and the dynamic nature of weather conditions. Furthermore, other components, such as contextual factors, have not yet been addressed in preventive strategies in for elite alpine skiing. Contextual factors are those 'structural and institutional systems' in which individuals are embedded, influencing their injury and rehabilitation experience.¹¹ In this connection, qualitative research methods¹¹ provide insight into the meaning and understanding of contextual factors and can help us understand how and why injury prevention is adopted in elite sports.^{12,13} Accordingly, this qualitative study explored the perspectives and perceptions on sports injury prevention among HPSS alpine skiing, snowboarding and freestyle skiing stakeholders.

METHODS

Study design

This exploratory qualitative study is based on the grounded theory (GT) principles through a systematic and inductive approach.¹⁴ Our analysis intended to address processes and interactions by interpreting and generating connections from multiple perspectives and participants' realities within an interpretive and constructivist paradigm.^{15,16} The results were reported according to the COREQ guidelines (Consolidated criteria for Reporting Qualitative research; Online supplemental material 1).¹⁷

Equity, diversity and inclusion statement

The research team comprised four men and one woman (the senior author). OBM is a PhD candidate from Andorra and a sports physiotherapist with experience in sports injury prevention. CB is a Brazilian sports physical therapist with experience in sports injuries and a postdoctoral researcher. JS is a Swiss human movement scientist with wide experience in alpine skiing research and injury prevention. EV is a Dutch sports scientist and epidemiologist with extensive experience in injury prevention. VG is a French sports medical doctor, researcher and former professional athlete. The study population included European national teams and mostly represented males, including the most developed skiing federations in terms of resources and sports culture, but missing the small and less developed countries and federations in this regard. Females were under-represented in this study, which matches the HPSS reality regarding their staff.

Participants

The participants in this study were HPSS athletes (n=5), on-snow coaches (n=3), physical therapists (n=2) and off-snow

strength and conditioning (S&C) coach (n=1) from different national teams competing in the World Cup (WC) and European Cup circuits. Participants were working at the elite level in alpine skiing (n=6), snowboarding (n=3) and free skiing (n=3), and they were from the national teams of Switzerland (n=4), Finland (n=3), Germany (n=2), Liechtenstein (n=1) and Italy (n=1). To guarantee confidentiality, no additional demographic details will be presented. A contact person (JS) who worked closely with FIS recruited potential participants who met the eligibility criteria of either representing their country in elite-level competitions or participating in the 2018 Winter Olympic Games. All potential participants were first contacted through an invitation email containing an information letter. After agreeing to participate, they were contacted by the research team. We aimed to ensure a diverse group from different countries, disciplines and roles, including less and more experienced participants. Based on the maximum variation sampling method, we allowed a wider view of the topics from various perspectives, backgrounds and experiences.¹⁸

Data collection

Data were collected through semistructured interviews during June–July 2021. All interviews were conducted by video call by one researcher (CB). The interviews were audio recorded and conducted in English. The mean length of the interviews was 42 min (ranging from 32 to 56 min). The questions were about injury prevention beliefs, perceptions and experiences. A preliminary analysis was performed during the data collection, influencing theoretical sampling.¹⁹ The interview questions could evolve and could be adjusted in response to newly gained insights. The topic list is presented in [table 1](#). After 11 interviews, no additional information emerged from the data, indicating saturation.²⁰

Data analysis

All interviews were transcribed verbatim. They were further inductively analysed based on constant comparative data analysis,²¹ employing the principles of GT.¹⁴ In the first stage, two researchers (CB and OBM) independently open-coded two interviews using ATLAS.ti software (Scientific Software Development GmbH, Berlin, Germany; V.8.4.5). Then, they discussed their codes. This procedure was repeated, respectively, with one and two more interviews. Subsequently, codes and memos were discussed. Once consensus was reached, one researcher (OBM) coded the remaining interviews (n=6). After a meeting between the two researchers (OBM and CB) in which they discussed the emerging findings and potential interactions, an overview was presented to two independent researchers (EV and JS), who were not involved during the interviews. During this meeting between the researchers (OBM, CB, EV and JS), codes, categories and divergences were discussed and compared until the categories of interest were agreed on for analysis. Subsequently, the structure of the analysis results was developed following the constant comparative data analysis by looking for similarities, differences and connections to get to the main concepts with a description of the core concepts (online supplemental material 2).

