

Perceptions of experts on key injury risk factors in alpine ski racing as a function of stakeholder role and associated level of competition

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ABSTRACT

Objectives (1) To update experts' priorities of perceived key injury risk factors in alpine ski racing based on a framework and list derived 10 years ago, (2) to identify additionally emerging risk factors since then and (3) to compile a list with countermeasure suggestions.

Methods A sample of 532 expert stakeholders (athletes, coaches, team medical staff, Ski Racing Suppliers (SRS) and International Ski Federation (FIS) representatives) from the World Cup (WC), European Cup (EC) and FIS-race level participated in a cross-sectional online survey. Experts were asked to name those risk factors with the highest believed impact on injury risk and rank them according to their current priority from a predefined list. In addition, experts were encouraged to name additional (not listed) risk factors and to suggest countermeasures.

Results Regardless of stakeholder role and competition level, snow-related factors appeared to have the highest perceived priority. However, WC athletes' and coaches' perceptions were also related to equipment, while at the EC and FIS-race level fatigue and physical fitness-related factors were considered important. Athletes' perceptions were largely in agreement with SRS (ie, snow-related and equipment-related factors). At the same time, while coaches, team medical staff and FIS representatives additionally emphasised fatigue and physical fitness-related factors.

Conclusion Experts' perceptions on key injury risk factors in alpine ski racing depend on the stakeholder role and differ between the competition levels. Thus, to develop effective prevention measures and to successfully implement them, all relevant stakeholders should be given a voice, and prevention efforts should be targeted to the specific level.

INTRODUCTION

Despite a decade of extensive research and prevention efforts, the risk of injuries in elite alpine ski racing is still high.^{1–3} According to a recent study, the risk of suffering at least one injury during an entire season is as high as 95%, which corresponds to an absolute injury rate of 184.1 injuries per 100 athletes per season.² This is particularly striking

Key messages

What is already known?

- Severe injuries in World Cup (WC) alpine ski racing are frequent and can have various causes.
- Knowing and understanding the perceptions of expert stakeholders is crucial for deriving and implementing successful prevention measures, and giving them a voice may help achieve better countermeasures during the implementation stages.
- At the WC level, the five main risk factor categories perceived by the experts are: the system ski, binding, plate and boot; changing snow conditions; physical aspects of the athletes; speed and course setting aspects and speed in general. However, the last expert survey was conducted 10 years ago and knowledge about the perceptions of experts competing/working at lower levels than WC is lacking entirely.

What are the new findings?

- Experts' perceptions on key injury risk factors in alpine ski racing depend on the stakeholder role and differ between the competition levels (WC, European Cup (EC), International Ski Federation (FIS)-race), which underlines that all relevant stakeholders should be given a voice for successful prevention efforts, and prevention should be targeted at the specific competition level.
- Regardless of stakeholder role and competition level snow-related factors seem to have the highest priority among all risk factors explored. In addition to snow-related factors, WC athletes' and coaches' perceptions related to equipment, while at the EC and FIS-race level fatigue and physical fitness-related factors were considered important.
- Athletes, Ski Racing Suppliers (SRS) representatives and FIS representatives additionally emphasised equipment-related factors. In contrast, coaches, team medical staff and FIS representatives additionally perceived fatigue and physical fitness-related factors as key drivers for injuries.
- The comprehensive list of perceived risk factors and suggested countermeasures provided as online supplemental file 2 may equally serve both researchers and practitioners as source of inspiration for their prevention efforts.

since approximately one-third of all injuries are severe (>28 days of absence in training and competition).² Thus, injuries, especially severe ones, are obvious in alpine ski racing and preventative action is required.

Consequently, the International Ski Federation (FIS) has recently launched a long-term project: the 'FIS Injury Surveillance and Prevention Programme' (ISPP) to prevent and reduce the number of injuries.⁴ Under FIS ISPP, a group of experts, the 'Alpine Injury Prevention Working Group' works to identify the most important injury hot-spots through methodical injury surveillance and evaluation to propose effective solutions and projects for implementation. As a foundation for prioritising the work agenda and to give voice to all relevant stakeholders, the current study was designed to hear and understand alpine ski racing stakeholders' perceptions on key injury risk factors and potential countermeasures.

A similar process was already initiated by FIS 10 years ago with a qualitative interview study involving expert stakeholders from the World Cup (WC) alpine ski racing community, which explored perceived risk factor categories and ranked them according to their impact on injury risk.⁵ In total, 32 risk factor categories within the basic categories athlete, course, equipment and snow were derived from this qualitative study approach. They were subsequently ranked regarding their perceived impact on injury risk.⁵ However, our knowledge of effective injury prevention has increased significantly in certain areas over the past decade (eg, course setting).^{6–11} In other areas, there have been further developments and adaptations to new competition rules (eg, equipment), which may even have recently undermined the rules and led to changes in specific risk factors and injury patterns.^{1 12} Accordingly, it is likely that experts' perceptions have also altered or even that new perceived risk factor categories may have emerged. Thus, there is a renewed need for an updated assessment of corresponding expert perceptions.

