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

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Keywords: Head injuries, Epidemiology, Injury incidence, Skiing, Snowboarding.

Word Count: 3311
ABSTRACT

**Background:** Traumatic brain injury is the leading cause of death for skiers and snowboarders. Fatal head injuries have also occurred at the FIS (International Ski Federation) 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 7 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 results database for all WC competitions for each of the athletes interviewed.

**Results:** A total of 2080 injuries were reported during 7 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; 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). Females had a higher injury incidence (5.8, 95% CI 4.8 to 6.9) vs. males (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).

**Conclusion:** 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 females than in males.
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 10.0% and 13.4%. [1-3] Data from the recreational level reports 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. [5-7] Recent studies found that head injury and concussion risk was increased in terrain parks, which consist primarily of aerial elements, compared to on traditional ski slopes, and that the odds of head/neck injury was 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 males in sports with similar actions, rules and equipment. [8-10] Males and females compete in the same courses in snowboarding and freestyle skiing, whereas in alpine skiing males and females have separate race circuits. Comparing sex differences in a population where 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 7 WC seasons (2006-2013).

Athletes on the WC teams from USA, Austria, Canada, Finland, France, Germany, Italy, Switzerland, Norway and Sweden were interviewed at the WC finals at the end of each of the 7 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 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 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”. 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 (www.fis-ski.com) for each of the 7 seasons (2006-2013). The result lists for each of the WC, World Ski/Snowboard Championships (WSC) and Olympic Winter Games (OWG) competitions during the 7 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 i.e. 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 11g, Oracle Corporation, California, USA) and linked to the injury data recorded through the interviews. We calculated total exposure, as well as exposure for males versus females and for each of the different snowboarding, freestyle and alpine sub-disciplines.

**Statistical analysis**

The injury rate was expressed as both 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 injury rate and injury pattern between groups. Injury incidences and risk ratios (RR) are presented with 95% confidence intervals (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 7 seasons (2006-2013), 3203 males and 2044 females (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 team physiotherapists (n=106, 2.0%).

Table 1. The number of athletes interviewed in FIS World Cup alpine skiing, freestyle skiing and snowboarding for each of the 7 seasons (2006-13) among males and females.

<table>
<thead>
<tr>
<th>Season</th>
<th>Snowboard</th>
<th>Freestyle</th>
<th>Alpine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>2006/07</td>
<td>92</td>
<td>50</td>
<td>107</td>
</tr>
<tr>
<td>2007/08</td>
<td>186</td>
<td>94</td>
<td>177</td>
</tr>
<tr>
<td>2008/09</td>
<td>173</td>
<td>96</td>
<td>143</td>
</tr>
<tr>
<td>2009/10</td>
<td>172</td>
<td>99</td>
<td>96</td>
</tr>
<tr>
<td>2010/11</td>
<td>202</td>
<td>113</td>
<td>171</td>
</tr>
<tr>
<td>2011/12</td>
<td>102</td>
<td>54</td>
<td>89</td>
</tr>
<tr>
<td>2012/13</td>
<td>238</td>
<td>125</td>
<td>207</td>
</tr>
<tr>
<td>Total</td>
<td>1165</td>
<td>631</td>
<td>990</td>
</tr>
</tbody>
</table>

A total of 2080 injuries (749 in snowboard, 668 in freestyle, 663 in alpine) were reported during the 7 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.
Table 2. Distribution of injury types for head/face injuries (n= 245) reported during 7 seasons (2006-13) of the FIS 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>1</td>
<td>0</td>
<td>1</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>0</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>

**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 e.g. 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 5 cases (2.0%) 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 days 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 to 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 females compared to males (table 3). Freestyle and snowboard females had a higher injury incidence compared to males, while no sex difference was found in alpine skiing (table 3).