RESULTS

The main core concept that emerged from the data analysis was risk management, modulated by athlete-related, external and contextual features. Experience, open communication and shared responsibilities were overarching aspects that influenced the risk management process. The entire process led

| Topic | Questions |
|---|--|
| Injury definition | Which aspects do you consider defining a sports injury in your context? (Symptoms? Time? Training modification? Need of medical care?) |
| Factors influencing injury | Which factors influence the occurrence of an injury? |
| | How can these factors affect the occurrence of an injury? |
| Believes and responsibilities in injury prevention | Do you believe that injuries can be prevented? |
| | How can injuries be prevented? |
| | Who do you think is the main responsible for preventing injuries? |
| Injury prevention strategies, criteria and motivations | Which injury prevention strategies do you apply? Why do you apply these strategies? |
| | What do you consider when choosing the injury prevention strategies that you currently use? |
| | How do you choose each strategy to apply, and why do you choose them? |
| | What motivates you to apply an injury prevention strategy? |
| Influence of the context and sports culture: facilitators and barriers within the FIS snow sports context | How does the context of elite sports/your reality influence injury prevention (facilitators and barriers)? |
| | How does your sports culture/elite sports structure nationwide influence the way that you prevent injuries? |
| | Which factors in your daily routine support injury prevention? Which factors make injury prevention more difficult? |
| FIS, International Ski and Snowboard Federation. | |

to developing decision-making behaviours to deal with such inherent risks from their sports. Figure 1 depicts a comprehensive overview of the system around the athlete, the factors influencing risk management and how it influences injury and its prevention. All the mentioned stakeholders are represented, from the athletes and team staff to the federations and media. The related codes and quotes are presented in tables 2–5.

It is all about dealing with risks

Participants defined risk management as a core concept in which participants approached injury prevention by assessing, managing and sometimes accepting risks. Many dimensions modulate this process: injury perception, athlete-related and external factors, the learning process, the nature and culture of the HPSS and the teamwork of all stakeholders.

"I needed to learn it the hard way (through injuries). I wish I didn't have to. It is what it is." **Athlete 5**

Injury perception

Regularly, participants touched on pain and 'big and small' injuries when they discussed their perception of injury. This perceived severity of a potential injury was also considered in their decision-making. They highlighted that pain, small injuries and complaints were normal elements of their daily practice, mostly resulting from skiing-related accidental events, crashes or falls, which occur during training or racing. Likewise, they defined 'big injuries' as those with longer periods of absence from training and competition. The main concepts employed when defining an injury were performance level and participation.

Participants defined injury as an event that prevents them from performing in training and racing, thus impacting performance.

Athlete-related factors

All participants agreed that athletes should, or indeed they already do, focus on improving and preparing themselves to take risks. Most importantly, they emphasised physical training, such as S&C, and insisted on the value of mental training. Rest, sleep, nutrition and working on skiing techniques were described as influential factors to minimise injury risks. Last, having sustained previous injuries and the potential effects and consequences that an injury can lead to were notably considered in their risk management process.

External factors

Athletes and coaches reported that speed, course design and setting and equipment are factors related to injuries. Additionally, it was emphasised that snow conditions and their quality can change throughout the racing or training course, yet altered by weather conditions. Participants stated the importance of safe conditions, including the above-mentioned factors and the use of safety nets and other protective equipment. Furthermore, a busy schedule of races and trips in between were perceived as detrimental.

Learning process

Coping with the inherent risks was presented as a learning and educational process influenced not only by the athlete's experience, but also by the experiences of the rest of the team. These learnings and insights were acquired under different circumstances, entailing learning from others, their own or others' mistakes and injuries, throughout their professional careers and by being exposed repeatedly to the limit or at-risk situations. Furthermore, coaches highlighted different approaches towards injury prevention by athletes and athletes' proactive or passive roles with their coaches. Equally, such features were also related to the athlete's age, experience and maturation.

Nature and culture of HPSS

Speed, riding under pressure, great performances, show and business (ie, economic aspects) are part of the nature and culture of snow sports based on participants' views. Mainly coaches drew attention to bringing efforts to balance speed and safety. A noteworthy contrast was pointed out in comparing the different types of pressure that elite or experienced athletes and younger athletes deal with. Such pressure could come from themselves, their team, or external sources, such as media and sponsors. Considering that the goal is to win, elite level and experienced athletes have to deliver results and excel at their performances. In contrast, youth have the pressure to achieve good results to become elite athletes. Last, the term business was often used when participants described the context of their snow sports. For instance, these HPSS have become an economic business because organising and being selected as a venue in the racing calendar brings large budgets and considerable financial resources from the organising committees.