In this context, an important yet absent perspective are stakeholder role and competition level-dependent differences in experts' perceptions on risk factor categories, especially for younger athletes competing on the European Cup (EC) or FIS-race levels. To date, most research in alpine ski racing focused on the protection of WC athletes¹³; however, severe injuries are relatively frequent among younger athletes as well.^{14–16} Accordingly, knowing and understanding the perceptions of expert stakeholders competing/working on levels lower than WC is crucial for deriving and implementing successful, specifically tailored prevention measures. Moreover, giving all relevant stakeholders a voice may help achieve better countermeasures during the implementation stages.¹⁷

Based on these considerations, the aims of the current study were: (1) to update experts' priorities of perceived key injury risk factor categories in alpine ski racing based on a framework derived 10 years ago; (2) to assess potential priority differences among expert subgroups in dependency of their stakeholder roles the level of

Table 1 Participants' roles in alpine ski racing

Expert stakeholder group	Level/professional background
<i>Athletes</i> (n=298, male ASR: n=154; female ASR: n=144)	WC level athlete (n=115) EC level athlete (n=75) FIS-race level athlete (n=108)
<i>Coaches</i> (n=130, male ASR: n=84; female ASR: n=46)	WC level coach (n=62) EC level coach (n=31) FIS-race level coach (n=37)
<i>TMS</i> (n=59)	Doctor (n=21) Physiotherapist (n=36) Other (n=2)
<i>SRS representatives</i> (n=33)	Service men (n=9) R&D and management (n=18) Other (=6)
<i>FIS representatives</i> (n=12)	FIS staff for alpine competitions (n=3) Committee member (n=5) Other (n=4)

ASR, Alpine Ski Racing; EC, European Cup; FIS, International Ski Federation; FIS-race, FIS race; R&D, Research and Development; SRS, Ski Racing Supplier; TMS, team medical staff; WC, World Cup.

competition at which they operate; (3) to identify additional emerging risk factors and (4) to compile a list with countermeasure suggestions for all risk factors reported.

METHODS

Study design, setting and participants

During the off-snow season preparation period, in June 2020, an online questionnaire was sent to Alpine Sports Directors of all National Ski Associations (NSAs), FIS (ie, the FIS technical expert alpine; Atle Skaardal) and Ski Racing Suppliers (SRS) representatives (ie, the Ski Racing Supplier Association General Manager; Rudi Huber) and subsequently spread by them among the WC, EC and FIS-race level alpine ski racing communities. A reminder was sent after 4 weeks and the questionnaire closed 2 months later. Participation in this cross-sectional survey was voluntary. Inclusion criteria were: alpine ski racing athletes and coaches related to a specific FIS competition level (WC, EC, FIS-race), team medical staff, SRS representatives and FIS representatives. A total of 542 questionnaires was returned. Questionnaires were excluded if the baseline entries concerning stakeholder group and the specific level (relevant for athletes and coaches only) were not fully completed (n=10). The final analysis included 532 questionnaires completed by experts from 28 countries (table 1). Experts' perceptions were assessed and stored in encrypted form, and no health-related data were collected.

Data collection methodology

Data were collected and managed using the *REDCap* electronic data capture tool.^{18 19} The questions of the online

Table 2 Framework of perceived risk factor categories within the basic categories athlete, course, equipment and snow (in alphabetic order respectively), as derived from qualitative expert stakeholder interviews 10 years ago by Spörri *et al*⁵

Athlete	Course
Aspects of body temperature	Bad visibility
Athlete's adaptability	Course maintenance during race
Athlete's crash behaviour	Course setting in general
Athlete's individual responsibility	Jumps
Athlete's race preparation	Level of course difficulty
Fatigue	Safety net position and spill zone
Genetics and Anthropometry	Speed and course setting aspects
Physical aspects	Speed and topographic aspects
Psychological aspects	Speed in general
Preinjury aspects	Topography in general
Skiing technique and tactics	
Equipment	Snow
Binding/plate	Aggressive snow conditions
Gates (panels and poles)	Changing snow conditions
Protectors and helmets	Smooth snow surface
Racing suits	Techniques of snow preparation
Ski	
Ski boot	
System ski, plate, binding, boot	

survey were posed in English, and the questionnaire was divided into five sections: (1) introduction including information on the study background and purpose; (2) completion of the personal information on the year of birth, nation, gender-focus, competition level for athletes and coaches (WC, EC, FIS-race) and stakeholder role (athlete, coach, team medical staff, SRS representative or FIS representative), and professional background for team medical staff, SRS and FIS representatives; (3) rating of the personal top 1–5 injury risk factor categories according to their perceived impact on injury risk based on the framework and predefined list with the 32 risk factor categories derived from the 2010 qualitative interview study (table 2)⁵; (4) the naming of additional risk factors (ARF) originally not reflected within one of the 32 risk factor categories (maximum of five, no minimum) and (5) the collection of countermeasures for the risk factor categories in part 3 and risk factors in part 4 of the questionnaire. The detailed questionnaire is provided as an online supplemental file 1.

Data analysis

Risk factor rating

The participants named between 1 and 5 perceived risk factor categories regarding their potential impact on injury risk. Overall, an average of 4.92 categories per participant was mentioned. 96.6% of the participants named five risk factors, 0.8% four risk factors, 1.5% three risk factors, 0.9% two risk factors and 0.2% one risk

factor. In the analysis, and in accordance with Spörri *et al*⁵ a rank number was given to every top 1–5 risk factor categories mentioned, with ranking number '1' given to the risk factor category with the highest impact. The average ranking number was then calculated for each risk factor category, depending on the stakeholders' priority assigned. A lower average ranking number can be interpreted as a higher potential impact on the category. The frequency of how often the risk factor was mentioned in the expert stakeholders' personal top five was reported along with this average ranking number. Then, a rank order for the frequency of mention and rank order of the assigned average ranking number was created. Finally, based on these two rank orders, an overall ranking list of risk factor categories was defined. Such risk factor rating (RFR) analysis was conducted (1) for the overall group of participants, as well as (2) for the five stakeholder subgroups and (3) for the different competition levels (only athletes and coaches considered). In the case of fewer than six mentions in the overall RFR, the risk factor category was not presented in the ranking, assuming it is not representative.

Additional risk factors

In a second part of the online survey, expert stakeholders were asked to identify all risk factors that they perceived as relevant but did not fit into one of the 32 risk factor categories derived from the 2010 qualitative interview study by Spörri *et al*.⁵ As the priority rating of such ARF was, due to methodological considerations, not mergeable with those of the given 32 risk factor suggestions (rated by all vs only rated by some expert stakeholders), participants were asked to classify their potential impact on injury risk with an independent priority ranking scale as (1) *minor*, (2) *moderate* or (3) *high importance*.

Suggested countermeasures

In the final part of the survey, experts were allowed to suggest prevention measures for all risk factors mentioned in the RFR or ARF parts. If several suggestions had the same intention they were fused to one corresponding countermeasure category.

Participant and public involvement

Participants were recruited by the involvement of corresponding sports bodies (NSAs, SRS and the FIS). Overall findings were disseminated to all relevant expert stakeholder groups, FIS committees and working groups through internal research reports.

RESULTS

Risk factor rating

The stakeholders' overall perspective on key injury risk factor category priorities is presented in table 3. In total, the top five risk factor categories were 'changing snow conditions', 'system, ski, plate, binding, boot', 'fatigue', 'course maintenance during the race', as well as 'physical



Table 3 Risk factor rating (RFR): that is, stakeholders' priorities of perceived key injury risk factor categories regarding their potential impact on injury risk, for the overall group

Perceived priority	Key injury risk factor category	Mentions in RFR	Rank	Mean rank RFR	Rank	ΣRank points
1	Changing snow conditions	322	1	2.53	1	2
2	System ski, plate, binding, boot	193	4	2.80	3	7
3	Fatigue	225	2	2.85	6	8
4	Course maintenance during race	128	7	2.79	2	9
5	Physical aspects	176	5	2.92	10	15
5	Aggressive snow conditions	127	8	2.87	7	15
5	Bad visibility	194	3	2.99	12	15
8	Smooth snow surface	82	12	2.80	4	16
9	Techniques of snow preparation	129	6	3.08	15	21
10	Athlete's race preparation	64	15	2.88	8	23
10	Athletes' crash behaviour	67	14	2.90	9	23
12	Speed and course setting aspects	83	11	3.08	16	27
13	Skiing technique and tactics	123	9	3.13	19	28
14	Course setting in general	70	13	3.09	17	30
14	Athletes' individual responsibility	48	19	2.94	11	30
16	Psychological aspects	85	10	3.24	21	31
16	Protectors and helmets	24	26	2.83	5	31
18	Binding/plate	29	24	3.03	14	38
19	Ski	35	23	3.09	17	40
19	Athletes' adaptability	60	17	3.27	23	40
21	Preinjury aspects	61	16	3.36	25	41
22	Racing suits	13	30	3.00	13	43
22	Speed and topographic aspects	42	21	3.26	22	43
24	Jumps	53	18	3.74	30	48
24	Level of course difficulty	45	20	3.60	28	48
26	Genetics and anthropometry	37	22	3.49	27	49
27	Speed in general	29	24	3.48	26	50
28	Gates (panels and poles)	20	28	3.30	24	52
29	Safety net position and spill zone	22	27	3.95	31	58
30	Topography in general	7	31	3.71	29	60
31	Aspects of body temperature	19	29	4.05	32	61
	Ski boot	≤6		3.17		

aspects' of the athletes, 'aggressive snow conditions' and 'bad visibility' equally on the fifth place.

Table 4 highlights the expert stakeholders' category priorities in dependency of the competition level. Expert stakeholders' risk factor perceptions from all three competition levels (WC, EC and FIS-race) concerned 'changing snow conditions' to be highly important. Additionally, WC athletes and coaches prioritised equipment-related risk factors, while the focus of EC and FIS-race athletes and coaches was more on 'fatigue' and 'physical aspects'.

Table 5 summarises the perceived category priorities of the expert stakeholders in dependency of their stakeholder role within the alpine ski racing community

based on the sum of rank points. All stakeholder groups expressed a perceived priority for snow-related factors. Athletes, SRS representatives and FIS representatives additionally emphasised equipment-related factors. In contrast, coaches, team medical staff and FIS representatives also perceived fatigue and physical fitness-related factors as key drivers for injuries. FIS representatives only prioritised speed and course-setting related aspects.

Additional risk factors

Sixty-five suggestions were given and these suggestions were summarised into nine ARF, which were not part of the original list derived from the 2010 qualitative

Table 4 Risk factor rating (RFR), that is, stakeholders' top three priorities of perceived key injury risk factor categories regarding their potential impact on injury risk per level in dependency of the competition level

Perceived priority	Key injury risk factor category	Mentions in RFR	Rank	Mean rank RFR	Rank	ΣRank points
WC level						
1	Changing snow conditions	122	1	2.30	2	3
2	System ski, plate, binding, boot	71	2	2.71	5	7
3	Aggressive snow conditions	51	6	2.66	4	10
EC level						
1	Fatigue	59	1	2.43	1	2
2	Changing snow conditions	59	1	2.51	2	3
3	Physical aspects	35	5	2.76	6	11
3	Bad visibility	44	3	2.88	8	11
FIS-race level						
1	Changing snow conditions	83	1	2.58	5	6
2	Physical aspects	51	4	2.53	3	7
3	Course maintenance during race	41	6	2.57	4	10

EC, European Cup; FIS-race, International Ski Federation (FIS) race; WC, World Cup.

interview study by Spörri *et al.*⁵ These were: 'environmental influences'; 'forced jury decisions'; 'lacking athlete-/stakeholder voice'; 'level differences'; 'medication'; 'parallel events'; 'race organisation'; 'warm-up slopes' and 'ski edge tuning'. 'Ski edge tuning' for the injury risk factor category 'ski' was suggested with the justification that skis are prepared by factories in the WC competition, in contrast to the EC and FIS-race level competitions where athletes are using edge machines to sharpen the skis leading to a too aggressive setup. Notably, 'forced jury decisions' were suggested to substantiate that races should be cancelled when certain weather conditions are met and that athletes should be FIS priority, in contrast to, for example, television broadcast.

