Head injuries among FIS World Cup alpine and freestyle skiers and snowboarders: a 7-year cohort study

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ABSTRACT
Background Traumatic brain injury is the leading cause of death for skiers and snowboarders. Fatal head injuries have also occurred at the International Ski Federation (FIS) World Cup (WC) level. We therefore wanted to describe the risk of head injuries across disciplines and sex among WC skiers and snowboarders.

Method We conducted retrospective interviews with FIS WC athletes at the end of seven consecutive seasons (2006–2013) to register injuries sustained during the competitive season. Head injuries were classified as ‘head/face’ injuries and did not include neck or cervical spine injuries. To calculate the exposure, we extracted data from the official FIS website for all WC competitions for each of the athletes interviewed.

Results A total of 2080 injuries were reported during seven WC seasons. Of these, 245 (11.8%) were head/face injuries. Of the 245 head/face injuries reported, nervous system injuries/concussions were the most common (81.6%) and 58 of these were severe (23.7%). The injury incidence per 1000 competition runs was higher in freestyle (1.8, 95% CI 1.2 to 2.4) than in alpine skiing (0.9, 95% CI 0.6 to 1.2; risk ratio (RR) 2.05, 95% CI 1.25 to 3.46) and snowboard (1.0, 95% CI 0.6 to 1.3; RR 1.85, 95% CI 1.15 to 2.99). Women had a higher injury incidence (5.8, 95% CI 4.8 to 6.9) versus men (3.9, 95% CI 3.2 to 4.6; RR 1.48, 95% CI 1.15 to 1.90) throughout the season (per 100 athletes).

Conclusions The majority of head/face injuries were nervous system injuries/concussions and one in four injuries was severe. Freestyle skiers had the highest overall head injury incidence. Across all disciplines, the injury incidence was higher in women than in men.

INTRODUCTION
At the International Ski Federation (FIS) World Cup (WC) level, the rate of head injuries in alpine skiing, freestyle skiing and snowboarding has been reported to range between 10% and 13.4%.¹⁻³ Data from the recreational level report that traumatic brain injury is the leading cause of death and catastrophic injury for skiers and snowboarders.⁴ Two fatal head injuries have occurred at the FIS WC level in recent years. It is therefore of interest to investigate the risk of head injuries among WC skiers and snowboarders, with the long-term goal of preventing head injuries in this setting.

Jumping and falling have been reported as potential risk factors for head injuries in recreational skiers and snowboarders.⁵⁻⁶ Recent studies found that head injury and concussion risk were increased in terrain parks, which consist primarily of aerial elements, compared with on traditional ski slopes, and that the odds of head/neck injury were greater on aerial features in a terrain park.⁵⁻⁶ The WC includes disciplines with aerial elements (alpine downhill and super-G, ski cross and snowboard cross, half pipe, big air, aerials, slopestyle and moguls) and disciplines without aerial elements (alpine slalom and giant slalom, snowboard parallel slalom and parallel giant slalom). So far, we do not know whether aerial disciplines have the highest injury risk at the WC level.

A higher incidence of concussion has been reported among female athletes than among male athletes in sports with similar actions, rules and equipment.⁸⁻¹⁰ Men and women compete in the same courses in snowboarding and freestyle skiing, whereas in alpine skiing men and women have separate race circuits. Comparing sex differences in a population where the competition conditions are similar (snowboard and freestyle) and different (alpine), can give us valuable insight into how this could affect injury risk, which is important in order to prevent injuries.

The aim of this study was therefore to investigate the incidence of head injuries, including the severity and the types of injuries, in the different alpine, freestyle and snowboarding disciplines, in addition to examining any sex differences in head injury risk.

MATERIALS AND METHODS
Study design and population
We recorded injuries through the FIS Injury Surveillance System (ISS)¹¹ based on annual retrospective athlete interviews during seven WC seasons (2006–2013).

Athletes on the WC teams from the USA, Austria, Canada, Finland, France, Germany, Italy, Switzerland, Norway and Sweden were interviewed at the WC finals at the end of each of the seven seasons. During the study period, we also included athletes from several other teams to increase the study population. The WC season was defined as starting at the first WC competition of the season (usually October/November) and ending at the last WC competition of the season (usually at the end of March), resulting in a 5-month to 6-month WC season. If an athlete was not present at the event, due to injury or other reason, or if the athlete did not understand English, the team coach, physician or physiotherapist was interviewed. The team had to have a response rate of ≥80% to be included. All athletes included were registered in the FIS database, had started in at least one FIS WC competition and had to be confirmed by the team.
coach as a member of the official WC team. The team coaches reviewed our lists of athletes to confirm which athletes belonged to the official WC team and added athletes if any were missing from our lists.