Teamwork of all the stakeholders involved

Athletes, coaches and medical staff were united when foregrounding the power of building strong bonds within the team and their influence on effective teamwork. Athletes, coaches and the medical staff coincided that teamwork lay with three pillars. First, athletes underscored how essential their social surroundings

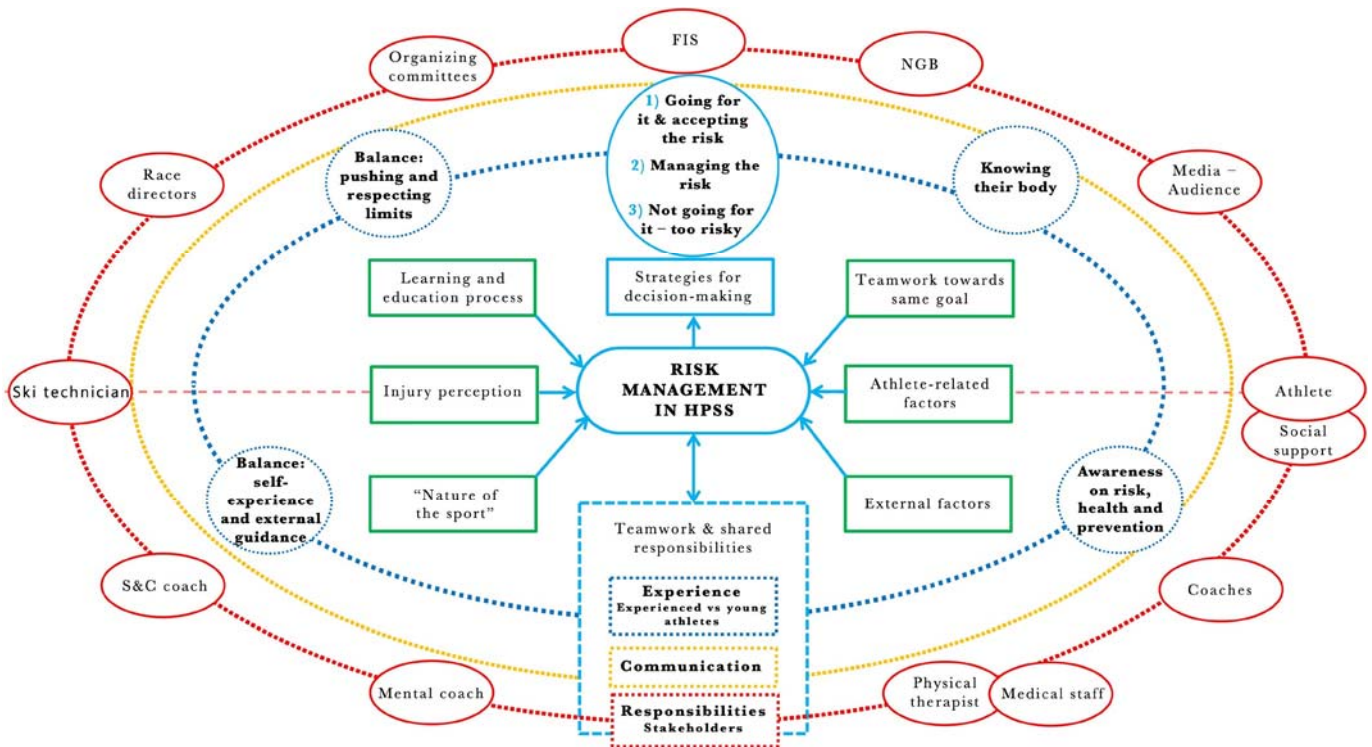


Figure 1 Development of strategies for decision-making on risk management in HPSS. Based on our data analysis, this figure outlines the development of strategies for decision-making on risk management in high-performance snow sports. These sports share intrinsic factors and features (green box), which are remarkably influenced by experience (blue-dashed overarching circle), leading to new attitudes in the approach of such features (blue-dashed lines). Concurrently, communication (yellow-dashed overarching circle) and shared responsibilities among all stakeholders (red-dashed overarching circle) influence the whole development process. At the end of the path, athletes and their teams acquire, develop and implement strategies for their decision-making on their risk management process, with the contribution of all the stakeholders involved within this high-performance snow sports context (red circles anchored to the red-dashed overarching circle). Stakeholders are divided by the horizontal red-dashed line into the athlete's team (bottom part) and external stakeholders (top part). HPSS, high-performance snow sports; FIS, International Ski and Snowboard Federation; NGB, National Governing Bodies; S&C coach, strength and conditioning coach.