Suggested countermeasures

The suggested countermeasures for all risk factors mentioned in the RFR or ARF parts are presented in an online supplemental file 1. The top five risk factor categories that received the most prevention suggestions were 'fatigue'; 'changing snow conditions'; 'physical aspects'; 'ski, plate, binding, boot' and 'bad visibility'. For 'fatigue' most countermeasure suggestions included recommendations for adjusting the organisation and competition schedule. Experts stated that the race schedule is too busy and does not allow for enough rest. Especially allrounders, who participate in more than one discipline, have an overscheduled competition calendar. It was suggested to avoid 'changing snow conditions' by providing the same snow conditions throughout the course (ie, using the same snow preparation techniques, such as water injection, from top to bottom) to help athletes to find an appropriate equipment setup. To avoid injuries resulting from the risk factor category 'physical aspects', injury screenings and a certain minimum physical condition

have been suggested, especially for younger athletes. For the risk factor category 'ski, plate, binding, boot', a large group of stakeholders suggested a less aggressive setup. Finally, regarding the risk factor category 'bad visibility', stakeholders stated that the races should be cancelled if the visibility is too bad, and blue dye should be used more often.

DISCUSSION

Expert stakeholders' perceptions on injury risk factor categories differ between the WC, EC and FIS-race level

Regardless of competition level affiliation, snow-related factors were perceived to have the highest priority among all risk factors explored. In addition to snow-related factors, WC athletes' and coaches' perceptions related to equipment, while at the EC and FIS-race level fatigue and physical fitness-related factors were considered important. To date, there is no research on competition level-dependent stakeholder perception on injury risk factors in alpine ski racing. Nevertheless, snow-related factors are a recurring theme throughout the skiing community, given that alpine ski racing has to deal with a changing and uncontrollable outdoor environment.⁵ Moreover, at the top level, that is, WC alpine ski racing, it is entirely plausible that equipment and its setup play a key role in performance enhancement and sportive success, which is why corresponding limits are constantly being explored. This also applies to finding the optimal aggressiveness in the ski-snow interaction, characterised by direct force transmission (beneficial for performance) and difficulty getting the ski off its edge once the ski is carving (injury-promoting).²⁰ In contrast, it is understandable that on lower levels, for example, FIS-race level, physical aspects are perceived by expert

**Table 5** Risk factor rating (RFR), that is, stakeholders' priorities of perceived key injury risk factor categories regarding their potential impact on injury risk in dependency of their role within the alpine ski racing community

Perceived priority	Key injury risk factor category	Mentions in RFR	Rank	Mean rank RFR	Rank	ΣRank points
Athletes						
1	Changing snow conditions	181	1	2.60	2	3
2	Course maintenance during race	82	6	2.56	1	7
3	System ski, plate, binding, boot	97	4	2.69	4	8
3	Bad visibility	134	2	2.81	6	8
Coaches						
1	Changing snow conditions	83	1	2.29	2	3
2	Fatigue	57	2	2.77	7	9
3	Aggressive snow conditions	39	6	2.69	5	11
TMS						
1	Fatigue	30	1	2.67	7	8
2	Physical aspects	24	3	2.54	6	9
3	Changing snow conditions	28	2	2.79	10	12
SRS representatives						
1	Changing snow conditions	22	1	2.18	5	6
2	System ski, plate, binding, boot	17	2	2.88	12	14
2	Techniques of snow preparation	15	3	2.80	11	14
FIS representatives						
1	Athletes' individual responsibility	4	3	1.50	4	7
2	System ski, plate, binding, boot	3	5	1.33	3	8
3	Athlete's race preparation	3	5	2.67	9	14
3	Fatigue	3	5	2.67	9	14
3	Speed and course setting aspects	4	3	3.00	11	14
3	Smooth snow surface	2	10	1.50	4	14

FIS, International Ski Federation; SRS, Ski Racing Supplier; TMS, team medical staff.

stakeholders as of higher importance for the causation of injury, compared with the WC level. As WC athletes are professionals, they train more targeted than EC and FIS-race athletes, making it likely that deficits in physical aspects play a greater role for EC and FIS-race athletes. In addition, EC and FIS racers often compete within race series of different levels and therefore complete a higher number of events than WC athletes, who mainly compete in the highest level events. This may have a significant impact on overall fatigue.

Expert stakeholders' perceptions on injury risk factor categories depend on their roles

Comparable to the level-specific ranking, all stakeholder groups prioritised snow-related factors. Athletes, SRS representatives and FIS representatives additionally emphasised equipment-related factors. Contrastingly, coaches, team medical staff and FIS representatives additionally perceived fatigue and physical fitness-related factors as key drivers for injuries. This may reflect the interests, different backgrounds and areas of expertise among different stakeholder groups. It is important to

be aware that when interviewing expert perceptions, but ultimately also when implementing injury prevention measures, the understandings and attitudes of individual stakeholders may vary and that knowledge of such contextual factors is crucial to effective prevention.²¹ Therefore, it is essential to involve all relevant stakeholders to develop a comprehensive and total picture of health protection for athletes.