All interviews were conducted in person by physicians or physiotherapists from the Oslo Sports Trauma Research Center in the finishing area, after team captains’ meetings or during organised meetings at the competitors’ hotels. We completed a standardised interview form for each athlete, where the athlete consented to participate in the FIS ISS.11

**Injury registration**

If the athlete reported an injury, a specific injury form was also completed for each injury.11 We defined injuries as “all acute injuries that occurred during training or competition and required attention by medical personnel.”12 The injury form included information about the date and place of injury, injury circumstances, body part injured, side (left/right), injury type, injury severity and the specific diagnosis. The injury definition and the classification of injury information was based on a consensus document on injury surveillance in football.12 Head injuries were classified as ‘head/face’ injuries and did not include neck or cervical spine injuries. Injury type was classified as fractures and bone stress, joint (non-bone) and ligament, muscle and tendon, contusions, lacerations and skin lesions, nervous system including concussion, other injury or no information available. We also recorded the specific diagnosis, and for all head/face injuries classified as ‘nervous system injuries including concussion’, the diagnosis was ‘concussion’. Injury severity was classified according to the duration of absence from training and competition as follows: slight (no absence), minimal (1–3 days), mild (4–7 days), moderate (8–28 days) and severe (>28 days).12

**Exposure registration**

To calculate exposure, we obtained the exact number of started runs by each of the athletes interviewed from the official FIS competition website (http://www.fis-ski.com) for each of the seven seasons (2006–2013). The result lists for each of the WC, World Ski/Snowboard Championships (WSC) and Olympic Winter Games (OWG) competitions during the seven seasons were extracted one by one from the FIS website into an Excel file. Specific variables were added to the result for each of the athletes, that is, date, discipline, place and sex. In addition, we created a new variable to calculate the number of started runs for each athlete per competition. The exposure data were transferred to our database (Oracle Database 11 g, Oracle Corporation, California, USA) and linked to the injury data recorded through the interviews. We calculated total exposure, as well as exposure for men versus women and for each of the different snowboarding, freestyle and alpine subdisciplines.

**Statistical analysis**

The injury rate was expressed as the absolute injury rate (number of injuries per 100 athletes per season) and the relative injury rate (number of injuries per 1000 competition runs). When calculating the absolute injury rate, we included all recorded injuries during all training and competitions throughout the seasons, while we only included injuries in WC, WSC and OWG competitions when calculating the relative injury rate, as exposure data (the number of runs started) were only available for these events. The WC, WSC and OWG exposure calculation includes competition runs (qualification and final runs) only, not official training runs. Calculations were based on the Poisson model, and Z tests were used to compare the injury rate and injury pattern between groups. Injury incidences and risk ratios (RR) are presented with 95% CI, and a two-tailed p value of <0.05 was considered significant.

**RESULTS**

We interviewed 5247 snowboard, freestyle and alpine skiing athletes during the seven seasons (2006–2013), including 3203 men and 2044 women (table 1). The majority of interviews were conducted with the team coach (n=2954, 56.3%) or athlete (n=1843, 35.1%). In some cases, information was also obtained from doctor/technical delegate reports (n=325, 6.2%), from team physicians (n=19, 0.4%) and from team physiotherapists (n=106, 2%).

A total of 2080 injuries (749 in snowboard, 668 in freestyle, 663 in alpine) were reported during the seven WC seasons. Of these, 245 (11.8%) were head/face injuries (table 2). The most common injury type was classified as nervous system injuries/concussions (n=200, 81.6%), and of these, all were reported to us with a diagnosis of concussion.

**Injury circumstances and severity**

All head/face injuries occurred while skiing/riding on snow and 122 (49.8%) injuries took place during competitions. The 122 competition injuries included injuries occurring during non-FIS competitions such as, for example, the X-Games or Dew Tour. Of the 122 competition injuries, a total of 96 head/face injuries (39.2%) took place during WC, WSC and OWG competitions. Only the 96 WC, WSC and OWG injuries were included for further analyses of competition injuries, as exposure data were only available for these events. There were 118 (48.2%) training injuries. In five cases (2%), we did not have information about the circumstances of injury. Of all head/face injuries (n=245), 57 (23.3%) were moderate and 58 (23.7%) severe, leading to an absence from training or competition of 8–28 or >28 days, respectively.