are on and off the slopes. However, they also mentioned that a bad social environment (eg, toxic relationships, unhealthy teams) could negatively affect them, thus denoting a double-edged sword. Second, all stakeholders supported athletes' view that athletes need a working team surrounding them, starting in the early stages of their careers, to become professional athletes. Last, athletes, in particular, insisted on the significance of themselves being understood by every team member, with a special focus on the coaches. Such understanding and strong relationships encouraged and promoted the development of the athlete's decision-making related to risk management.

Experience as a guide and learning tool: shaping risk management behaviours

Experiences acted as an overarching modifier of the previous factors by different processes, which all combined contribute to attitudes towards managing risks. Therefore, risk management behaviours were developed through experience by improving knowledge and skills to address risk acceptance and risk management. Experienced athletes felt more empowered and owners of their decisions, especially when dealing with load management and the criteria of keeping or stopping training.

"In the end, it is a mix. The main part should be not to get an injury, so we still have the balance between protecting them, coaching them and still going to the limit of their risk, sometimes over the limit. And then still to being and staying healthy, not injured. That is a big balance." **Coach 3**

knowing themselves: body and mind

Athletes stated the relevance and influence of learning to take care of and listen to their bodies for better risk-taking decisions. All participants, but primarily athletes, dwelled on the mental aspect beyond the physical training. They highlighted the pivotal role that mental readiness and being mentally focused play in their sports.

Awareness of risk-taking, health and injury prevention

Athletes and the medical team emphasised that increasing their understanding on risk and safety, the value of health and the impact of an injury, raised athletes' awareness towards injury prevention and staying fit and healthy to perform optimally. In contrast, coaches pointed out that young athletes lacked these learning experiences because of their limited experience, resulting in a lack of awareness of the need for prevention. Primarily, athletes and coaches accentuated the need for exposure and training sessions to acquire, develop and master strategies to improve their decision-making and risk management.

The balance between pushing and respecting limits

Exposure to unpredictable conditions and being on the edge of the limit during training or racing gave athletes insights into balancing pushing their bodies to their limits and respecting them, while also constantly seeking a balance between risks and

Table 2 Concepts, subcodes and exemplary quotes on the risk management factors: 'it is all about dealing with risks'

| Main concept | Subcode | Exemplary quote |
|-------------------------|---|--|
| Risk management factors | Injury perception | "If I can't compete. That is, for me, an injury. So, with my broken hands, I always competed the next day. That is, in essence, an injury, but it is not anything that stops me. But if you lose training days or like a lot of training days or races, then that is what I would call an injury." Athlete 1 "You also train with some little problems, everybody is doing that, but the big question is when it starts to be a bigger problem. I think it starts when it disturbs you to bring your best." Coach 1 |
| | Athlete-related factors | "We do train. But it goes a lot in that way to protect them, and we invest a lot in that way to have good athletes healthy, mentally prepared, and body prepared physically." Coach 3 "A bit consistent behaviour with physical training, warming up, nutrition and planning of the programs. Those are probably the big things, and being really aware of what the conditions are on those days and the conditions of the park." S&C coach |
| | External factors | <u>Environmental factors, course setting-related and equipment-related factors</u> "Factors such as environmental conditions, weather, snow preparation, and course setting, for example. They have, from my point of view, a big influence. And also, material, this is skis, boots, plates. So, we are really fighting against this really expensive setup which is clear because everything is performance-driven." Physical therapist 2 <u>Safety conditions</u> "We try to make the training as safe as possible when they crash. It is maybe hard to say. We try to make it as safe as possible that they don't crash, but when they crash, we try they don't hit a tree, for example." Coach 1 <u>Competition-related and schedule-related factors</u> "I feel our everyday life on snow is very intense, not only because of those few very intense runs we do but also because we have to carry so much stuff such long distances. We never have easy access to our training facility. So, for example, from the hotel until we are on snow, that can be around 1.5 hours. So, that is three hours every day of just travelling, and that is just draining and makes you really tired." Athlete 1 |
| | Learning process | "I needed to learn it the hard way (through injuries). I wish I didn't have to. It is what it is." Athlete 5 "Education is giving them an idea about better strengths and control of the different situations that they have in alpine skiing. We have critical or crucial movement situations that they learn to steer these critical movement situations better. But this is just one part. Then give them an idea about what risk management means. So, this is a lot of knowledge dissemination and not just giving them a certain exercise. [...] This is just working on some small puzzle pieces in injury prevention." Physical therapist 2 |
| | Nature and culture of snow sports | "We are in racing, and it is the fastest athlete that wins the medal and not the safest athlete." Physical therapist 2 "We grew up to be athletes, to be fast athletes, but not to prevent injuries. So, I think in our culture, you just want to see the result, you want to improve, you want to become better, but an athlete never thinks about an injury. So, I think the culture of injury prevention has to improve." Athlete 4 |
| | Teamwork of all the stakeholders involved | "We know our body, and we know what feels right, but then there is also so much knowledge that we don't have and that we need from other people surrounding us. [...] I think that other than what we feel, we should have a team surrounding us who knows the facts about mental and physical stuff and also about the actual sort. The knowledge and knowing ourselves can make us perform at our best." Athlete 3 "Given we are a small team, what we do well in our ski federation is that we try to involve them all the team in the whole process, to discuss a lot with the different stakeholders, to discuss with coaches, with the management level team on the ski federation, but also to discuss with the athletes." Physical therapist 2 |