Potential change of perception over the last decade

Compared with our previous study with qualitative interviews collected in 2010,⁵ it appears that expert stakeholders' perceptions on key injury risk factor categories have changed over the past decade. A direct comparison, however, was not possible due to the different data collection methods and a more diversified target group (including the EC and FIS-race levels). While 'changing snow conditions', 'system ski, plate, binding, boot' and 'physical aspects' seem to have an unchanged high perceived priority, it looks like the risk factors 'fatigue' and 'course maintenance during the race' have increased in perceived priority. In contrast, it seems that 'course

setting' and 'speed' have lost attention within the alpine ski racing community. In addition, ARF have emerged, such as 'environmental influences'; 'forced jury decisions'; 'lacking athlete-/stakeholder voice'; 'level differences'; 'medication'; 'parallel events'; 'race organisation'; 'warm-up slopes' and 'ski edge tuning'.

Prevention measure suggestions

A scientifically and practically very useful outcome of the current study is the systematic compilation of potential prevention measures suggested by the expert stakeholders. In this regard, the risk factor categories 'fatigue'; 'changing snow conditions'; 'physical aspects'; 'ski, plate, binding, boot' and 'bad visibility' received the most attention in terms of countermeasure suggestions. For 'fatigue' most countermeasure suggestions pointed in the direction of race schedule and organisation adaptations. It is plausible that injuries are more likely to happen when athletes are fatigued (either within race,²² or over the season⁵). 'Changing snow conditions' were considered avoidable by providing the same snow conditions from top to bottom. This is fully in line with our previous investigation from 2010.⁵ Especially when conditions change during a run, snow conditions challenge the athletes and SRS representatives to choose and adapt their equipment setup and technique. Regarding 'physical aspects', injury screenings and certain minimum criteria for physical fitness have been suggested. Physical aspects are indeed known to be a key driver for injury risk in alpine ski racing.^{23–29} Moreover, also in many sports other than alpine ski racing, the benefits of physical fitness-related injury prevention programmes have been demonstrated.^{30–32} Concerning the 'ski, plate, binding, boot' category, several stakeholders suggested a less aggressive setup as one of the most promising approaches. Thus, in alpine ski racing, this remains one of the greatest prevention challenges to be addressed.^{5,33} Regarding 'bad visibility', particularly measures related to appropriate jury decisions and race cancellations despite external pressures have been suggested. Poor visibility is a known relevant key component of events leading to ACL injuries in alpine ski racing.³⁴ The proposed measures certainly seem plausible, although difficult to optimise given the high level of professionalism in the sport at the WC level.

Study limitations

There are some limitations one should be aware of when interpreting the study findings. First, the methodological approach taken does not allow or claim to verify whether the perceived injury risk factors are 'true' risk factors. For this purpose, further aetiological studies are needed to confirm their status as being injury risk factors. Second, to obtain as integrated a picture as possible, experts from different stakeholder groups were involved in this study; however, sample sizes of the different expert stakeholder groups are not equally distributed. Accordingly, major emphasis has been laid on the analysis and interpretations

of the subgroup-specific (ie, level-dependent and role-dependent) results, which can be considered being highly representative for the corresponding stakeholder subgroups. At the same time, the overall rankings must be interpreted with caution. Third, as the alpine ski racing community is a close-knit group of stakeholders that travels around the world together, there is some risk that they will answer questions similarly or in a way that they believe will be accepted and liked by their peers (social desirability bias).

CONCLUSION

This study demonstrated that expert stakeholders' perceptions on key injury risk factor categories in alpine ski racing depend on their role and differ between the competition levels (WC, EC, FIS-race). Generally, snow-related factors were prioritised by stakeholders. In addition, WC stakeholders, athletes and SRS representatives highlighted equipment-related injury risk factor categories, while EC and FIS-race level stakeholders, coaches, team medical staff and FIS representatives prioritised fatigue and physical fitness-related injury risk factor categories. Thus, to develop effective prevention measures and to successfully implement them, all relevant stakeholders should be given a voice, and prevention efforts should be targeted to the specific level.

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Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

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Data availability statement All data relevant to the study are included in the article or uploaded as supplemental information. Additional data from the digital database of the "Risk Factor Rating", "Additional Risk Factors" and "Countermeasure Suggestions" parts of this study is presented in the online supplemental file 2.