Table 3. Sex differences in the incidence of head/face injuries for snowboarders, freestyle and alpine skiers during 7 seasons (2006-13) 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><strong>All head/face injuries (n=245)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Incidence (injuries per 100 athletes) with 95% CI</strong></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><strong>WC, WSC and OWG head/face injuries (n=96)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Incidence (injuries per 1000 runs) with 95% CI</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total all disciplines</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>Snowboard</td>
<td>0.9 (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>
<tr>
<td>Freestyle</td>
<td>1.5 (0.8 to 2.2)</td>
<td>2.4 (1.3 to 3.5)</td>
<td>1.59 (0.82 to 3.09)</td>
</tr>
<tr>
<td>Alpine</td>
<td>0.7 (0.3 to 1.1)</td>
<td>1.1 (0.6 to 1.6)</td>
<td>1.55 (0.74 to 3.26)</td>
</tr>
</tbody>
</table>

*Significant difference (p<0.05)

**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 injury incidence across disciplines and sub-disciplines 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.
Figure 1. Head/face injury incidence (with 95% CI) per 1000 WC, WSC and OWG competition runs for the different freestyle, snowboarding and alpine disciplines during 7 seasons (2006-13) of the FIS WC. Moguls include moguls and dual moguls. The snowboard parallel discipline includes parallel slalom and giant slalom.
DISCUSSION

This is the largest cohort study to date examining 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 2.0 to 4.0 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 slapback 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 contacts 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 slapback episodes.[14]

Slopestyle, ski cross and snowboard cross all contain challenging aerial features. In slopestyle, 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 vs. non-aerial features.[5] Both skiers and snowboarders were more likely to suffer injuries to the head and concussions in a terrain park compared to 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. 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 females have about 1.5 times the risk of attaining a head/face injury compared to males.

Our results correspond with other studies, where females had an increased risk of concussion compared to males.[8] In US high school sports, girls had a 70% to a twofold increase in concussion risk compared to boys.[10, 19] Apart from in big air competitions, freestyle and snowboard males and females share courses. Sharing the same course does not mean that males and females perform the same tricks or attain the same speeds or jumping heights. Males perform more challenging tricks than females, and attain higher speeds in for example ski cross or snowboard cross.[20] However, as we only have epidemiological data, we can only speculate about why females 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 females. Systematic video analyses of actual injury situations are needed to describe in detail the events leading to head injuries among both males and females.

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 to 6-month competitive season, not the preparation period when athletes practice performing new tricks. However, during the 7-year observation period two fatalities due to head injuries have occurred in our cohort (one in 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 neurologic injuries are the most common cause of death and disability for skiers and snowboarders.[4, 7, 21-23]
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.[24-26] For all WC alpine, freestyle and snowboarding events, the use of helmets is compulsory during course inspection, official training and competitions.[27] The helmets must be specifically designed and manufactured for the respective discipline, bear a CE mark and conform to established standards.[28-32] A new helmet standard for downhill, super-G, and giant slalom is enforced from the 2013/14 season, where the helmet, in addition to existing standards, must pass a specific test with a test speed of 6.8 m/s compared to 5.4 m/s previously.[28]

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.[33] 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.[34-37]

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 7 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 to prospective injury registration by team medical personnel or FIS Technical Delegates.[11] Interview forms based on the race schedules were used to help the interviewee recall the date, location and circumstances of injury.[11] Still, even if a recall bias may exist, we can not 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 to date examining 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 females than in males.

ACKNOWLEDGEMENTS

We thank the International Ski Federation staff and officials for all practical support in collecting the injury data. We also thank the alpine, freestyle and snowboard athletes, coaches and medical team personnel who participated in this study.

COMPETING INTERESTS

None

FUNDING

The Oslo Sports Trauma Research Center has been established at the Norwegian School of Sports Sciences through generous grants from the Royal Norwegian Ministry of Culture, the South-Eastern Norway Regional Health Authority, the International Olympic Committee, the Norwegian Olympic Committee & Confederation of Sport and Norsk Tipping AS. The FIS Injury Surveillance System is supported by the International Ski Federation and has been established through a generous grant from Don Joy Orthotics (DJO).
ETHICAL APPROVAL

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

What this study adds:

- This is the largest cohort study to date examining the rate of head injuries in 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 females than in males.

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.
REFERENCES