safety to be able to assess risks. Thus, experiences influenced the skill of balancing risks and integrating different approaches concerning risk acceptance and management. Moreover, they acknowledged the value of training, where they had to be constantly exposed to risk to improve their decision-making strategies when racing.

Balancing self-experience and external guidance

All participants referred to the connection between experience and its impact on their knowledge of risk management. Younger athletes, mainly because of their age and lack of exposure and awareness, needed guidance from coaches and staff to educate them on accepting and managing risks. Thus, throughout the different stages of an athlete's career, athletes attain equilibrium between learning through self-experiences and their team's external guidance.

Communication and shared responsibilities

All stakeholders in the HPSS diverge from the athlete's team and external stakeholders. While the athlete's team included the coach, physiotherapist, medical staff, mental coach, S&C coach, ski technician and athlete's social environment, the external parties consisted of race directors, organising committees, FIS, national governing bodies, media and audience. Likewise, all participants reflected on the importance of every stakeholder and their key role in injury prevention,

making the training and racing environment as safe as possible to best control and handle the intrinsic risks of such sports. Trustworthy, honest and open communication, mostly between athletes, their teams and external stakeholders, was considered pivotal for trustful relationships for shared decision-making on risk management.

"I think one of the ways which I think has a bit of impact is lots of small conversations with the riders, put a little bit more emphasis on to whether there is self-awareness and talking about if they do realize that they know what they are doing in certain aspects and reflecting a little bit. So, hopefully, that is having some impact." **S&C coach**

Trust the process: decision-making as the outcome

The final result of the risk management process is decision-making. It can be categorised into three behaviours. First, accepting the unavoidable risks and pushing them to their limits were linked to the performance-driven mentality, assuming that '*it is the fastest who wins, not the safest*'. Second, an alternative response was described as managing and dealing with the risk. This approach was vastly influenced by experience and the potential to mitigate risk factors and was mostly executed by experienced athletes based on their knowledge and awareness of risk-taking. Last, some situations and conditions might be '*too dangerous*' and could potentially lead to injury. Therefore, they

Table 3 Concepts, subcodes and exemplary quotes on the experience as a guide and learning tool: 'experience as a guide and learning tool: shaping risk management behaviours'

| Main concept | Subcode | Exemplary quote |
|---|---|--|
| Experience as a guide and learning tool | Knowing their body: listening to and taking care of their body and mind | "What I did good was especially listening to myself and saying, " <i>Ok, now I am tired, now my head is not focused anymore, now I have to stop.</i> " So, that was a good thing. So, I think I prevented a lot of injuries." Athlete 4 "Like the centre of my career was, first of all, I need to stay healthy. [...] I really listened to my body, like analysing myself if I was mentally tired or if I was emotional, just being really honest to myself and then also acting on it. That was something I have learned the hard way, but it really turned out well." Athlete 1 "When I am tired and still keep pushing, I think this is something that I learned a little bit more throughout my career to listen to my body, knowing when I am tired because I know this is the critical moment and when something bad could happen." Athlete 2 |
| | Raised awareness on risk perception, health and injury prevention | "There are some outstanding athletes, of course: self-responsible, self-steering and so on. They think about health and performance by themselves, and normally they are the ones who can manage this." Physical therapist 2 "The athletes that have injuries are more open for injury prevention because they just experience what it actually means to have an injury and to be out and to come back." Physical therapist 1 "I had to deal for 11 years with the situation of every turn can be the last one I do, and that was probably the most difficult. The mental side of knowing that any day it can be over, and that is why I started to be like really aware of injury prevention. I thought about getting hurt every day. So, for the next 11 years of my career, I always left my room in the morning so that it was easy to pack if I didn't come back. And I only realize that now, after my career, how crazy that is to like to be in a position every day where you are not sure if you come back to your room or if your career is over." Athlete 1 |
| | Balance between pushing while respecting the limits | "It is really borderline because you need that balance because if you are always being too safe, you are not going to learn the big tricks and the tricks, which even the young ones are doing now are so huge that it is really difficult to draw that line with holding it back and progressing the tricks." S&C coach "In the end, it is a mix. The main part should be not to get an injury, so we still have the balance between protecting them, coaching them and still going to the limit of their risk, sometimes over the limit. And then still to being and staying healthy, not injured. That is a big balance." Coach 3 |
| | Learning process between self-experience and external guidance | "I ask myself how they found their limit if they never went over it. It is like I almost needed that to figure out this is the line." Athlete 1 "I think the learning process is a balance because if you always have someone around you, then you are not going to learn to handle everything or make decisions by yourself. But if you don't have anyone, then it is also going to take something away from the quality of it maybe. So, it is kind of the balance, I think. It is good you can do stuff alone without a coach or someone telling you what to do, but then also, I think at some point it will help you also to move forward and get like the quality you want and need by having someone around you." Athlete 3 |

could consider it not worth taking these risks. Athlete-related factors, such as fatigue or mental readiness, and external factors, such as bad snow and weather conditions, influenced these decisions.

"You accept risk. You learn to deal with it. This is part of the game."
Physical therapist 2

DISCUSSION

The present qualitative study outlines multiple perspectives on risk management in HPSS. These findings provide an overview of how athletes deal with the inherent risks of their sports and how their context influences and modulates their sports injury prevention behaviours.

Table 4 Concepts, subcodes and exemplary quotes on effective teamwork based on communication and shared responsibilities: 'communication and shared responsibilities'

| Main concept | Subcode | Exemplary quote |
|--------------------|---------------------------------|---|
| Effective teamwork | Open and trustful communication | "I think one of the ways which I think has a bit of impact is lots of small conversations with the riders, put a little bit more emphasis on to whether there is self-awareness and talking about if they do realize that they know what they are doing in certain aspects and reflecting a little bit. So, hopefully, that is having some impact." S&C coach "I feel if you have a strong relationship with the people around you that are also good with reading you and understanding you well, then that can help a lot with energy management. Also, with the coach, I feel like if he sees you skiing today and he feels I am tired, we would take a day off tomorrow." Athlete 1 "I think communication plays a big role, also probably for the athletes. If they have doubts themselves or they don't know if it is time to stop or to push a little bit further, I can imagine it really helps to talk to their coach or the physio. Someone who knows them well and especially when they are full of adrenaline, probably it is even tougher to make judgements. So, I think it is important if they can just come to you and check in and verbalize their decision-making process and get help from outside. Communication is really important and also that they dare to go to the coach with their thoughts." Physical therapist 1 |
| | Shared responsibilities | "The physical coach, which is not that easy, has to build up an athlete to be strong, to be fast, to be resistant, but also to be prepared for every situation in which an athlete has to react. [...] Technicians set the courses, so they have to set a nice course, a fair course and especially a safe course. So, for example, if a jump is too big, which can be an influence to get injured, the technician has an influence on this. [...] Race director has a very important role because he has to make happy all the parts, so the athletes [...], the media [...], race organisers [...]." Athlete 4 "The athlete is at the very centre of the people included in injury prevention. Then, the next circle is, of course, the coaches because they are pretty close to them. Then, of course, it is us, the medical staff. Depending on if it is a really young athlete, parents and the coach are on the same level. If it is an older athlete, there is the system, let's say the federation. [...] When it comes to competition, the next level includes all the persons who are involved in the competition, which are race directors. Finally, the next level is all about society, governance and government." Physical therapist 2 "Whenever there is an incident, who was responsible? The athlete, the FIS, the race director, the coaches, the ski technician? Do we find the balance and the compromise? It is the whole system that is responsible." Coach 2 |

Table 5 Concepts, subcodes and exemplary quotes on the strategies for decision-making: 'trust the process: decision-making as the outcome'

| Main concept | Subcode | Exemplary quote |
|--------------------------------|-------------------------------------|---|
| Strategies for decision-making | Going for it and accepting the risk | "For example, alpine skiing is a high-speed sport, so we have a high-risk situation, and the point is you have to do risk management, and it means you have to decide "do I stop on these weather conditions, do I go for 100% in these weather conditions or do I go 100% in these snow conditions?" You have to decide it by yourself immediately." Physical therapist 2 "I would start with the mental aspect. One of the major aspects of becoming a racer, and especially a ski racer, is the ability to manage risk. The acceptance of risk and dealing with risk has to be kind of the fascination of the sport itself. I mean, this needs to be the driver, doing something that not many people can do on that level. Manage risks, going at high speed around narrow turns, over jumps and whatsoever." Coach 2 "You accept risk. You learn to deal with it. This is part of the game." Physical therapist 2 |
| | Managing risks | "I don't think I have to struggle too much with the balance. I feel like I can do, when it is needed, I can push, but then when it is not time to push, then I can take it easy. Athlete 5 We try to make the training as safe as possible when they crash. It is maybe hard to say. We try to make it as safe as possible that they don't crash, but when they crash, we try they don't hit a tree, for example." Coach 1 "I think I prevented a lot of injuries by listening to myself. For example, during training, when the conditions weren't that good, I said, "Maybe I have to stop because it is dangerous", and others, maybe I said "No, it is not dangerous, we can make it". So that was the good thing." Athlete 4 "Training needs to prepare them for managing a certain kind of, managing risk, managing the limit. Knowing where it is, how I do get there when it makes sense to be at the limit when it makes way more sense to stay away." Coach 2 |
| | Not going for it—too risky | "Sometimes I feel I am still young, and I will need someone to tell me "Hey, you're tired, I can see it, just go home." This is something that I think is good that might prevent injury some days." Athlete 3 "It is not always 100% certain, but most of the time it is a feel, a strange feeling like "Ah, I am not sure about it". It is always a thin line where you think of stopping the training." Coach 2 "It is always a thin line where you decide to stop the training, but sometimes we have to. "Today is training. Let's go." It is always like "is it safe enough?" That is always the first question, and then "is it worth it to train today?" It is always a bit of balance." Coach 2 "Standing at the start and you have the wrong mindset to go, if you are not focused, or you just try something that is impossible, then you will get hurt." Athlete 1 |

The process of risk management in decision-making

Our findings showed that injury prevention is perceived as a risk management process. The interview questions were about injury prevention strategies, while the interviewees used the word risk management in their answers to name how they protect their health and performance. Given the complexity and dynamic nature of sports injuries and the constant exposure to risk,^{5 9 12} the risk management concept seems more representative and precise than injury prevention within the HPSS. The concept of risk management in sports was proposed by Fuller *et al*,²² describing risk assessment, risk mitigation, risk acceptance or management, risk perception and risk communication. Our findings are in line with this concept. The endpoint of the decision-making process described by participants included accepting and taking the risk to reach the desired performance level, managing and learning through risk exposure, or not accepting the risk and stopping. These risk-taking behaviours are also consistent with recent perspectives on fear and risk management from Canadian WC alpine skiers, where contextual factors and athletes' physical and mental preparation influenced their decision-making process.²³ While previous literature showed the high risk of approximately 90% of sustaining at least one injury per season in alpine ski racing,⁶ efforts have been made to understand risk-taking behaviours. On the one hand, from a social perspective, a study explored the reasoning behind the risk-taking strategies of freeride skiers.²⁴ On the other hand, another study compiled the key injury risk factors and recommendations on preventive strategies.⁹ Interestingly, both studies emphasised the importance of risk management.^{9 24} Therefore, as in other sports, attention should be given to acknowledging and playing how much risk can be dealt with rather than looking for null risk when preventing sports injury. Within the HPSS, research should focus on designing and developing tools and strategies to improve the risk management process, from risk assessment to decision-making.

The role of experience in managing and dealing with risks

The current study found that athletes' and stakeholders' experiences largely dictated preventive behaviours. Participants' experiences dealing with speed and safety contributed to a learning process in which maturation, previous injuries, and exposure to dangerous situations influenced the development and implementation of preventive strategies.^{25 26} Skiers and coaches acknowledged that to become an elite athlete, coping with and understanding pain and complaints is crucial.²⁷ Finding such a balance between speed and safety is of utmost importance if skiers are to perform at their best while staying healthy.¹² Risk management involves a maturation process in which athletes take ownership of their own decisions on and off the slopes.²⁶ These findings are consistent with previous literature, where experience and athlete ownership play a significant role in developing preventive behaviours.^{12 25-28} Considering the differences between young and more experienced elite athletes, different approaches should be considered based on the athlete's experience and age to mitigate the injury risk. Thus, education in sports injury prevention is crucial and should be addressed accordingly.²⁹ For instance, focusing on athletes' self-efficacy adapted to their specific context may improve their risk management process and available tools to make better decisions.³⁰ Therefore, educational efforts founded on a systematic long-term athlete development programme will provide them with risk exposure skills to assess, manage and develop their risk management behaviours in a controlled, conscious and safe environment.

The power of communication and shared responsibilities

Participants highlighted the value of communication in HPSS, where good, open and trustworthy communication is key in the decision-making related to risk management. Furthermore, risk communication among all stakeholders is also instrumental in the decision-making process of an athlete around accepting, managing or avoiding taking risks.²² Athletes may deal with pain

and complaints,^{26 27 31} and they might hide it from their team and accept a high risk of injury for performance purposes,²⁷ thus hampering the communication process. Communication involves teamwork and cooperation from all stakeholders within the sport^{25 32 33} as they all have specific roles and responsibilities regarding injury prevention.⁹ Additionally, the show of great performances, the media, the spectators, and the business are part of the HPSS culture, and consequently, they also influence injury prevention. Hence, integrating all stakeholders in an interdisciplinary team should be critical in assessing, mitigating, managing, evaluating and communicating the risks mentioned above when further designing, adopting, implementing and monitoring preventive interventions.^{9 10 22 31 33}

Strengths and limitations

The trustworthiness of our findings was reinforced by applying various methods.³⁴ Data and investigator triangulation were employed for credibility by including different stakeholders, such as athletes, coaches and healthcare providers. Researchers from various backgrounds and cultures conducted the data analysis process. We acknowledge that one main researcher providing contact (JS) might have coloured the sample and influenced the data collected and the study results. However, two independent researchers (OBM and CB) conducted the data analysis and presented it to a third independent researcher (EV) who was not involved in the data analysis process. Multiple meetings and discussions took place to validate the analysis and the relations with previous literature to increase confirmability. The participants were elite alpine skiing, snowboarders and freestyle skiing athletes/staff competing in FIS events regarding transferability. Such a diverse sample with diversity in experience, backgrounds, countries and culture concerning injury prevention provides a comprehensive description of the topic.¹⁰ However, given the specificity of our participants, our findings are context-specific, and comparisons with other sports contexts should be cautiously made. Dependability was accomplished by creating an audit trail in which memos were written to record the development and reporting of the findings.

Clinical implications

Our findings provide an understanding of the athlete-related, external and contextual factors that guide and influence the risk management process in the HPSS, thus suggesting a shift towards risk management strategies. This comprehensive view of risk management provides an idea of the diversity of factors that might influence injury prevention in HPSS, ranging from fatigue and athletes' physical and mental preparation to weather and snow conditions and pressure from media and race organisers. Contextual factors were clearly highlighted as influencing injury and the risk management process. Clinicians working in the field should explore how to influence potential contextual factors and support athletes and coaches in their decision-making process. To improve the compliance and buy-in of athletes in any preventive strategy, it is pivotal to consider the athlete's experience and their ability to make decisions, giving them ownership in this process. Future investigations should examine the contextual factors and their influence on injury prevention measures, focusing on providing a thorough description of factors influencing injury prevention behaviours. These include, aside from athlete-related factors, snow and weather conditions, course design and equipment, and even societal factors, such as pressure from media, sponsors, spectators and parents. Furthermore, future prevention approaches in HPSS should incorporate

educational interventions supporting young athletes in skill development to adequately assess and manage risks. Again, integrating all internal and external stakeholders in such a process would facilitate shaping and implementing readily applicable context-driven prevention strategies.

CONCLUSION

Our study suggests a shift towards risk management strategies within HPSS. Within these high-risk environments, diverse contextual factors and their interactions influence the complex and dynamic process of injury risk management. The decision-making process is the outcome of the risk management process, where these behaviours are shaped by experience, communication and shared responsibilities among all stakeholders within this context.

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