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

Kirsten Kiers, Josef Kröll, Gerald Mitterbauer, Johannes Scherr, Jörg Spörri

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 skiing 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...
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 undermined the rules and led to changes in specific risk factors and injury patterns.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 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>
<thead>
<tr>
<th>Expert stakeholder group</th>
<th>Level/professional background</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athletes (n=298, male ASR: n=154; female ASR: n=144)</td>
<td>WC level athlete (n=115) EC level athlete (n=75) FIS-race level athlete (n=108)</td>
</tr>
<tr>
<td>Coaches (n=130, male ASR: n=84; female ASR: n=46)</td>
<td>WC level coach (n=62) EC level coach (n=31) FIS-race level coach (n=37)</td>
</tr>
<tr>
<td>TMS (n=59)</td>
<td>Doctor (n=21) Physiotherapist (n=36) Other (n=2)</td>
</tr>
<tr>
<td>SRS representatives (n=33)</td>
<td>Service men (n=9) R&amp;D and management (n=18) Other (n=6)</td>
</tr>
<tr>
<td>FIS representatives (n=12)</td>
<td>FIS staff for alpine competitions (n=3) Committee member (n=5) Other (n=4)</td>
</tr>
</tbody>
</table>

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.
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 were 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, 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. 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.
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 3

<table>
<thead>
<tr>
<th>Perceived priority</th>
<th>Key injury risk factor category</th>
<th>Mentions in RFR</th>
<th>Rank</th>
<th>Mean rank RFR</th>
<th>Rank</th>
<th>∑Rank points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Changing snow conditions</td>
<td>322</td>
<td>1</td>
<td>2.53</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>System ski, plate, binding, boot</td>
<td>193</td>
<td>4</td>
<td>2.80</td>
<td>3</td>
<td>7</td>
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<tr>
<td>3</td>
<td>Fatigue</td>
<td>225</td>
<td>2</td>
<td>2.85</td>
<td>6</td>
<td>8</td>
</tr>
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<td>4</td>
<td>Course maintenance during race</td>
<td>128</td>
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<td>2.79</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>Physical aspects</td>
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<td>5</td>
<td>2.92</td>
<td>10</td>
<td>15</td>
</tr>
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<td>6</td>
<td>Aggressive snow conditions</td>
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<td>2.87</td>
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<td>15</td>
</tr>
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<td>7</td>
<td>Bad visibility</td>
<td>194</td>
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<td>2.99</td>
<td>12</td>
<td>15</td>
</tr>
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<td>8</td>
<td>Smooth snow surface</td>
<td>82</td>
<td>12</td>
<td>2.80</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>9</td>
<td>Techniques of snow preparation</td>
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<td>6</td>
<td>3.08</td>
<td>15</td>
<td>21</td>
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<td>Athlete’s race preparation</td>
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<td>2.88</td>
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<td>Athletes’ crash behaviour</td>
<td>67</td>
<td>14</td>
<td>2.90</td>
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<td>23</td>
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<tr>
<td>12</td>
<td>Speed and course setting aspects</td>
<td>83</td>
<td>11</td>
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<td>16</td>
<td>27</td>
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<tr>
<td>13</td>
<td>Skiing technique and tactics</td>
<td>123</td>
<td>9</td>
<td>3.13</td>
<td>19</td>
<td>28</td>
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<td>14</td>
<td>Course setting in general</td>
<td>70</td>
<td>13</td>
<td>3.09</td>
<td>17</td>
<td>30</td>
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<tr>
<td>15</td>
<td>Athletes’ individual responsibility</td>
<td>48</td>
<td>19</td>
<td>2.94</td>
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<td>30</td>
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<td>16</td>
<td>Psychological aspects</td>
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<td>3.24</td>
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<td>31</td>
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<tr>
<td>17</td>
<td>Protectors and helmets</td>
<td>24</td>
<td>26</td>
<td>2.83</td>
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<td>18</td>
<td>Binding/plate</td>
<td>29</td>
<td>24</td>
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<td>Athletes’ adaptability</td>
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<td>17</td>
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<tr>
<td>21</td>
<td>Preinjury aspects</td>
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<td>16</td>
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<td>22</td>
<td>Racing suits</td>
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<td>13</td>
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<tr>
<td>23</td>
<td>Speed and topographic aspects</td>
<td>42</td>
<td>21</td>
<td>3.26</td>
<td>22</td>
<td>43</td>
</tr>
<tr>
<td>24</td>
<td>Jumps</td>
<td>53</td>
<td>18</td>
<td>3.74</td>
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<td>48</td>
</tr>
<tr>
<td>25</td>
<td>Level of course difficulty</td>
<td>45</td>
<td>20</td>
<td>3.60</td>
<td>28</td>
<td>48</td>
</tr>
<tr>
<td>26</td>
<td>Genetics and anthropometry</td>
<td>37</td>
<td>22</td>
<td>3.49</td>
<td>27</td>
<td>49</td>
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<tr>
<td>27</td>
<td>Speed in general</td>
<td>29</td>
<td>24</td>
<td>3.48</td>
<td>26</td>
<td>50</td>
</tr>
<tr>
<td>28</td>
<td>Gates (panels and poles)</td>
<td>20</td>
<td>28</td>
<td>3.30</td>
<td>24</td>
<td>52</td>
</tr>
<tr>
<td>29</td>
<td>Safety net position and spill zone</td>
<td>22</td>
<td>27</td>
<td>3.95</td>
<td>31</td>
<td>58</td>
</tr>
<tr>
<td>30</td>
<td>Topography in general</td>
<td>7</td>
<td>31</td>
<td>3.71</td>
<td>29</td>
<td>60</td>
</tr>
<tr>
<td>31</td>
<td>Aspects of body temperature</td>
<td>19</td>
<td>29</td>
<td>4.05</td>
<td>32</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Ski boot</td>
<td>≤6</td>
<td></td>
<td>3.17</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
open access interview study by Spörri et al. These were: ‘environmental influences’; ‘forced jury decisions’; ‘lacking athlete-/stakeholder voice’; ‘level differences’; ‘mediation’; ‘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. 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). In contrast, it is understandable that on lower levels, for example, FIS-race level, physical aspects are perceived by expert stakeholders to be of more importance.
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

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

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. 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, 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, or over the season). ‘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. 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. Moreover, also in many sports other than alpine ski racing, the benefits of physical fitness-related injury prevention programmes have been demonstrated. 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. 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. 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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Contributors JSp and JK conceptualised and designed the study. JSp recruited the participants and collected the data. KK processed the data and performed the statistical analysis. All authors substantially contributed to the interpretation of data. KK and JSp drafted the current manuscript; all authors revised it critically, approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

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Competing interests None declared.

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.

Ethics approval This study was approved by the Cantonal Ethics Committee KEK Zurich (BASEC Nr. Req. 2020-00643), and was judged not to fall under the scope of the Human Research Act (HRA), which is why no written informed consent was required from the participants.

Provenance and peer review Not commissioned; externally peer reviewed.

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


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
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.)

<table>
<thead>
<tr>
<th>ATHLETE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspects of body temperature</td>
<td></td>
</tr>
<tr>
<td>Athlete's adaptability</td>
<td></td>
</tr>
<tr>
<td>Athlete's crash behaviour</td>
<td></td>
</tr>
<tr>
<td>Athlete's individual responsibility</td>
<td></td>
</tr>
<tr>
<td>Athlete's race preparation</td>
<td></td>
</tr>
<tr>
<td>Fatigue</td>
<td></td>
</tr>
<tr>
<td>Genetics and Anthropometry</td>
<td></td>
</tr>
<tr>
<td>Physical aspects</td>
<td></td>
</tr>
<tr>
<td>Psychological aspects</td>
<td></td>
</tr>
<tr>
<td>Pre-injury aspects</td>
<td></td>
</tr>
<tr>
<td>Skiing technique and tactics</td>
<td></td>
</tr>
</tbody>
</table>

| 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  
- [x] 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

**SHE**
- 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:

______________________________

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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:
__________________________________________
<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>In your opinion, how important is this factor regarding its potential</td>
<td>○ Minor importance</td>
</tr>
<tr>
<td>impact on injury risk? Please select:</td>
<td>○ Moderate importance</td>
</tr>
<tr>
<td></td>
<td>○ High importance</td>
</tr>
<tr>
<td>Do you have a personal suggestion for a concrete prevention measure</td>
<td>○ no</td>
</tr>
<tr>
<td>on this risk factor?</td>
<td>○ yes</td>
</tr>
<tr>
<td>If yes, please specify here:</td>
<td></td>
</tr>
</tbody>
</table>

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*?

If yes, please specify here: 

5. Finalize and Submit