**Overall head/face injury incidence**

The overall incidence (number of injuries per 100 athletes per season) of head/face injuries (n=245) was higher in freestyle (5.7, 95% CI 4.5 to 6.8) and snowboard (5.0, 95% CI 4.0 to 6.0) compared with alpine skiing (3.5, 95% CI 2.7 to 4.4; RR 1.61, 95% CI 1.17 to 2.22 vs freestyle; RR 1.43, 95% CI 1.04 to 1.96 vs snowboard).

The overall incidence of head/face injuries was higher for women compared with men (table 3). Freestyle and snowboard

<table>
<thead>
<tr>
<th>Season</th>
<th>Snowboard Male</th>
<th>Snowboard Female</th>
<th>Freestyle Male</th>
<th>Freestyle Female</th>
<th>Alpine Male</th>
<th>Alpine Female</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006/2007</td>
<td>92</td>
<td>50</td>
<td>107</td>
<td>46</td>
<td>144</td>
<td>116</td>
<td>555</td>
</tr>
<tr>
<td>2007/2008</td>
<td>186</td>
<td>94</td>
<td>177</td>
<td>86</td>
<td>148</td>
<td>113</td>
<td>804</td>
</tr>
<tr>
<td>2008/2009</td>
<td>173</td>
<td>96</td>
<td>143</td>
<td>103</td>
<td>148</td>
<td>115</td>
<td>778</td>
</tr>
<tr>
<td>2009/2010</td>
<td>172</td>
<td>99</td>
<td>96</td>
<td>56</td>
<td>140</td>
<td>128</td>
<td>691</td>
</tr>
<tr>
<td>2010/2011</td>
<td>202</td>
<td>113</td>
<td>171</td>
<td>105</td>
<td>157</td>
<td>118</td>
<td>866</td>
</tr>
<tr>
<td>2011/2012</td>
<td>102</td>
<td>54</td>
<td>89</td>
<td>53</td>
<td>148</td>
<td>118</td>
<td>564</td>
</tr>
<tr>
<td>2012/2013</td>
<td>238</td>
<td>125</td>
<td>207</td>
<td>132</td>
<td>163</td>
<td>124</td>
<td>989</td>
</tr>
<tr>
<td>Total</td>
<td>1165</td>
<td>631</td>
<td>990</td>
<td>581</td>
<td>1048</td>
<td>832</td>
<td>5247</td>
</tr>
</tbody>
</table>
women had a higher injury incidence compared with men, while no sex difference was found in alpine skiing (table 3).

**WC, WSC and OWG competition injury incidence**

The incidence of head/face injuries (n=96) in WC, WSC and OWG competitions (number of injuries per 1000 runs) was significantly higher in freestyle (1.8, 95% CI 1.2 to 2.4) than in alpine skiing (0.9, 95% CI 0.6 to 1.2; RR 2.05, 95% CI 1.25 to 3.46) and snowboard (1.0, 95% CI 0.6 to 1.3; RR 1.85, 95% CI 1.15 to 2.99). The competition head injury incidence across disciplines and subdisciplines is depicted in figure 1.

No sex differences were found in total for the three disciplines or within disciplines for head/face injuries occurring per 1000 competition runs (n=96; table 3).

**DISCUSSION**

This is the largest cohort study until now to examine the rate of head/face injuries in WC alpine and freestyle skiers and snowboarders. The majority of injuries were concussions and one in four injuries was severe. Freestyle skiers had the highest overall injury rate.

**Disciplines**

The head/face injury incidence was highest in freestyle, followed by snowboard and alpine skiing, respectively. Since all freestyle disciplines include aerial elements, this finding was not surprising.

In freestyle aerials, athletes perform inverted aerials with a take-off speed of around 70 km/h. The jumps range in height from 2 to 4 m and in inclination angle from 50° to 70°. Competitors land on a steep 37±1° landing hill of chopped snow.13 One injury mechanism thought to be typical of aerials is a slaphack episode where the skier over-rotates in the air, resulting in a backwards rotation after the ski tails contact the snow.14 As the upper back and head contact the snow, athletes experience both direct head impacts and rotational acceleration of the head. Maximum head acceleration ranging from 27 to 92 g has been reported during slaphack episodes.14

Slostyle, ski cross and snowboard cross all contain challenging aerial features. In slostyle, athletes ski/ride through a course including rails, jumps and other terrain park features, scoring points for amplitude, originality and quality of tricks.15 Cross disciplines are a motocross-inspired mixture of freestyle and alpine events, characterised by courses which include banks, compressions, jumps and giant slalom-type turns.16 Recent video analyses have revealed that the main injury situations in both cross disciplines involved jumping.17 18

For recreational snowboarders in a terrain park, a higher incidence of head injuries and concussions occurred on aerial features versus non-aerial features.3 Skiers and snowboarders were more likely to suffer injuries to the head and concussions in a terrain park rather than on a traditional ski slope.6 These findings correspond to our results, which show that freestyle athletes, who compete in courses containing several aerial elements, were at the highest risk of head/face injuries.