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REFERENCES

- Alhammad M, Racinais S, Rousseaux-Blanchi M-P, *et al*. Recording injuries only during winter competitive season underestimates injury incidence in elite alpine skiers. *Scand J Med Sci Sports* 2020;30:1177–87.
- Fröhlich S, Helbling M, Fucentese SF, *et al*. Injury risks among elite competitive alpine skiers are underestimated if not registered prospectively, over the entire season and regardless of whether requiring medical attention. *Knee Surg Sports Traumatol Arthrosc* 2021;29:1635–43.
- Barth M, Platzer H-P, Giger A, *et al*. Acute on-snow severe injury events in elite alpine ski racing from 1997 to 2019: the injury surveillance system of the Austrian Ski Federation. *Br J Sports Med* 2020. doi:10.1136/bjsports-2020-102752. [Epub ahead of print: 06 Oct 2020].
- FIS. Book of reports 2020. Available: https://assets.fis-ski.com/image/upload/v1592999292/fis-prod/assets/FIS_BOOK_OF_REPORTS_2020_FINAL.pdf
- Spörri J, Kröll J, Amesberger G, *et al*. Perceived key injury risk factors in world cup alpine ski racing—an explorative qualitative study with expert stakeholders. *Br J Sports Med* 2012;46:1059–64.
- Spörri J, Kröll J, Schwameder H, *et al*. Course setting and selected biomechanical variables related to injury risk in alpine Ski racing: an explorative case study. *Br J Sports Med* 2012;46:1072–7.
- Gilgien M, Spörri J, Kröll J, *et al*. Mechanics of turning and jumping and skier speed are associated with injury risk in men's World Cup alpine skiing: a comparison between the competition disciplines. *Br J Sports Med* 2014;48:742–7.
- Gilgien M, Crivelli P, Spörri J, *et al*. Characterization of course and terrain and their effect on skier speed in world cup alpine ski racing. *PLoS One* 2015;10:e0118119.
- Spörri J, Kröll J, Fasel B, *et al*. Course setting as a prevention measure for overuse injuries of the back in alpine Ski racing: a kinematic and kinetic study of giant slalom and slalom. *Orthop J Sports Med* 2016;4:2325967116630719.
- Gilgien M, Crivelli P, Kröll J, *et al*. Preventing injuries in alpine skiing giant slalom by shortening the vertical distance between the gates rather than increasing the horizontal gate offset to control speed. *Br J Sports Med* 2020;54:1042–6.
- Gilgien M, Crivelli P, Kröll J, *et al*. Injury prevention in Super-G alpine ski racing through course design. *Sci Rep* 2021;11.
- Platzer H-P, Barth M, Giger A, *et al*. Did injury incidence in alpine ski racing change after equipment regulations? An evaluation based on the injury surveillance system of the Austrian Ski Federation. *J Sci Med Sport* 2020;43. doi:10.1016/j.jsams.2020.07.005. [Epub ahead of print: 24 Jul 2020].
- Spörri J, Kröll J, Gilgien M, *et al*. How to prevent injuries in alpine Ski racing: what do we know and where do we go from here? *Sports Med* 2017;47:599–614.
- Westin M, Alricsson M, Werner S. Injury profile of competitive alpine skiers: a five-year cohort study. *Knee Surg Sports Traumatol Arthrosc* 2012;20:1175–81.
- Schoeb T, Peterhans L, Fröhlich S, *et al*. Health problems in youth competitive alpine skiing: a 12-month observation of 155 athletes around the growth spurt. *Scand J Med Sci Sports* 2020;30:1758–68.
- Mueller L, Hildebrandt C, Mueller E, *et al*. Injuries and illnesses in a cohort of elite youth alpine ski racers and the influence of biological maturity and relative age: a two-season prospective study. *Open Access J Sports Med* 2017;8:113–22.
- Donaldson A, Lloyd DG, Gabbe BJ, *et al*. We have the programme, what next? Planning the implementation of an injury prevention programme. *Inj Prev* 2017;23:273–80.
- Harris PA, Taylor R, Thielke R, *et al*. Research electronic data capture (REDCap)—A metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009;42:377–81.
- Harris PA, Taylor R, Minor BL, *et al*. The REDCap consortium: building an international community of software platform partners. *J Biomed Inform* 2019;95:103208.
- Kröll J, Spörri J, Gilgien M, *et al*. Effect of ski geometry on aggressive ski behaviour and visual aesthetics: equipment designed to reduce risk of severe traumatic knee injuries in alpine giant slalom ski racing. *Br J Sports Med* 2016;50:20–5.
- Bekker S, Bolling C, H Ahmed O, *et al*. Athlete health protection: why qualitative research matters. *Journal of Science and Medicine in Sport* 2020;23:898–901.
- Bere T, Flørenes TW, Krosshaug T, *et al*. A systematic video analysis of 69 injury cases in world cup alpine skiing. *Scand J Med Sci Sports* 2014;24:667–77.
- Raschner C, Platzer H-P, Patterson C, *et al*. The relationship between ACL injuries and physical fitness in young competitive Ski racers: a 10-year longitudinal study. *Br J Sports Med* 2012;46:1065–71.
- Müller L, Hildebrandt C, Müller E, *et al*. Long-term athletic development in youth alpine Ski racing: the effect of physical fitness, Ski racing technique, Anthropometrics and biological maturity status on injuries. *Front Physiol* 2017;8:656.
- Steidl-Müller L, Hildebrandt C, Müller E, *et al*. Relationship of changes in physical fitness and anthropometric characteristics over one season, biological maturity status and injury risk in elite youth Ski Racers: a prospective study. *Int J Environ Res Public Health* 2020;17:364.
- Westin M, Harringe ML, Engström B, *et al*. Prevention of anterior cruciate ligament injuries in competitive adolescent alpine skiers. *Front Sports Act Living* 2020;2:11.
- Franchi MV, Ellenberger L, Javet M, *et al*. Maximal eccentric Hamstrings strength in competitive alpine skiers: cross-sectional observations from youth to elite level. *Front Physiol* 2019;10:88.
- Ellenberger L, Oberle F, Lorenzetti S, *et al*. Dynamic knee valgus in competitive alpine skiers: observation from youth to elite and influence of biological maturation. *Scand J Med Sci Sports* 2020;30:1212–20.
- Ellenberger L, Jermann J, Fröhlich S, *et al*. Biomechanical quantification of deadbug bridging performance in competitive alpine skiers: reliability, reference values, and associations with skiing performance and back overuse complaints. *Phys Ther Sport* 2020;45:56–62.
- Huang YL, Jung J, Mulligan CMS. A majority of anterior cruciate ligament injuries can be prevented by injury prevention programs: a systematic review of randomized controlled trials and cluster-randomized controlled trials with meta-analysis. *Am J Sports Med* 2019;363546519870175.
- Petushkek EJ, Sugimoto D, Stoolmiller M. Evidence-based best-practice guidelines for preventing anterior cruciate ligament injuries in young female athletes: a systematic review and meta-analysis. *Am J Sports Med* 2018;363546518782460.
- Webster KE, Hewett TE. Meta-analysis of meta-analyses of anterior cruciate ligament injury reduction training programs. *J Orthop Res* 2018;36:2696–708.
- Müller E, Spörri J, Kröll J, *et al*. Equipment designed to reduce risk of severe traumatic injuries in alpine ski racing: constructive collaboration between the International Ski Federation, industry and science. *Br J Sports Med* 2016;50:1.2–2.
- Bere T, Flørenes TW, Krosshaug T, *et al*. Events leading to anterior cruciate ligament injury in world cup alpine skiing: a systematic video analysis of 20 cases. *Br J Sports Med* 2011;45:1294–302.

FIS - Injury Surveillance & Prevention Program (ISPP) Questionnaire on Key Injury Risk Factors and Countermeasures

Introduction

Injuries have become a critical problem for alpine ski racing. The FIS Council has therefore newly established a long-term project working group on "alpine injury prevention", organized by the FIS Injury Surveillance & Prevention Program (ISPP). The working group participants consist of alpine experts from different nations and areas of expertise. The working group and ISPP will report on its work directly to the FIS professionals, and relevant FIS committees.

As sports practitioners, you have valuable insight into the complicated issues of injury causes and possible prevention strategies. Therefore, as a first step, a questionnaire is being sent to a large number of alpine stakeholders with the purpose to hear and understand your perspective on key risk factors and potential countermeasures. Questionnaire responses will be summarized and used to help guide further directions of the FIS athlete health protection efforts.

Questionnaire Objective

The aim of this online questionnaire is to rank 32 previously reported key injury risk factors, to identify additionally perceived risk factors and to collect and structure prevention ideas with respect to those injury risk factors.

The expert groups being invited to answer the questionnaire include:

- Athletes
- Coaches
- Team Medical Staff
- Ski Racing Suppliers (SRS) / Industry
- FIS Group

The gathered information will serve in two ways:

1. In the short-term, to support next steps concerning directly implementable prevention suggestions and potential decisions in May 2021
2. In the long-term, to help identify and prioritize focus areas for the continuing work of the FIS working group on areas with lacking knowledge

Collected Data Information

The subsequent questionnaire should be thoroughly answered for precise evaluation. Please note that the questionnaire is graphically optimized for filling out by computer, not smartphone. Your anonymised questionnaire answers will only be available to members of the working group and ISPP. Overall reports and summarized suggestions will be presented to FIS professionals, relevant FIS committees, Ski Racing Suppliers (SRS), national ski associations, athletes' representatives and coaches working groups and will be publicly available to all interested alpine stakeholders.

Your voice matters!

On behalf of the FIS ISPP working group, we thank you for your active participation, which is highly appreciated.

1. Personal Information

Which of the following description fits best for you?

- Athlete
 Coach
 Team Medical Staff
 SRS / Industry
 FIS Group

Year of birth

(e.g. 1995)

Nation

(e.g. FRA, ITA, GER ...)

Your Gender

- female
 male

On which level do you compete?

- WC level
 EC level
 FIS level
 Other

Please, specify

Nation

(e.g. FRA, ITA, GER ...)

Of which gender is your team?

- female
 male

On which level are your athletes?

- WC level
 EC level
 FIS level
 Other

Please, specify

Nation

(e.g. AUT, SUI, NOR, ...)

I am a

- Doctor
 Physiotherapist
 Other

Please, specify

My professional background

- Service Men
 R&D and Management
 Other

Please, specify

My professional background

- FIS Staff for alpine competitions
 Committee Member
 Other
-

Please, specify

2. Rating of Risk Factors and Suggesting Potential Prevention Measures

In the following sub-questions Q1-Q5 you are asked to name your top 5 key injury risk factors from the list below and to suggest corresponding countermeasures. If you would like to name additionally perceived risk factors not included in the list, you can do this under point 3 below, after answering Q1-Q5.

Q1

What do you, personally, consider to be the most important perceived injury risk factor?

(Potential key risk factors assigned in alphabetic order within four basic domains athlete, equipment, course and snow.)

ATHLETE

- Aspects of body temperature
 Athlete's adaptability
 Athlete's crash behaviour
 Athlete's individual responsibility
 Athlete's race preparation
 Fatigue
 Genetics and Anthropometry
 Physical aspects
 Psychological aspects
 Pre-injury aspects
 Skiing technique and tactics

EQUIPMENT

- Binding / plate
 Gates (panels and poles)
 Protectors and helmets
 Racing suits
 Ski
 Ski boot
 System ski, plate, binding, boot

COURSE

- Bad visibility
 Course maintenance during race
 Course setting in general
 Jumps
 Level of course difficulty
 Safety net position and spill zone
 Speed and course setting aspects
 Speed and topographic aspects
 Speed in general
 Topography in general

SNOW

- Aggressive snow conditions
 Changing snow conditions
 Smooth snow surface
 Techniques of snow preparation

Do you have a personal suggestion for a concrete prevention measure on this risk factor?

- no
 yes
-

If yes, please specify here:

Q2

What do you, personally, consider to be the second most important perceived injury risk factor?

(Potential key risk factors assigned in alphabetic order within four basic domains athlete, equipment, course and snow.)

- ATHLETE**
- Aspects of body temperature
- Athlete's adaptability
- Athlete's crash behaviour
- Athlete's individual responsibility
- Athlete's race preparation
- Fatigue
- Genetics and Anthropometry
- Physical aspects
- Psychological aspects
- Pre-injury aspects
- Skiing technique and tactics
- EQUIPMENT**
- Binding / plate
- Gates (panels and poles)
- Protectors and helmets
- Racing suits
- Ski
- Ski boot
- System ski, plate, binding, boot
- COURSE**
- Bad visibility
- Course maintenance during race
- Course setting in general
- Jumps
- Level of course difficulty
- Safety net position and spill zone
- Speed and course setting aspects
- Speed and topographic aspects
- Speed in general
- Topography in general
- SNOW**
- Aggressive snow conditions
- Changing snow conditions
- Smooth snow surface
- Techniques of snow preparation

Do you have a personal suggestion for a concrete prevention measure on this risk factor?

- no
- yes

If yes, please specify here:

Q3

What do you, personally, consider to be the third most important perceived injury risk factor?

(Potential key risk factors assigned in alphabetic order within four basic domains athlete, equipment, course and snow.)

- ATHLETE**
- Aspects of body temperature
- Athlete's adaptability
- Athlete's crash behaviour
- Athlete's individual responsibility
- Athlete's race preparation
- Fatigue
- Genetics and Anthropometry
- Physical aspects
- Psychological aspects
- Pre-injury aspects
- Skiing technique and tactics
- EQUIPMENT**
- Binding / plate
- Gates (panels and poles)
- Protectors and helmets
- Racing suits
- Ski
- Ski boot
- System ski, plate, binding, boot
- COURSE**
- Bad visibility
- Course maintenance during race
- Course setting in general
- Jumps
- Level of course difficulty
- Safety net position and spill zone
- Speed and course setting aspects
- Speed and topographic aspects
- Speed in general
- Topography in general
- SNOW**
- Aggressive snow conditions
- Changing snow conditions
- Smooth snow surface
- Techniques of snow preparation

Do you have a personal suggestion for a concrete prevention measure on this risk factor?

- no
- yes

If yes, please specify here:

Q4

What do you, personally, consider to be the fourth most important perceived injury risk factor?

(Potential key risk factors assigned in alphabetic order within four basic domains athlete, equipment, course and snow.)

- ATHLETE**
- Aspects of body temperature
- Athlete's adaptability
- Athlete's crash behaviour
- Athlete's individual responsibility
- Athlete's race preparation
- Fatigue
- Genetics and Anthropometry
- Physical aspects
- Psychological aspects
- Pre-injury aspects
- Skiing technique and tactics
- EQUIPMENT**
- Binding / plate
- Gates (panels and poles)
- Protectors and helmets
- Racing suits
- Ski
- Ski boot
- System ski, plate, binding, boot
- COURSE**
- Bad visibility
- Course maintenance during race
- Course setting in general
- Jumps
- Level of course difficulty
- Safety net position and spill zone
- Speed and course setting aspects
- Speed and topographic aspects
- Speed in general
- Topography in general
- SNOW**
- Aggressive snow conditions
- Changing snow conditions
- Smooth snow surface
- Techniques of snow preparation

Do you have a personal suggestion for a concrete prevention measure on this risk factor?

- no
- yes

If yes, please specify here:

Q5

What do you, personally, consider to be the fifth most important perceived injury risk factor?

(Potential key risk factors assigned in alphabetic order within four basic domains athlete, equipment, course and snow.)

- ATHLETE**
- Aspects of body temperature
- Athlete's adaptability
- Athlete's crash behaviour
- Athlete's individual responsibility
- Athlete's race preparation
- Fatigue
- Genetics and Anthropometry
- Physical aspects
- Psychological aspects
- Pre-injury aspects
- Skiing technique and tactics
- EQUIPMENT**
- Binding / plate
- Gates (panels and poles)
- Protectors and helmets
- Racing suits
- Ski
- Ski boot
- System ski, plate, binding, boot
- COURSE**
- Bad visibility
- Course maintenance during race
- Course setting in general
- Jumps
- Level of course difficulty
- Safety net position and spill zone
- Speed and course setting aspects
- Speed and topographic aspects
- Speed in general
- Topography in general
- SNOW**
- Aggressive snow conditions
- Changing snow conditions
- Smooth snow surface
- Techniques of snow preparation

Do you have a personal suggestion for a concrete prevention measure on this risk factor?

- no
- yes

If yes, please specify here:

3. Additional Key Injury Risk Factors

Do you perceive additional key injury risk factors not included in the aforementioned list?

- no
- yes

How many additional factors?

- 1
- 2
- 3
- 4
- 5

Additional risk factor 1; please specify here:

In your opinion, how important is this factor regarding its potential impact on injury risk? Please select:

- Minor importance
 Moderate importance
 High importance

Do you have a personal suggestion for a concrete prevention measure on this risk factor?

- no
 yes

If yes, please specify here:

Additional risk factor 2; please specify here:

In your opinion, how important is this factor regarding its potential impact on injury risk? Please select:

- Minor importance
 Moderate importance
 High importance

Do you have a personal suggestion for a concrete prevention measure on this risk factor?

- no
 yes

If yes, please specify here:

Additional risk factor 3; please specify here:

In your opinion, how important is this factor regarding its potential impact on injury risk? Please select:

- Minor importance
 Moderate importance
 High importance

Do you have a personal suggestion for a concrete prevention measure on this risk factor?

- no
 yes

If yes, please specify here:

Additional risk factor 4; please specify here:

In your opinion, how important is this factor regarding its potential impact on injury risk? Please select:

- Minor importance
 Moderate importance
 High importance

Do you have a personal suggestion for a concrete prevention measure on this risk factor?

- no
 yes

If yes, please specify here:

Additional risk factor 5; please specify here:

In your opinion, how important is this factor regarding its potential impact on injury risk? Please select:

- Minor importance
 Moderate importance
 High importance

Do you have a personal suggestion for a concrete prevention measure on this risk factor?

- no
 yes

If yes, please specify here:

4. Additional Personal Comments

Do you want to add additional comments directed to the members of FIS ISPP steering committee and/or the FIS working group "alpine injury prevention"?

- no
 yes

If yes, please specify here:

5. Finalize and Submit