**Sex differences**

It should be noted that we detected a significant sex difference in the overall head/face injury incidence (per 100 athletes per season), but not in the competition head/face injury incidence (per 1000 runs). In all likelihood, this is due to a power problem caused by the limited number of competition injuries.

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**Table 2 Distribution of injury types for head/face injuries (n=245) reported during seven seasons (2006–2013) of the International Ski Federation World Cup, during competition and training, for snowboard, freestyle skiing and alpine skiing**

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Sex</th>
<th>Nervous system including concussion</th>
<th>Laceration/skin lesion</th>
<th>Fractures/bone stress</th>
<th>Contusions</th>
<th>Muscle and tendon</th>
<th>Other</th>
<th>Total (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snowboard</td>
<td>Males</td>
<td>40</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>39</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>79</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Freestyle</td>
<td>Males</td>
<td>41</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>35</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>76</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>89</td>
</tr>
<tr>
<td>Alpine</td>
<td>Males</td>
<td>27</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>18</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>45</td>
<td>11</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>66</td>
</tr>
<tr>
<td>Total (n, %)</td>
<td></td>
<td>200 (81.6)</td>
<td>19 (7.8)</td>
<td>11 (4.5)</td>
<td>9 (3.7)</td>
<td>1 (0.4)</td>
<td>5 (2.0)</td>
<td>245</td>
</tr>
</tbody>
</table>

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**Table 3 Sex differences in the incidence of head/face injuries for snowboarders, freestyle and alpine skiers during seven seasons (2006–2013) of the FIS WC**

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
<th>Risk ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All head/face injuries (n=245)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incidence (injuries per 100 athletes)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total all disciplines</td>
<td>3.9 (3.2 to 4.6)</td>
<td>5.8 (4.8 to 6.9)</td>
<td>1.48 (1.15 to 1.90)*</td>
</tr>
<tr>
<td>Snowboard</td>
<td>3.8 (2.7 to 4.9)</td>
<td>7.3 (5.2 to 9.4)</td>
<td>1.93 (1.27 to 2.91)*</td>
</tr>
<tr>
<td>Freestyle</td>
<td>4.5 (3.2 to 5.9)</td>
<td>7.4 (5.2 to 9.6)</td>
<td>1.63 (1.07 to 2.47)*</td>
</tr>
<tr>
<td>Alpine</td>
<td>3.4 (2.3 to 4.6)</td>
<td>3.6 (2.3 to 4.9)</td>
<td>1.05 (0.65 to 1.70)</td>
</tr>
<tr>
<td>WC, WSC and OWG head/face injuries</td>
<td>1.0 (0.7 to 1.2)</td>
<td>1.4 (1.0 to 1.8)</td>
<td>1.47 (0.98 to 2.20)</td>
</tr>
<tr>
<td>Incidence (injuries per 1000 runs)</td>
<td>1.0 (0.5 to 1.3)</td>
<td>1.2 (0.6 to 1.8)</td>
<td>1.39 (0.69 to 2.78)</td>
</tr>
</tbody>
</table>

*Significant difference (p<0.05).
FIS, International Ski Federation; OWG, Olympic Winter Games; WC, World Cup; WSC, World Ski/Snowboard Championships.
Figure 1  Head injury incidence (with 95% CI) per 1000 World Cup (WC), World Ski/Snowboard Championships and Olympic Winter Games competition runs for the different freestyle, snowboarding and alpine disciplines during seven seasons (2006–2013) of the International Ski Federation WC. Moguls include moguls and dual moguls. The snowboard parallel discipline includes parallel slalom and giant slalom.

Nevertheless, as can be seen in table 3, the risk ratios for injuries overall and in competition were consistent across disciplines, with the exception of the overall head/face injury rate in alpine skiing. Thus, it appears that women have about 1.5 times the risk of attaining a head/face injury compared with men.

Our results correspond with other studies, where women had an increased risk of concussion compared with men. In US high school sports, girls had a 70% to a twofold increase in concussion risk compared with boys. In our data, only men participated in big air competitions. Therefore, apart from in big air competitions, freestyle and snowboard men and women share courses and compete under the same conditions. Sharing the same course does not mean that men and women perform the same tricks or attain the same speeds or jumping heights. Men perform more challenging tricks than women, and attain higher speeds in, for example, ski cross and snowboard cross. However, as we only have epidemiological data, we can only speculate about why women attain more head injuries. It may be hypothesised that courses and course elements designed to challenge the best male athletes may be too challenging for some women. Systematic video analyses of actual injury situations are needed to describe in detail the events leading to head injuries among men and women.

Severe head injuries
Almost 1/4 of reported head/face injuries were severe, causing at least 4 weeks of time-loss during the competitive season. Our injury registration method does not allow us to report how many of the severe injuries were season or career ending. Also, the study only covers the 5-month to 6-month competitive season, not the preparation period when athletes practise performing new tricks. However, during the 7-year observation period, two fatalities due to head injuries have occurred in our cohort (one in a ski cross competition and one in ski half pipe training). In other words, fatal head injuries represent a real concern among WC athletes. This is well documented from the recreational level, where head injuries and neurological injuries are the most common cause of death and disability for skiers and snowboarders.

Prevention
Helmets reduce the risk of head injuries in recreational skiers and snowboarders, and are not thought to increase the risk of cervical spine injury or risk compensation behaviour. For all WC alpine, freestyle and snowboarding events, the use of helmets is compulsory during course inspection, official training and competitions. The helmets must be specifically designed and manufactured for the respective discipline, bear a CE mark and conform to established standards. A new helmet standard for downhill, super-G and giant slalom is enforced from the 2013/2014 season, where the helmet, in addition to the existing standards, must pass a specific test with a test speed of 6.8 m/s compared with 5.4 m/s previously.

The new helmet standard in alpine skiing represents an attempt at reducing the rate of severe head injuries, but more research is needed if injury rates are to be decreased in all disciplines. For instance, if rule changes or changes in course design are to be considered to decrease injury incidence or severity, clear-cut injury mechanisms must be identified. Video analyses of injury situations would help us understand the mechanisms of head injuries in WC skiing and snowboarding, as they have done for knee injuries.

In addition to continuing research into head injuries and helmet standards in alpine skiing, we suggest that future prevention strategies should address severe injuries across all disciplines, promote adequate recognition and medical attention for all head injuries, and target freestyle and snowboarding athletes, with particular attention to female athletes.

Methodological considerations
All injury recording during the seven WC seasons was through interviews with athletes, medical personnel or coaches. Recall bias is a challenge with retrospective interviews. However, a methodological study found that in the WC setting, retrospective interviews were the best method compared with prospective injury registration by team medical personnel or FIS Technical Delegates. Interview forms based on the race schedules were used to help the interviewee recall the date, location and circumstances of injury. Still, even if a recall bias may exist, we cannot see any reason why this should be sex or discipline related.
A greater problem could be that concussions are not recognised by athletes, coaches or medical personnel, and therefore are under-reported. Athletes might not self-report an injury they do not recognise as being harmful or dangerous at the time of competition. 38 Although much focus has been given to concussion recognition through recent consensus conferences, we do not know what the uptake of new guidelines have been in the skiing and snowboarding medical community. 33 39 From other sports, it is known that concussions are considerably under-reported, with the most common reason in football being that the athlete did not think the injury was serious enough to warrant medical attention. 40 41

CONCLUSION
This is the largest cohort study until now to examine the rate of head injuries in WC alpine and freestyle skiers and snowboarders. The majority of head/face injuries were nervous system injuries/concussions and one in four injuries was severe. Freestyle skiers had the highest overall head injury incidence. Across all disciplines, the injury incidence was higher in women than in men.

What this study adds?

▸ This is the largest cohort study until now to examine the rate of head injuries in World Cup (WC) alpine and freestyle skiers and snowboarders.
▸ The majority of head injuries were concussions and one in four injuries was severe.
▸ Freestyle skiers had the highest overall head injury rate.
▸ Across all disciplines, the injury incidence was higher in women than in men.

How might it impact on clinical practice in the near future?

▸ Continued research into head injuries and helmet standards in all ski and snowboarding disciplines is needed.
▸ Future prevention strategies should address severe injuries across all disciplines, promote adequate recognition and medical attention for all head injuries, and target freestyle and snowboarding athletes, with particular attention to female athletes.
▸ Video analyses of injury situations would help us understand the mechanisms of head injuries in WC skiing and snowboarding.

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Contributors SES, TB and RB contributed to the study conception, design and methodology. SES and TB co-ordinated the study and managed the data collection. SES wrote the first draft of the paper, and all authors contributed to the final manuscript. SES and RB are the guarantors.

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Competing interests None.

Ethics approval The study was reviewed by the Regional Committee for Medical Research Ethics, South-Eastern Norway Regional Health Authority, Norway.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES