Oslo Sports Trauma
RESEARCH CENTER

Tonje Wåle Flørenes

Injury surveillance in World Cup skiing and snowboarding

Faculty of Medicine
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Den viktigste livsvisdom må vi oppdage med våre egne øyne

Fritjof Nansen

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List of papers

This thesis is based on the following original research papers, which are referred to in the text by their Roman numerals:

I. Flørenes TW, Nordsletten L, Heir S, Bahr R. Recording injuries among World Cup skiers and snowboarders: a methodological study. *Scand J Med Sci Sports*. 2009 Dec 18 [Epub ahead of print]

II. Flørenes TW, Nordsletten L, Heir S, Bahr R. Injuries among World Cup ski and snowboard athletes. *Scand J Med Sci Sports*, in press.

III. Flørenes TW, Bere T, Nordsletten L, Heir S, Bahr R. Injuries among male and female World Cup alpine skiers. *Br J Sports Med*. 2009 43: 973-8.

IV. Flørenes TW, Heir S, Nordsletten L, Bahr R. Injuries among World Cup freestyle skiers. *Br J Sports Med*, in press.

Abbreviations

The following abbreviations, in alphabetic order is used in this thesis

ACL	Anterior cruciate ligament
AIS	Abbreviated injury scale
CI	Confidence interval
e.g.	exempli gratia
FIFA	the International Football Association (Fédération Internationale de Football Association)
FIS	the International Ski Federation (Fédération Internationale de Ski)
FIS ISS	FIS Injury Surveillance System
IIHF	the International Ice Hockey Federation
IOC	the International Olympic Committee
ISS	Injury severity score
MDBI	Mean days between injuries
NAIRS	the National Athletic Injury/Illness Reporting System
RR	Relative risk
SBD/SBV	Snowboarder days/snowboarder visits
SD/SV	Skier days/skier visits
TD	Technical delegate from the FIS
UEFA	the Union of European Football Associations (Union des Associations Européennes de Football)
WC/WSC	World Cup/World Ski Championship

Summary

While the injury risk for recreational skiers and snowboarders has been well documented, there is almost no data published for the competitive level. It is only in competitive snowboarding where we find recent studies. Based on concerns regarding injuries to the competitive athletes, the International Ski Federation (FIS) established an injury surveillance system; FIS ISS in collaboration with the Oslo Sports Trauma Research Center prior to the 2006-07 winter season. The objective was to identify, describe and analyse the injury risks and injury patterns in the different disciplines of alpine skiing, freestyle skiing, snowboarding, ski jumping, cross-country skiing and Nordic combined with a view to use this knowledge to reduce the risk of injuries among the athletes in the future.

Injury recording (Paper I): To validate and compare possible ways of injury recording in competitive skiing and snowboarding, information regarding injuries sustained during the 2006-07 winter season was recorded through three separate and independent systems: prospective registration by selected medical teams, prospective injury recording by technical delegates from the FIS, and retrospective athlete interviews at the end of the season. A total of 100 unique acute injuries to 602 World Cup athletes were identified from any of the three recording methods. Of these, 91% were registered through the athlete interviews, 47% by the medical team registration and 27% by the technical delegates. Only 20% were captured by all three methods. A total of 64 time-loss injuries were registered. The interviews captured 60 (94%), the medical team registration 39 (61%) and the reports from technical delegates 23 (36%) time-loss injuries, while 18 (28%) were registered by all three systems. Retrospective interviews with athletes/coaches regarding injuries during the last 6 months gave the most complete picture of injuries to World Cup skiers and snowboarders. It is therefore important to consider the characteristics of the setting in each sport before constituting an injury registration system. We used the interviews to assess the injury risk and injury patterns in Papers II-IV.

Assessing the overall injury risk in World Cup skiing and snowboarding (Paper II): To increase our knowledge of injuries to the competitive skiers and snowboarders we interviewed 2121 athletes and recorded 705 injuries during the 2006-07 and 2007-08 winter seasons. The interviews were based on one to one interviews with all athletes present at the season ending events in all disciplines and with the coaches for athletes not present. Of all recorded injuries 520 (72%) were time-loss injuries and 196 (28%) severe injuries (absence >28 days). To compare the different disciplines we used absolute injury rate expressed as injuries per 100 athletes per season. In freestyle skiing, alpine skiing and snowboarding there were 27.6, 29.8 and 37.8 time-loss and 14.4,

11.3 and 13.8 severe injuries per 100 athletes per season, respectively. In Nordic combined, ski jumping and cross-country skiing there were 15.8, 13.6 and 6.3 time-loss and 3.3, 5.6 and 0.7 severe injuries per 100 athletes per season, respectively. About 1/3 of the World Cup alpine, freestyle and snowboard athletes sustain a time-loss injury each season, while the risk is low in the Nordic disciplines. There was an increase from minor injuries up to the severe injuries in alpine skiing, freestyle skiing and snowboarding which is in contrast to most other sports. Compared to professional footballers the overall injury risk was much lower among World Cup skiers and snowboarders, however, the risk of severe injuries was about the same.

The injury risk in the different disciplines of World Cup alpine and freestyle skiing (Papers III & IV): We calculated the relative injury rate expressed as injuries per 1000 runs to describe in detail the injury risk within the different disciplines of alpine and freestyle skiing. In alpine skiing we found the relative injury rate to increase with increasing speed (slalom 4.9 injuries per 1000 runs, 95% CI 2.5 to 7.4 - giant slalom 9.2, 5.1 to 13.3 - super-G 11.0, 5.2 to 16.8 - downhill 17.2, 11.6 to 22.7). The injury rate among World Cup alpine skiers is even higher than previously reported from competitive level. In freestyle skiing we found that mogul/dual moguls had the lowest injury rate 9.2 (95% CI 5.4 to 13.1) injuries per 1000 runs compared to the other disciplines (ski cross 18.5, 95% CI 13.9 to 23.2 – aerials 19.2, 8.8 to 29.6 – halfpipe 23.9, 9.1 to 38.7). The relative injury rate was almost twice as high in freestyle skiing compared to alpine skiing.

Injury pattern in the different World Cup disciplines (Papers II-IV): Overall, injuries to the lower extremity dominated and the knee was the most frequently injured body part (19-36%) in all disciplines except in cross-country skiing (Paper II). There was also a high frequency of head injuries where 3 of 4 were concussions. The severe knee injuries with absence >28 days dominated. In alpine skiing there were 28 knee injuries in World Cup competitions giving a knee injury incidence of 3.2 (95% CI 2.0 to 4.4) per 1000 runs (Paper III). In freestyle skiing the knee injury rate was 4.6 (95% CI 3.0 to 6.2) (Paper IV). ACL injuries were the most common specific diagnosis in both alpine and freestyle skiing with 38% of all knee injuries (Papers III-IV).

Comparing injury rate for men and women in World Cup skiing and snowboarding (Papers II-IV): For all injuries reported by World Cup athletes during two seasons, we found no difference in injury rate between males and females (Paper II). For World Cup alpine skiers we found, however, a higher absolute injury rate (expressed as injuries per 100 athletes per season) as well as a higher relative injury rate (expressed as injuries per 1000 runs) in males compared to females, but not for knee injuries (Paper III). In freestyle skiing we found, no sex difference in injury rate and no difference for knee injury (Paper IV).

Introduction

"I think we leave our brain somewhere at the start before we start racing"

Anja Pärsson in TV interview with Fredrik Skavlan, March 2010

Skiing and snowboarding are associated with a lot of fun and represent recreational activities millions of people enjoy each winter. Competitive skiing and snowboarding are reserved for a select group of people, but are popular sports. The Norwegian Ski Federation is the second largest sport federation in Norway with 161 000 members (Norges skiforbund 2008).

Every winter hours and hours are broadcast from skiing and snowboarding competitions and we watch with enthusiasm to see if our national "heroes" can beat their opponents and become number one. The flip side of the coin is that we sometimes, unwillingly, become witness to athletes who crash and injure themselves. Some example headlines include:

> "One of our best snowboarders was taken to hospital with extensive injuries after a bad crash" (Egeberg 2009)
>
> "Bad injury to one of the Norwegian freestyle Olympic prospects" (Herland 2009)
>
> "A Norwegian alpine skier may have sustained a serious knee injury after falling and did not finish the World Cup giant slalom race on Saturday" (NRK nett 2007)
>
> "The skier had to have his left leg amputated after the dramatic crash this weekend" (Strømnes & Elle 2008)

This is not what we want sports to be associated with, but we know that there is a definite risk of getting injured. Nevertheless, we want to see as few injures as possible.

Preventing injuries is a process consisting of several steps. First, we need to know what the problem is and how big it is. Secondly, we need to find out how and why the injuries happen. Only then can preventive measures be developed to reduce the number of injuries. This thesis focuses on the first step, defining the magnitude of the injury problem in competitive skiing and snowboarding.

History of skiing

(The history of skiing is described based on works by ski historians (Bø 1993; Vaage 1979) as well as the websites of the International Ski Federation (FIS) and The Olympic Committee (IOC) (International Olympic Committee 2009; International Ski Federation 2008c).

Rock carvings indicate that the history of skiing goes back over 4000 years. Skis have also been found in Norway, Sweden, Finland and Russia dating back at least 4000 to 5000 years. In Old Norse mythology we find ski gods of both sexes, the ski god Ull (such a good skier that nobody could compete with him) and the goddess Skade (ironically the translation of the goddess name is "injury"). The presence of skiing gods indicates that even in early Viking times skiing was well known. The first usage of skis is believed to be for hunting across snow-covered terrain as a means of transportation. Skis have also played an important role in Norwegian history. One famous episode is from the life of Håkon IV Håkonsson, king of Norway from 1217-1263. Soon after Håkon was born, the reigning king died and conflicting groups fighting to get their man on the throne made life dangerous for little Håkon. When Håkon was only 2 years old he was brought into safety by two skiers who transported him over the mountains from Lillehammer to Østerdalen and further up to Nidaros, a long and arduous journey, for which the Birkebeiner race has been named.

The first written instructions of skiing technique were published in a manual for the Norwegian army in 1765. Skiing as a sport is, however, "recent", with the first non-military skiing competitions held in the 1840s in northern and central Norway. Thereafter the sport spread to Europe and the United States. Sondre Norheim from Morgedal, Telemark (Norway) is regarded as a pioneer in modern skiing and is said to be the first to use bindings around the heel and slightly carved skies in the late 1830s to perform turns and jumps while descending the slopes. Another milestone in the history of skiing was Fritjof Nansen and his journey on skis across Greenland in 1888. The story from this expedition came out as leaflets in English, French and German and created great enthusiasm. Eventually, the development of competitive skiing throughout the world lead to the establishment of the Fédération International de Ski (FIS) in 1924 at the time of the first winter Olympic Games. The Nordic disciplines (cross-country skiing, ski jumping and Nordic combined) have been on the Olympic program since these first winter Olympic Games, while alpine skiing made its debut on the Olympic programme in 1936 with combined competitions of downhill and slalom for both men and women. Freestyle skiing with the combination of speed, showmanship and aerial manoeuvres, developed from skiers performing somersaults, flips and spins. It was first recognised as a discipline in the FIS in 1979 and became a demonstration sport in the 1988 winter Olympic Games. Snowboarding is even younger with the first FIS' organised World Cup competition in 1994 and became part of the winter Olympic Games in 1998. Snowboarding as we know it today developed from various pioneers who produced boards from skies and with involvement from surfers and skateboarders.

Competitive skiing and snowboarding

Competitive alpine skiing

Alpine skiing as we know it today, with skiing between gates, is named after the Alps. The first slalom competition was organised in 1922 in Mürren, Switzerland (International Olympic Committee 2009). The alpine World Cup is popular and a TV-audience of up to 250 million watch an event (FIS, personal communication, 2009). The World Cup events today include downhill, super-G (super giant slalom), giant slalom and slalom, in addition to the combined event (slalom combined with downhill or super-G). Slalom has the shortest course, a vertical drop of 180-220 m for men and 140-220 m for women and includes a series of turns designed to allow the competitor to combine speed with neat execution and precision of turns in two runs. Giant slalom has a higher vertical drop than slalom (250-450 m for men and 250-400 m for women) and consists of a variety of fewer, wider and smoother turns. The distance between the nearest poles of two successive gates can not be less than 10 m. As in slalom, each skier makes two runs down two different courses on the same day. Super-G (super giant slalom) combines the precise turns of giant slalom with more high speed turns, jumps and gliding phases. The distance between the turning poles of two gates must be 15-25 m. Downhill is characterised by the five components of technique, courage, speed, risk and physical condition according to the International Ski Competition Rules (International Ski Federation 2008c) and it has the longest course (varying from place to place from around 2000-4500 m), the highest vertical drop (800-1100 m for males and 450-800 m for females) and hence the highest speed (average 95-105 km/h, maximal speed can exceed 140 km/h).

Competitive freestyle skiing

Competitive freestyle skiing includes a variety of disciplines at the World Cup level; from moguls and dual moguls to aerials, halfpipe and ski cross. In mogul skiing, the athlete skis down a 200-250 m long course with a mean gradient of approximately 25°, uniformly covered with moguls and also containing two jumps. The skier obtains a score determined by the technical execution of turns (50%), the difficulty of the manoeuvre performed and the execution at the two jumps

(25%) and the speed (25%). In dual moguls, competitors compete head to head on parallel mogul courses. In aerials the athletes compete at jumps with a gradient/steepness of 55-70º and they are scored according to the difficulty of the manoeuvre performed and their execution (20% air, 50% form and 30% landing). In halfpipe the skiers perform a series of manoeuvres skiing off the walls into the air, landing back into the pipe again. The snow-constructed pipe is 100-140 m long, the vertical drop is 14-18 m and the walls are 3-4.5 m high. The athletes are scored according to the difficulty of the manoeuvres performed and their execution. Ski cross has the longest course (900-1200 m) with a vertical drop of 180-250 m and challenges several freestyle skiing elements (e.g. turns, jumps and waves). Groups of four to six skiers race head to head in heats. The fastest skiers of each heat advance to the next round until the final heat settles the podium positions (International Ski Federation 2008a).

Competitive snowboarding

In the parallel events, two competitors ride simultaneously side by side down two parallel courses. For parallel slalom (PSL) there is a vertical drop of 80-120 m with recommended 23-30 gates. The length is 250-450 m, 30 m width and has an average steepness of 17-22º. In parallel giant slalom (PGS), there is a vertical drop of 120-200 m, recommended 18-25 gates, a length of 400-700 m and 40 m width. Halfpipe (HP) is a channel constructed in the snow the same way as for freestyle skiing. (There is even an oversized pipe). The snowboarders perform a series of manoeuvres while going from one side to the other with tricks in the air above the sides of the pipe. Five judges score the run of overall precision with regards to the manoeuvres both individually and as a sequence. In snowboard cross (SBX), the athletes race down a course with a vertical drop of 100-240 m, length approx 500-900 m and a minimum of 40 m width. It contains different snowboard constructions of banks, jumps (single, double or triple) and turns. For the qualification there are individual starts, but in the final 4-6 snowboarders compete against each other head to head. Intentional contact is not allowed, but unavoidable "casual contact" may be acceptable. Big air (BA) is a discipline where the snowboarders perform tricks after launching off a jump. The height of the jump is 2.5-3.5 m with a 25-30° take-off angle and it has a width of minimum 5 m. The landing should have a sufficient angle to accommodate both flips and spins. Five judges judge the control of the trick, the amplitude and the landing (International Ski Federation 2008f).

Competitive ski jumping

Ski jumping has developed from the 9.5 m launch of Olaf Rye (a Norwegian lieutenant) in 1809 to 239 m in ski flying (currently the World record set by Bjørn Einar Romøren in 2005 in Planica, Slovenia). In World Cup the jumping hills are regularly classified as large hills with a hill size (measured distance from the take off to the end of the landing area) of 110 m and larger and 185m and larger in flying hills (ski flying). The in-run for the jumping hill is designed to provide the necessary speed at which a maximum jumping distance for the hill can be reached. The ski jumpers take off trying to get into an aerodynamic flight position as soon as possible, fly with the V-style (invented by the Swede Jan Boklöv in the mid 1980's) and land with preferably a Telemark-landing (one leg a little behind the other, bending this while the skis are parallel). There are two jumps in the competition and they are scored according to distance points and style points by five judges (the highest and lowest marks are annulled) (International Ski Federation 2009a). Jumping skis are manufactured especially for use on ski jumping hills and the maximum ski length is 146% of the total body height of the competitor (a minimum BMI of 20 is required). For the ski jumping suits the maximum tolerance in the size is 6 cm to the body size at any part of the suit. There is no World Cup for women where the highest competitive level is the Continental Cup (International Ski Federation 2008e; International Ski Federation 2009b).

Competitive cross-country skiing

In cross-country skiing there are two techniques; classic and free (skating). Classical technique includes diagonal, double poling, herringbone, downhill and turning techniques, while free technique (skating) includes all cross-country skiing techniques. World Cup cross-country skiing includes several competition formats: Interval start competition with distances from 5 km to 50 km, mass start competitions, pursuit, relay competitions with 3-4 competitors, individual and team sprint (0.8-1.4 km women, 1-1.8 km men). In principle, the cross-country course should consist of 1/3 up hills (gradient 9-18%) plus some short climbs steeper than 18%, 1/3 undulating, rolling terrain and 1/3 varied downhills. The length of the cross-country skis must be at a minimum of the height of the skier minus 100 mm. Two poles of equal heights must not exceed the competitor's height nor measure below the hip (International Ski Federation 2008b; International Ski Federation 2009b).

Competitive Nordic combined

Nordic combined is a combination of ski jumping and cross-country skiing (free technique). For the individual Gundersen competition, the jumping competition is held first and the best ski jumper starts first in the cross-country race where the skier who crosses the finish line first wins the race. In the individual mass start competition the events are in reverse order and here they start with a mass start cross-country race followed by a two-run ski jumping competition. The first round of the jumping competition is in reverse order of the cross-country results. Only men compete in Nordic combined (International Ski Federation 2008d).

The extent of skiing injuries

Regardless of the different skiing and snowboarding disciplines, a common ambition for all competing athletes is a dream – to be the best and win! Nevertheless, the spectacular crashes and significant injuries seen regularly on television and described in the press, remind us of the risks associated with the sports.

There is no doubt that a physical active lifestyle is beneficial for our health. Regular physical activity is associated with a reduction in cardiovascular and coronary heart disease, a reduction in the incidence of obesity, type 2 diabetes mellitus, colon cancer and osteoporosis (Kesaniemi et al,. 2001). Being elite athletes (world-class athletes and champions) have also been described to entail a reduced risk of cancer, pulmonary and cardio-vascular disease and in addition live longer than others (Kujala et al,. 1996; Pukkala et al,. 2000; Sarna et al,. 1993). A study among Finnish champion cross-country skiers found a life expectation three to four years longer than for the general male population (Karvonen et al,. 1974). Nevertheless, when we watch a downhill race and see an alpine skier crash in 120 km/h and being transported down the slope on a toboggan, it is a reminder that participation in sports activities such as alpine skiing represents a very real risk of injury.

Sports injuries account for 17% of all injuries treated at Norwegian hospitals and skiing/snowboarding injuries account for 16-18% of these (Lereim 1999). Injury implications – in terms of costs and severity – vary, but besides the financial aspects, injuries can cause long-time absence from sports. Injuries can also increase the risk of long-term effects – like abnormal joint biomechanics and early onset of degenerative joint disease after serious knee injuries (Myklebust et al,. 2003; Natri et al,. 1999; von Porat et al,. 2004), or permanent disability or even death in the case of serious head and neck injuries in skiing and snowboarding (Koehle et al,. 2002; Nakaguchi et al,. 1999; Tarazi et al,. 1999). Consequently, if being physical active is meant to be beneficial for our health, we need to focus on how to prevent sports and skiing injuries.

The first published article of a skiing injury was an abdominal penetration of a ski pole described in 1901, where luckily the injured boy survived (Forsell 1901). After this, the injury situation among recreational skiers and snowboarders has been described in several studies, but we have very little knowledge of the risk our best athletes in skiing and snowboarding are subjected to. Before we know more about the injuries and how they occur, we have limited chances of reducing skiing and snowboarding injuries for our elite athletes through effective preventive measures.

How to deal with sport injuries?

The long-term goal of epidemiological sports injury research is to prevent injuries. The process to reach this important goal is suggested as a four-step sequence described by van Mechelen and co-workers (1992) since measures to prevent sports injuries do not stand by themselves.

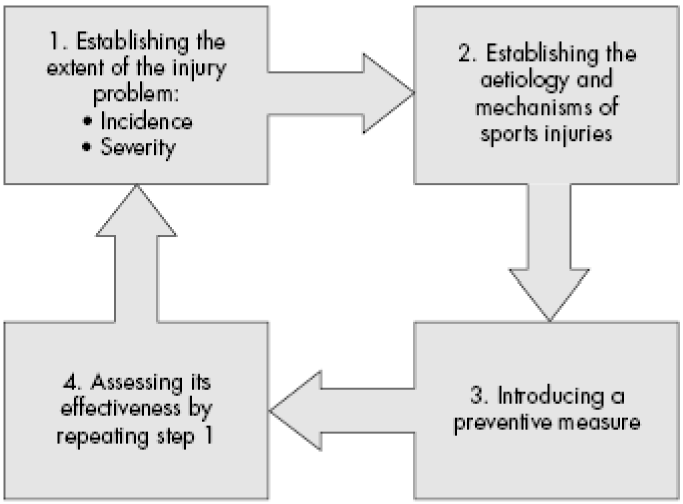

Figure 1. The four-step sequence of injury prevention first described by van Mechelen et al (1992)

First, the magnitude of the sports injury problem needs to be identified and described in terms of frequency and severity. Important questions of interests here are: What is the injury incidence? What is the most frequent injury type and body location? What is the severity of the injury? Next, the risk factors and injury mechanisms that play a part in the occurrence of sport injuries have to be identified. The third step is to introduce measures that are likely to reduce the future risk and/or severity of sports injuries, based on information collected during step two. Finally, the effect of these measures must be evaluated by repeating the first step. Finch (2006) introduced an addition to this sequence, pointing out the need for research into implementation issues to ensure that prevention methods are adopted. It is critical that all safety interventions have a strong evidence base, are effective and can readily be taken up by athletes, coaches and sporting bodies (Finch 2006; Finch & Donaldson 2009). It is also crucial to have governing bodies understand that they have a responsibility and a cooperation between investigators, physicians, sports organisers and policy makers is important in risk management (Fuller & Drawer 2004; Parkkari et al,. 2001; Regnier & Goulet 1995). Standardized assessment for injury recording and monitoring long-term changes is essential in injury prevention and dependent on proper sports injury surveillance research (Finch et al,. 1999; Fuller & Drawer 2004; Janda 1997; Junge et al,. 2004b, 2008; Meeuwisse & Love 1997; van Mechelen et al,. 1992).

Injury causation

Injury causation is usually complex but understanding the cause of injury is critical to advance our epidemiology knowledge towards injury prevention (Meeuwisse 1994). This means that we have to examine all the factors involved, including obtaining information on why a particular athlete might be at risk in a given situation (risk factors) and how the injury happens (injury mechanisms). Meeuwisse (1994) developed a model to account for all of the factors involved with internal risk factors, like e.g. age, sex, and body composition, and external risk factors, factors that have an impact on the athlete from outside, e.g. weather, field conditions, rules and equipment. In addition, there is the final inciting event as the link in the chain that causes the injury. Bahr & Krosshaug (2005) have developed a comprehensive model that include a biomechanical perspective, as well as focuses on the characteristics of the sport in question (Figure 2). They describe the need for a complete description of the mechanisms for a particular injury type from the events leading to the injury situation to a detailed description of the whole-body and joint biomechanics at the time of injury. It is the internal and the external risk factors that prepare the athlete for injury in a given situation, and conditions like the playing/competing situation, the behaviour of the athlete and possibly the behaviour of an opponent that contribute to the occurrence of the injury. The interactions between all these factors put the athlete in a vulnerable situation for sustaining an injury.

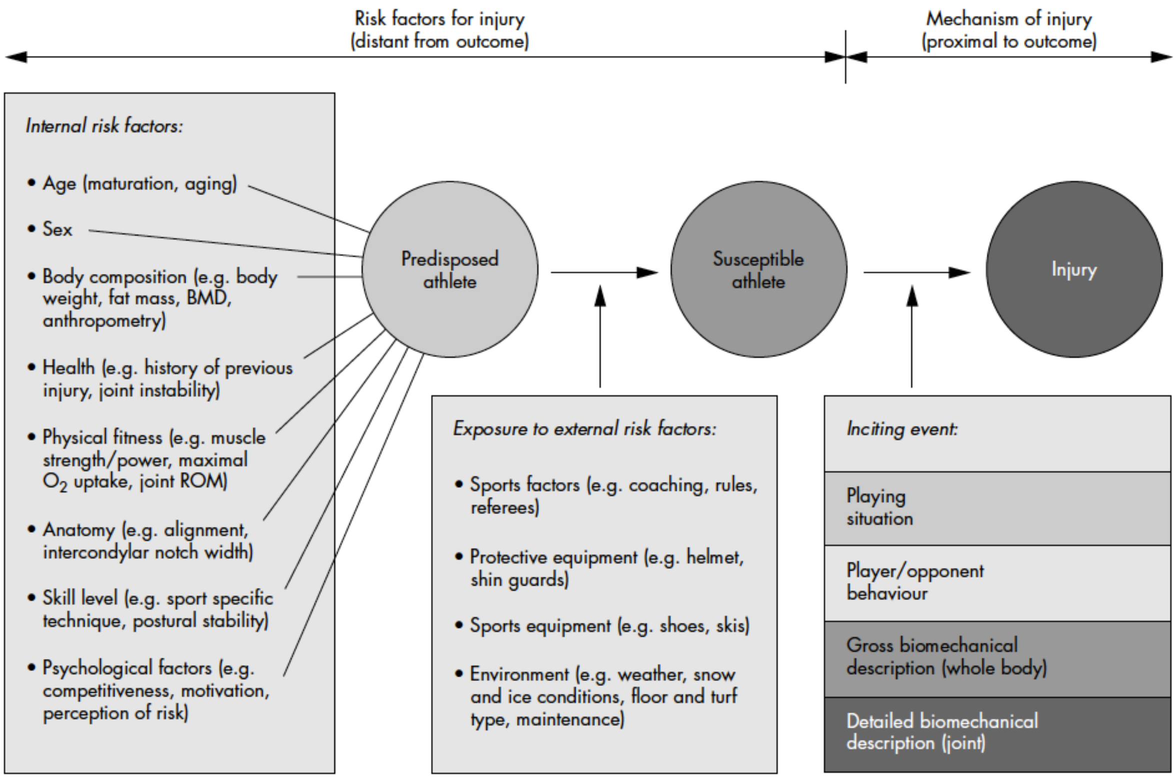

Figure 2. Comprehensive model for injury causation. Reproduced with permission from Bahr & Krosshaug 2005.

A new model has also been introduced by Meeuwisse and co-workers (2007) emphasizing the need of a more dynamic approach in the aetiology of sport injury. This model is described as a dynamic cycle that incorporates the consequences of repeated participation in sport, both with and without injury. They suggest that to understand the causes of injury it is necessary to look beyond the initial set of risk factors that are thought to precede an injury and also take into consideration how these may have changed, whether associated with prior injury or not.

Therefore, effective prevention depends on information of risk factors and injury mechanisms, both in terms of pure *mechanical considerations*, but also as seen from a *sport-specific* point of view. To fully understand the causes of injury it has recently been stated that it is equally important to ask why an injury did not occur and understand the "mechanism of no injury" (Meeuwisse 2009). If we learn to distinguish between the "mechanism of no injury" and the "mechanism of injury" we might have uncovered the critical component of the inciting event that ultimately causes an injury. Unfortunately, our understanding of injury mechanisms in skiing and snowboarding are limited; consequently, so is our ability to suggest effective preventive measures.

Risk factors

Among competitive skiers and snowboarders there is not much data available for risk factors. In competitive alpine skiing there are conflicting findings regarding sex. Two studies (Bergstrøm et al,. 2001; Ekeland et al,. 1996) described a significantly higher injury incidence among female as compared to male competitive racers in studies from the winter Olympic Games in Lillehammer and a World Junior Championship. Another study (Ekeland & Holm 1985) reported no significant sex differences for Norwegian competitive skiers of lower levels during the winter season 1981-1982. From World Cup and competitive national level snowboarding no sex difference was found for injury incidence (Torjussen & Bahr 2005, 2006). Regarding specific injury types, one study found significantly more female than male Olympic racers to have sustained an ACL injury previously (Ekeland et al,. 1996). In contrast, no significant sex difference was found for ACL injuries in a 25- year survey of national elite French skiers (Pujol et al,. 2007). The literature is divided as to whether there are sex differences in injury risk in competitive skiing. We will address this question for alpine and freestyle skiing in Paper III & IV.

Injury surveillance

Establishing reliable systems for injury surveillance is a key risk management tool and represents the first step in the injury prevention process. The sequence of prevention research cannot be applied without proper sports injury surveillance (van Mechelen 1997b). For federations and organisations it allows determination of trends of injuries and survey overall as well as specific injury types from one season/tournament to the next. It is also essential to have a successful injury surveillance to monitor data both pre- and post- intervention (Parkkari et al,. 2001).

Surveillance is defined as being systematic, continuous and ongoing (Porta 2008). "Injury surveillance" is therefore expressed as an ongoing collection of data describing the occurrence of, and factors associated with, injuries (Finch 1997).

The National Collegiate Athletic Association Injury Surveillance System (NCAA) is an example of a surveillance system that has been ongoing for 25 years and is currently the largest athletic injury database in continuous operation in the world (Dick et al,. 2007). Another injury reporting system for a specific group of athletes is the Canadian Intercollegiate Sport Injury Registry (CISIR) (Meeuwisse & Love 1998), where consideration for a prospective design, continuous input of data, ability to extract information while ensuring confidentiality, assessment of diagnostic accuracy and measure of injury severity were underlined in the establishment of the system.

There are also international federations which have focused on injury surveillance, e.g. football. The Fédération Internationale de Football Association (FIFA) has developed an injury reporting system for tournaments for both men and women, which was initiated during the football World Cup 1998 in France (Junge et al,. 2004b; Junge & Dvorak 2000, 2007). The Union of European Football Associations (UEFA) has developed a model with practical guidelines for future epidemiological studies on professional football players (Hägglund et al,. 2005) and also developed a football-specific injury reporting system as exemplified with studies from seven consecutive seasons in UEFA Champions League (Ekstrand et al,. 2009). Also national systems have been established in football and prospective injury reporting has been performed for two or more seasons in England (Hawkins et al,. 2001; Hawkins & Fuller 1999), Sweden (Hägglund et al,. 2006) and Norway (Andersen et al,. 2004).

The International Ice Hockey Federation (IIHF) has an injury reporting system since the 1998-99 season, where medical supervisors assisted by the team physician are responsible for the collection of data in championships after every game. This system allows the IIHF to determine trends of injuries and cautiously survey overall as well as specific injury types from one season to the next. Their main focus is to make the sport safer for all the participants and they can make comparison with other leagues and sports (International Ice Hockey Federation 2009).

Rugby, cricket, team handball and athletics are examples of other sports where injury reporting systems also have been established for several seasons and/or tournaments (Alonso et al,. 2009; Bathgate et al,. 2002; Best et al,. 2005; Fuller et al,. 2008; Langevoort et al,. 2007; McManus 2000; Orchard et al,. 2006). The International Olympic Committee (IOC) has also developed an injury reporting system for multi-sports events with the goal of serving as a role model for future studies in both single- and multi-sport events and hence ensure the comparability of results using standardised injury definitions, report forms and methodology (Junge et al,. 2008).

There are several regional (Dohjima et al,. 2001; Johnson et al., 2000; Langran & Selvaraj 2002; Made & Elmqvist 2004) and even national (Ekeland & Rødven 2006; Laporte et al., 2000) prospective ski injury recording systems for recreational alpine skiing and snowboarding. No long-term injury surveillance program has existed for competitive skiing or snowboarding. However, prior to the 2006-07 winter season the International Ski Federation (FIS) developed in collaboration with the Oslo Sports Trauma Research Center an injury surveillance system (FIS Injury Surveillance System; FIS ISS) with the intent of capturing all injuries occurring to athletes competing in FIS events. Papers I-IV is based on information from the World Cup level derived from the FIS ISS and represents the basis for this thesis.

Reliable, continuous injury reporting with uniform criteria is needed to enhance comparability of data (Clarke 1975; Dick et al,. 2007; Levy 1988; Mendryk & Kramer 1978). To enable comparison between sports, the optimum would be to use the same injury surveillance method in all sports (Parkkari et al,. 2001; van Mechelen 1997b). The method needs, however, to be adapted to the specific sports to also identify aetiological factors or effectiveness of preventive measures (Clarke 1975; Phillips 2000; van Mechelen 1997b; Wallace 1988). Although the aim of a study determines the precise information needed, there are basic characteristics of the injury that always should be described such as the diagnosis (body part and injury type), characteristics of the injury conditions/circumstances (surface, competition/training) and consequences (absence from sport, treatment of injury) (Lindenfeld et al,. 1988). Prospective, cohort studies for data collection of sport injuries are recommended (Fuller et al,. 2006, 2007; Kuhn et al,. 1997; Meeuwisse & Love 1998; Pluim et al,. 2009; Walter et al,. 1985). Retrospective studies are challenged by recall bias. Some studies have shown that prospective registration record more injuries than retrospective registration (Fonseca et al,. 2002; Junge & Dvorak 2000; Twellaar et al,. 1996), although there are few methodological studies reported from specific sports.

One challenge with competitive skiing and snowboarding is the amount of travelling and competitions all around the world during the winter season. In addition, even at the World Cup level, there are teams travelling without medical personnel while other teams have a large medical team. In addition, a downhill course in alpine skiing might be up to 4.5 km long and the distance covered in cross-country skiing is up to 50 km. Consequently, it is difficult for any one person to fully control events occurring over the entire course. Possible ways for performing injury recording in competitive skiing and snowboarding are to ask athletes and/or coaches to report continuously during the season or alternatively retrospectively at the end of the season. Other possibilities could be to use medical personnel associated with the different teams or other people responsible for the events or race doctors to record injuries. As it is not known which method would provide the most complete and accurate data, for competitive skiing and snowboarding at the World Cup level, we have tested three different data collection procedures in a methodological study (Paper I).

Definition of injury

Various injury definitions make comparisons across sports as well as within a specific sport difficult. It may also influence results and conclusions from different studies. The National Athletic Injury/Illness Reporting System (NAIRS), which was established in the US in 1974 and has been used to collect information on large athletic populations, defined a reportable injury as one that limits athletic participation for at least the day after the day of onset (Clarke 1975; Levy 1988). The time-loss injury definition, which requires absence from competition and/or training, has commonly been used regardless of sport (Arnason et al,. 1996; Bahr & Bahr 1997; Ekstrand 1982; Faude et al,. 2005; Hawkins & Fuller 1999; Stephenson et al,. 1996). A challenge described is that also the minor injuries not leading to absence can have long-term effects (Drawer & Fuller 2001). In addition, when including time-loss injuries only, challenges with difference in frequency of training and matches might be a confounder. Another definition used is medical attention injuries with need for assessment and/or treatment by medical personnel (Fuller et al,. 2004; Junge et al,. 2004a). The NCAA uses a definition combining time loss and medical attention (Dick et al,. 2007). There are also other definitions used, such as tissue injuries (Junge et al,. 2004b; Junge & Dvorak 2000), insurance claims injuries (de Loës et al,. 2000) and hospital-treatment injuries (Hoy et al,. 1992). Although a study comparing the time-loss injury definition with absence from the next training session or match and the tissue injury definition at the elite level in football (Waldén et al,. 2005) found no difference in the injury incidence. This could be different at other levels with fewer training sessions and matches. Another aspect is subjectivity, where one athlete with an injury may train or compete while another athlete with the same injury will feel too impaired to do the same (Noyes et al,. 1988). A challenge with agreeing on a universally acceptable injury definition in sport is that an injury in one sport may not be regarded as such in another (Fuller & Drawer 2004; Harrison & Price 1992; Noyes et al,. 1988). A handball player may not be able to compete with a fractured thumb, while a snowboarder or speed skater might not be hampered by such an injury. Therefore, the need for agreement on injury definitions and standards in sports injury epidemiology has been expressed as essential to advance our understanding of athletic injury epidemiology and get reliable and comparable data (Finch 1997; Junge & Dvorak 2000; Meeuwisse & Love 1997; Noyes et al,. 1988; van Mechelen et al,. 1992).

The definition of what constitutes a skiing or snowboarding injury differs from study to study. A few studies from competitive skiing and snowboarding have used a time-loss definition (Dowling 1982; Torjussen & Bahr 2005, 2006), some only included severe injuries requiring an absence of >20 days (Margreiter et al,. 1976; Raas 1982), one required transport of or treatment by the medical team (Bergstrøm et al,. 2001) and one did not clearly define an injury (Ekeland et al,. 1996). Mostly, the definition used in recreational skiing and snowboarding is medical attention injuries, usually treated or consulted by the ski patrol and in some cases by well established base lodge clinics (Ekeland & Rødven 2000; Ekeland & Rødven 2006; Greenwald et al., 2003; Johnson et al., 1997; Langran & Selvaraj 2002; Laporte et al., 2000). However, there are also studies using self report (Jørgensen et al,. 1998; Oliver & Allman 1991) and reports from hospitals (Dohjima et al,. 2001; Molinari et al., 1996; Rønning et al,. 2000). It is quite clear that with so many different injury definitions it is difficult to compare the results across studies.

Cricket, football, rugby and tennis are sports where consensus statements have been developed and published (Fuller et al,. 2006, 2007; Orchard et al,. 2005; Pluim et al,. 2009). The consensus for football injuries was produced by a group consisting of experts involved in football injury research hosted by the Fédération Internationale de Football Associations Medical Assessment and Research Center (F-MARC) with the intention to standardise injury definition, methodology and reporting standards for injuries in football, as well as providing a basis for studies in other team sports (Fuller et al,. 2006). The rugby consensus was developed after reviewing and conducting minor revision to the football consensus to make it specific for and possible to adapt to rugby (Fuller et al,. 2007). By doing this, rugby developed a uniform consensus for research in their sport and at the same time adopted a broadly similar definition and methodology to other sports and should enable meaningful inter-sport comparison. The International Association of Athletics Federations (IAAF) and the IOC have also demonstrated that the consensus statements developed for multi-sports are feasible for individual sports (Alonso et al,. 2009; Junge et al,. 2008). Recently, tennis came with a consensus statement, drawn from the football and rugby proposals but reflecting specific issues to elite and community levels of play in tennis (Pluim et al,. 2009). There has been no consensus for injury recording in skiing and snowboarding and therefore it is difficult to directly compare studies and results. When establishing the FIS Injury Surveillance System, the consensus from football was chosen with regards to definition and categories. Their suitability was examined in Paper I.

Key epidemiological variables

In the sequence of prevention, van Mechelen and co-workers (1992) highlight two key variables in an epidemiological study; severity of the injury and the incidence. These are important aspects as they are used to assess the extent of the injury problem in the sport.

Severity

To assess the need for preventive efforts, injury severity is also important, as severe injuries should have priority (van Mechelen 1997a). It has been recommended that the severity is described based on six closely related criteria: nature of the injury, duration and nature of treatment, sporting time lost, working time lost, permanent damage and cost (van Mechelen et al,. 1992). Categorising injuries according to phrases such as minor, moderate and major might be misleading without knowledge about time lost from participation as a "minor" injury can involve significant tissue damage and time-loss (Fuller & Drawer 2004). The need for uniform classification of this variable is needed. The NAIRS defines the injuries based on the duration of time loss from sports as minor; under a week, moderate; from one to three weeks and major; greater than three weeks' absence from participation (Clarke 1975). The consensus statement from football defines severity as the number of days from the day of injury until full participation in training and competition and classify them into slight (0 days), minimal (1-3 days), mild (4-7 days), moderate (8-28 days), severe (> 28 days) and career ending (Fuller et al,. 2006). The consensus statements from rugby and tennis use the same with only minor modification to fit specific needs (Fuller et al,. 2007; Pluim et al,. 2009). In skiing and snowboarding, however, there is no consensus on injury severity and the definition varies. In competitive alpine skiing, freestyle skiing and snowboarding, severity has been classified according to the NAIRS definition (Torjussen & Bahr 2005, 2006), free reporting of days absence (Dowling 1982), severe injuries with absence >20 days (Ekeland et al., 1997; Margreiter et al,. 1976; Raas 1982) and the Injury Severity Score (ISS) (Bergstrøm et al,. 2001). The ISS is a mathematical scoring system developed for assessment of patients with multiple trauma (Baker et al,. 1974). It is based on the anatomical location and the Abbreviated Injury Scale (AIS). The AIS is a 6-point scale classifying minor injuries with 1 and unsurvivable injuries with 6 (Anonymous 1971). The ISS is rated from 1 to 75 and is defined as the sum of the square of the highest AIS grade in each of the three most severely injured areas (Baker et al,. 1974). A higher ISS score is more serious. Among recreational skiers and snowboarders this way of reporting severity is used in several studies, mainly those based on hospital recordings.

Incidence

The incidence of injury is the other key variable highlighted in the sequence of prevention (van Mechelen et al,. 1992). Incidence defined as number of new injuries in a given population within a specified period of time (Porta 2008) also gives an estimate of risk. The incidence rate of sports injuries is usually defined as number of new sports injuries in a specific time divided by the initial number of persons (Kirkwood & Sterne 2005; van Mechelen et al,. 1992). The injury risk may be calculated: per total population when there are also individuals who are not exposed to the sport and its injuries, per active population at risk, or most preferably, per time unit of exposure (de Löes 1997). In skiing and snowboarding, the injury rate depends in addition to the injury definition also on the reporting source and the exposure-time defined (Table 1). The most commonly used way to report injury rate is injuries per 1000 skier/snowboarder days (SD/SBD) or skier/snowboarder visits (SV/SBV). Mean days between injuries (MDBI) has also been introduced when the number of injuries per 1000 SD is less than one. The MDBI is the total number of skier/snowboarder-days divided by the total number of the specific injury seen, hence five injuries per 1000 SD means 200 MDBI (Johnson et al., 1993). The difference between SD/SBD and SV/SBV is that a skier/snowboarder day could be assumed to be the quantitative measure of the amount of skiing done, whereas a skier/snowboarder visit simply denotes that a specific number of people visited the ski area (without accounting for the number of ski runs during that visit). The amount of skiing performed by individual skiers in a day is unknown and likely variable, so SV and SD have just subtle differences (Lamont 1991). For competitive skiers and snowboarders, incidence has been described as the number of injuries per 1000 runs (Bergstrøm et al,. 2001; Ekeland et al,. 1996; Torjussen & Bahr 2005, 2006), per 1000 racers (Ekeland & Holm 1985), per 100 skier seasons (Pujol et al,. 2007) or per 1000 SD (Dowling 1982; Wright, Jr. et al,. 1986). The challenge with using injuries per 1000 runs is that only injuries happening in competitions can be recorded if not a specific strategy for counting the number of runs performed in training can be developed. Using SD/SBD as the measure makes comparison to recreational skiers and snowboarders possible, but perhaps not very helpful, as there may be large differences in the time spent on the course.

Relative and absolute injury risk

A recent study discussed the importance of using both relative injury risk (i.e. where the injury risk is expressed as a rate corrected for exposure) as well as the absolute injury risk (i.e. expressed as the total number of injuries during a season for a team or player/athlete) when comparing injury risk between different levels of play in football (Froholdt et al,. 2009). When using the absolute injury risk they found a five times higher injury risk at the elite level compared to 16- to 17-year old players, while the relative injury risk was only twice as high. By using the absolute injury rate it would be possible to compare the overall risk of being injured at different levels and maybe even more interestingly, across different sports. We address this issue by introducing a comparison of absolute injury risk between skiing and football in Paper II.

Injury incidence in skiing and snowboarding

Recreational skiing and snowboarding

Alpine skiing

Recreational alpine skiing has been studied quite extensively. Due to the development of the sport, the injury incidence has changed and varied a great deal up through the years. Data obtained from the Sun Valley experience (USA) disclosed that skiing injuries declined from an incidence rate of 7.6 injuries per 1000 SD between 1952 and 1957 to 2.6 injuries per 1000 SD between 1975 and 1976 (hospital and physician reported data) (Earle et al,. 1962; Moritz 1959; Tapper & Moritz 1974). Johnson and his colleagues (1997) have reported injures prospectively from a ski area in Vermont (USA) from 1972 based on injury reports from injuries reported to the injury clinic operated at the base of the lodge. They described a decline of all injuries by 44% between 1972 when the injury rate was 4.7 to 1994 when the injury rate was 2.5 injuries per 1000 SD. Thus, it appears as the injury rate for alpine skiing has decreased dramatically during the last 40-50 years (see Table 1).

Table 1. *Changes in injury rate reported by different studies over the past 40-50 years.*

Study	Design	Who reported	Data collection	Injury rate per 1000 SD	Nation
(Haddon et al,. 1962)	P	Physician/Medical	1962	5.9	USA
(McAlister et al,. 1965)	R	Ski Patrol	1965	7.3	USA
(Tapper & Moritz 1974)	R	Hospital/Clinic	1969-72	5.1 in 1969/70 3.2 in 1971/72	USA
(Young et al,. 1976)	P	Ski Patrol	1966-73	4.2 in 1966-67 2.8 in 1973-74	USA
(Requa et al,. 1977)	R	Self report	1971-73	9.3	USA
(Korbel & Zelcer 1982)	P	Ski patrol/Medical	1980	1.4	Australia
(Ascherl et al., 1982)	P	Hospital	1971-81	2.4	Germany
(Dubravcik et al., 1982)	P	Physician	1979-81	2.7	Canada
(Shealy 1985)	P	Physician	1979-81	2.16 in 1978/79 2.2 in 1980/81	USA
(Lystad 1989)	P	Physician	1982-86	0.9	Norway
(Johnson et al., 1989)	P	Medical report	1972-87	5 in 1971 2.5 in 1987	USA
(Sherry & Fenelon 1991)	R	Hospital	1988	3.22	Australia
(Young & Lee 1991)	P	Ski Patrol	1988-89	3.37	USA
(Oliver & Allman 1991)	R	Self report		24 (3.6 for those who were seen by ski patrol or physician)	USA
(Johnson et al., 1993)	P	Medical report	1972-90	5 in 1973 2.5 in 1990	USA
(Shealy & Ettlinger 1996)	P	Physician	1988-90	2.2 ♂[1] 3.4 ♀[1]	USA
(Molinari et al., 1996)	R	Hospital	1988-92	0.85	Italy
(Warme et al,. 1995)	P	Physician	1982-93	3.7	USA
(Langran et al,. 1996)	P	Physician	1993-94	2.43	Scotland
(Johnson et al., 1997)	P	Medical report	1972-1994	2.5 in 1994	USA
(Deibert et al,. 1998)	P	Medical report	1981-1994	2.79 (4.27 children, 2.93 adolescents, 2.69 adults)	USA
(Jørgensen et al,. 1998)	R	Self report	1995	33.6	Denmark

P = prospective; R = retrospective; [1] Per 1000 Skier visits

Most of the studies present a total injury incidence for all kind of skiing activities on the slope. The injury rate is dependent upon who is reporting the injury, in addition to the definition, as previously mentioned. Thus, self-reported injuries have been reported to have much higher injury rates than ski patrol reports followed by physician reported injury rates and hospital reported rates.

Table 2 summarizes the injury incidence from prospective surveillance studies among recreational skiers over the last 10 years. The longest injury surveillance is from Vermont, USA, where injury recording by physicians at mountain-based medical centers has continued since 1972 and is still running with a current rate of 1.9 injuries per 1000 SV (Johnson et al,. 2009). The injury rate varied between 0.35 to 40.5 injuries per 1000 SD/SV (Table 2). The study by Dohjima and co-workers (2001) reported hospital injuries and the incidence would therefore be expected to underreport rate compared to other studies, because minor injuries are often not seen in the hospital. The high figure of 40.5 injuries per 1000 SD (O'Neill & McGlone 1999) was from skiers attending a beginner package including equipment rental, lift ticket and instruction for one day. The rate was 6.5 injuries per 1000 SD for injuries with need for medical attention. Nevertheless, the majority of studies from skiing resorts in the US and Europe report an injury incidence between 1 and 3.7 injuries per 1000 SD.

Table 2. *Epidemiological studies on the incidence of injuries in recreational alpine skiing*

Reference, country, season, follow-up period	Population	Exposure	No of all injuries	Injury recording and definition	Injury incidence (per 1000 SD)
(O'Neill & McGlone 1999) USA 1994-96	Skiers with beginner packages (rental, lift ticket and instruction)	The day of the instruction	641	Medical report from local clinic of all injuries and subdivided to emergent[1] (necessitation immediate medical intervention) and nonemergent[2]	40.5 (6.5[1], 34.1[2])
(Bergstrøm et al,. 1999) Norway 1990-92	Skiers in a regional alpine ski center	Exposure from lift tickets	152 (183 injuries at the slope)	Ski patrol reporting of skiers transported or treated by the ski patrol for injuries with an ISS from 1 to 75	1.8 (83.1% alpine skiing)
(Langran & Selvaraj 2002) Scotland 1999-2000	Alpine skiers at three skiing areas	Exposure from lift tickets and control interviews	440	Ski patrol/physician reporting of all injuries attended by the ski patrol service or local medical clinic	3.7
(Ekeland & Rødven 2000) Norway, 1996-98	Skiers at 4-7 major ski resorts	Exposure from lift tickets and control interviews	3915 (alpine 57%)	Ski patrol reporting from skiers taken care of or consulted the ski patrol after a skiing accident	1.2 (57% of injuries in alpine skiing)
(Johnson et al., 2000) Vermont, USA 1972-98	Alpine skiers at a regional ski center	Exposure from lift tickets and control interviews	15526	Medical report and questionnaire from injuries treated at base lodge clinic within 48 h	2.3 in 1998
(Rønning et al,. 2000) Norway, 1997	Skiers from one skiing area	Exposure from lift tickets with control observation in lift line	35	Hospital recordings from injuries treated at local hospital	1.2
(Laporte et al., 2000) France, 1992-99	Skiers at 52 winter sports resorts	Exposure from lift tickets and control interviews	232571 (21303 ACL ruptures)	Medical report for injuries treated by a doctor in base lodge clinics	2.5 (0.3 for ACL)
(Dohjima et al,. 2001) Japan, 1988-97	Skiers from one skiing area	Exposure from lift tickets	5048	Hospital reports for injuries treated at hospitals	0.35*
(Greenwald et al., 2003) USA, 1998-00	Skiers at a large ski resort	Exposure from lift tickets with control observation in lift line	4584 (65% alpine)	All injuries recorded by ski patrol with follow up in base lodge clinic	2.2
(Ekeland et al., 2005) Norway, 2000-02	Skiers at eight major ski resorts	Exposure from lift tickets and control interviews	6402 (49% alpine)	Ski patrol reporting of all injuries treated by or consulted with the ski patrol after a skiing/snowboarding accident	1.1
(Zacharopoulos et al,. 2009) Greece, 2004-06	Skiers/snowboarders at two ski resorts	Exposure from lift tickets and control interviews	712 (978 skiing and snowboarding)	Medical report from physician at base lodge clinic of skiing/snowboarding injuries seen by physicians at resorts' medical station	6.05 (72.7% skiing)
(Johnson et al,. 2009) USA, 1972-2006	Alpine skiers at a regional ski center	Exposure from lift tickets and census of ski lifts	18692	Medical report and questionnaire from injuries treated at base lodge clinic within 48 h	1.9 in 2006

* Injuries per 1000 SV

Freestyle skiing

It is difficult to find studies in recreational freestyle skiing, as this is more or less a competitive sport only. Skiers riding in mogul pistes, or free riding skiers might be considered as performing freestyle elements, but in epidemiological studies these are generally categorized as alpine skiers, so no data is available from recreational freestyle skiing as a separate group.

Snowboarding

For recreational snowboarders, several studies have described the injury incidence over the last 10 years (Table 3). Reports from hospitals/medical clinics varies in their injury rate from 1.5 to 4.0 injuries per 1000 SBD, while the injury rate reported from ski patrol/medical attendance at the base lodge varies from 2.3 to 4.0. Some studies have only reported the injury rate for a specific group of snowboarders. O'Neill & McGlone (1999) reported an injury rate of 41.5 injuries per 1000 SBD for snowboarders attending a beginner package including equipment rental, lift ticket and instruction. Another study (Machold et al,. 2000) reported 10.6 injuries per 1000 SBD for Austrian school children. The same study also indicated that children snowboarding for the first time had an 8- times higher risk for injuries than children snowboarding >50 times. Other studies have also reported that beginner snowboarders are more likely to sustain an injury than those with more experience (Boldrino & Furian 1999; Langran & Selvaraj 2004; Rønning et al,. 2001; Shealy & Ettlinger 1996).

Depending on the population studied, there is again a large range in injury incidence from 1.5 injuries per 1000 SBV (Wakahara et al,. 2006) to 41.5 injuries per 1000 SBD (O'Neill & McGlone 1999).

Table 3. *Epidemiological studies on the incidence of injuries in recreational snowboarding*

Reference Country, season, follow-up period	Population	Exposure	No of all injuries	Injury recording and definition	Injury incidence (per 1000 SD)
(O'Neill & McGlone 1999) USA 1994-96	Snowboarders with beginner packages (rental, lift ticket and instruction)	The day of the instruction	273	Medical report from local clinic of all injuries and subdivided to emergent[1] (necessitation immediate medical intervention) and nonemergent[2]	41.5 (17.5[1], 24.0[2])
(Sasaki et al,. 1999) Japan, 1991-97	Snowboarders in a skiing/snowboarding area	Exposure obtained from National ski park association	1445	Clinic/hospital recording for injuries treated at a local clinic	3.5*
(Langran & Selvaraj 2002) Scotland 1999-2000	Snowboarders at three skiing areas	Exposure from lift tickets and control interviews	198	Ski patrol/physician reporting for all injuries attended ski patrol service or local medical clinic	4.0
(Matsumoto et al,. 2004) Japan, 1998-01	Snowboarders at 10 skiing facilities in Japan	Exposure estimation from counting snowboard passes	5110	Hospital recording for injuries treated at local hospital	2.1*
(Rønning et al,. 2000) Norway, 1997	Snowboarders from one skiing area	Exposure from lift tickets with control observation in lift line	16	Hospital recording for injuries treated at local hospital	4.0
(Machold et al,. 2000) Austria, 1996-97	2579 school children snowboarding during their sport-week	Exposure reported by the population	152	Medical report from either hospital or surgeons for medical attention injuries	10.6
(Dohjima et al,. 2001) Japan, 1988-97	Snowboarders from one skiing area	Exposure from lift tickets (snowboarders need special ticket)	2552	Hospital reports for injuries treated at hospitals	2.03*
(Greenwald et al., 2003) USA, 1998-00	Snowboarders at a large ski resort	Exposure from lift tickets and control interviews	4584 (33% SB)	All injuries recorded by ski patrol with follow up in base lodge clinic	4.1
(Made & Elmqvist 2004) Sweden, 1989-99	Snowboarders from two skiing areas	Exposure from lift tickets and control interviews	568	Medical report from physician for medical attention injuries seen at the local medical center within 48 h	3.0
(Ekeland et al., 2005) Norway, 2000-02	Snowboarders at eigth major ski resorts	Exposure from lift tickets and control interviews	2762	Ski patrol reporting of all injuries treated by or consulted with the ski patrol after a snowboarding accident	2.3

(Xiang et al,. 2005) USA, 2002	Snowboarding injuries registered in a database from 6100 hospitals in the US	Exposure estimation from national registry	62000	Hospital reporting for snowboard related injuries treated in emergency departments	15.9 age 10-13 15.0 age 14-17 13.5 age 18-24
(Wakahara et al,. 2006) Japan, 1995-90	Snowboarders in one skiing area	Exposure estimation from counting snowboard passes	15320	Hospital report of spinal cord injuries, but numbers for all snowboard-related injuries given	1.5*
(Zacharopoulos et al,. 2009) Greece, 2004-06	Skiers/snowboarders at two ski resorts	Exposure from lift tickets and control interviews	266 (978 skiing & snowboarding)	Medical report from physician at base lodge clinic of skiing/snowboarding injuries seen by physicians at resorts' medical station	6.05 (27.3 % snowboarding)

* Injuries per 1000 SV

Table 4. *Epidemiological studies on the incidence of injuries in recreational Nordic disciplines.*

Reference Country, season, follow-up period	Population	Exposure	No of all injuries	Injury recording and definition	Injury incidence (per 1000 SD)
Cross-country skiing					
(Boyle et al., 1985) USA, 1980-81	Cross-country skiers at touring centers	Estimation from touring centers with control of uninjured skiers	49	Skiers were encouraged to reporting all injuries to ski patrol members or personnel in the lodge. Questionnaire and follow up for more information.	0.72 (1.5 in 1980 and 0.48 in 1981)
(Sherry & Asquith 1987) Australia, 1984-85	Cross-country skiers in National park	Estimation based on gate counts	88	Medical records from injuries treated at local ski injury clinic	0.49
(Pigman & Karakla 1990)	638 male military recruits performing Nordic ski training during 4 weeks	Estimated for the group involved	45	Definition not given	5.63

Nordic disciplines

Studies from touring centres have reported injury incidences of 0.49 to 0.72 injuries per 1000 SD for cross-country skiers (Table 4). In even older studies, the injury rate has been estimated to be about 0.2 injuries per 1000 SD (Eriksson & Danielsson 1977). Accurate knowledge of the population at risk is a challenge because cross-country skiing is not confined to specific slopes or areas, but rather is possible wherever there is snow (Renström & Johnson 1989). The injury rate for cross-country skiing in male military recruits has been reported to be as high as 5.63 per 1000 SD (Pigman & Karakla 1990). It is, however, difficult to compare to other studies, as this group was on long skiing tours on ungroomed slopes carrying full backpacks and rifles. Again, it is challenging to compare the different studies because of different populations and methodological issues. The injury incidence in recreational cross-country skiing has therefore been suggested to lie between the figures by Sherry and Asquith and Boyle and co-workers (Smith et al,. 1996).

Competitive skiing and snowboarding

Alpine skiing

A handful studies have looked at the epidemiology of injuries to competitive alpine skiers. A study from 1976 (Margreiter et al,. 1976) reported that 79% (31 of 40) of female racers and 87.8% (65 of 74) of male racers had had at least one serious injury (absence over 20 days) during their career. Most of the events leading to serious injuries occurred in downhill and they estimated that the risk of injury was 25 times as high in racing as in practice. Another study (Raas 1982) reported that 83% of 148 racers had suffered serious injuries (absence over 20 days) during the previous three years. Two thirds of these injuries happened in downhill compared to 23% in slalom and 11% in giant slalom. Of the few studies reported on injury incidence within alpine skiing, two of these studies include relatively few participants from only one event (Junior World Championship and winter Olympic Games). The injury rate is given as number of injuries per 1000 runs, as the exposure for the included athletes was known (number of runs down the slope) and is described to be 1.9 to 4 injuries per 1000 runs. Only one, older study has studied a whole season, describing the injury risk in downhill to be 10 times that of slalom (Ekeland & Holm 1985) (Table 5).

Table 5. *Epidemiological studies on the incidence of injuries in competitive skiers and snowboarders*

Reference	Population	Exposure	No of all injuries	Injury recording and definition	Injury incidence (per 1000 runs)	Injury incidence (other)
Alpine skiing						
(Bergstrøm et al,. 2001)	Participants in one Junior World Championship (1995) (n=998) 15-19 years	Calculated from race completion rates	4	Medical report of skiers transported or treated by the medical team for injuries with an ISS from 1 to 75	4.0 Downhill 8.3	
(Ekeland et al,. 1996)	Alpine skiers participating in the winter Olympic Games 1994 (n=555)	Calculated from race completion rates	3	Medical report of all injuries during official training and competition	1.9 Downhill 1.1	
(Pujol et al,. 2007)	Athletes in the national, reserve, or rookie teams for the French Alpine ski team during 1980-2005 (n=379)	Estimated as injuries per 100 skier season	157	Review of the French Ski Federation database and medical report from one surgeon serving the team during the hole period for ACL injuries		8.5 ACL ruptures per 100 skier season (Prevalence of re-injury 19%, bilateral rupture 30.5%)
(Ekeland & Holm 1985)	Norwegian skiers competing in 251 national competitions during 1981-82 season (n=25446)	Not estimated	40	Injury report (A referee appointed by the Norwegian Ski Association for each competition recorded any injuries occurring during the race)		1.6 injuries per 1000 participating racers (downhill 10.3, giant slalom 0.7, slalom 0.8)
(Stevenson et al,. 1998) Vermont, USA	Competitive skiers in one geographic area (n=404)	Not estimated	110	Self-reported questionnaire sent out of previous knee injuries while skiing		Female-male ratio 2.3 (ACL 3.1)
Snowboarding						
(Torjussen & Bahr 2005) 2-parted study named 1 and 2	1. Snowboarders competing in 22 national tour events during the 2001-02 season (n=1465) 2. Snowboarders at the national championship at the end of the 2000-01 winter season (n=163)	Calculated as the number of events multiplied by a fixed number of runs for each discipline	1. 32 2. 84	1. Prospective medical reporting 2. Retrospective athlete interviews - of acute injuries causing cessation of the athlete's participation in competition or training for at least 1 day after the day of the incident	1. 4.0 (big jump 14.2, snowboard cross 6.1, halfpipe 3.1, giant slalom 1.9) 2. 3.4 (big jump 6.6, snowboard cross 5.8, halfpipe 2.1, giant slalom 6.6)	

(Torjussen & Bahr 2006)	Snowboarders at the World Cup level at the end of the 2002-03 seasons (n=258)	Calculated as the number of events multiplied by a fixed number of runs for each discipline	135 acute (122 overuse)	Athlete interviews of acute injuries resulting in missed participation and overuse injuries influencing performance	1.3 (big air 2.3, halfpipe 1.9, snowboard cross 2.1, parallel giant slalom 0.6, parallel slalom 0.3)	
Freestyle skiing						
(Dowling 1982)	Freestyle skiers competing in USSA sanctioned freestyle events during 1976-1980 (n=3180)	Calculated from chairman report	29	Accident reports (competition chairman) of all injuries with the loss of one or more full days of skiing reported to the competition chairman		2.8 injuries per 1000 SD (aerial 4.7, mogul 2.1, ballet 0.3)
Ski jumping						
(Wright, Jr. et al,. 1986) Lake Placid, USA, 1980-85	Ski jumpers; (n=47) WC 2233 jumps, non-WC 3899 jumps	Estimation from official results	72	Accident report completed by ski patrollers, coaches, or physician and medical information from hospitals in five seasons		1.2 per 1000 SD WC 4.3 per 1000 SD non- WC
(Wright, Jr. et al,. 1991) Lake Placid, USA, 1980-85	Active ski jumpers (n=133) 9-64 years Males	Not estimated	81	Injury questionnaire sent to registered active ski jumpers for injuries examined by physicians		9.4 injuries per 100 skier-years
(Yamamura et al., 1993) Sapporo, Japan, 1985-90	Competitive ski jumpers in 56 ski jumping games (n=not available but 7831 jumps)	Calculated jumps from competitions	43	Falls registered from official records. Follow up of falls (43 of 71) with injury information. Not further defined		5.04 injuries per 1000 jumps
Cross-country skiing						
(Butcher & Brannen 1998) USA, 1996	Male cross-country skiers in the American Birkebeiner ski marathon (55km) (n=833) 11-84 years	Not given	195	Self-administered questionnaire of any skiing-related injury or complaint during training before the race or during the marathon		234 injuries per 1000 skiers

Freestyle skiing

The only study available from competitive freestyle skiing reported injuries from the United States Ski Association events during the 1978-79 and 1979-80 seasons, estimating that there were 2.8 injuries per 1000 SD (Dowling 1982).

Snowboarding

There are two recent studies from elite snowboarding describing the injury incidence. Among 258 World Cup snowboarders, 135 acute time-loss injuries were recorded corresponding to 1.3 injuries per 1000 runs (Torjussen & Bahr 2006). A similar study from the national level reported 3.4 – 4.0 injuries per 1000 runs (Torjussen & Bahr 2005). The incidence for the different disciplines in World Cup were 2.3 injuries per 1000 runs in big air, 1.9 in halfpipe, 2.1 in snowboard cross, 0.6 in parallel giant slalom and 0.3 in parallel slalom. For the national athletes the figures appear to be somewhat higher (Table 5).

Ski jumping

There are few studies describing injuries to competitive ski jumpers and these are also old and not necessarily representative for the current level of performance (Table 5). A study from 1986 reported injuries over a 5-year period through accident reports from ski patrollers, coaches and physicians for injuries during World Cup competitions and training in Lake Placid, USA. They reported 1 injury during 864 SD, which corresponds to an injury rate of 1.2 injuries per 1000 SD. For non-World Cup ski jumpers during the same period 8 injuries were recorded during 1881 SD, an injury rate of 4.3 per 1000 SD (Wright, Jr. et al,. 1986). Two other retrospective studies have reported injuries to active ski jumpers as 9.4 injuries per 100 skier years and 5.04 injuries per 1000 jumps (Wright, Jr. et al,. 1991; Yamamura et al., 1993). The use of different injury definitions and methodology also makes a comparison between these studies difficult.

Cross-country skiing

For cross-country skiing, we are not aware of any studies from the World Cup level. From the American Birkebeiner cross-country ski marathon a figure of 234 injuries per 1000 skiers during training before the race or during the competition was reported (Butcher & Brannen 1998).

Nordic combined

No studies describing the injury incidence in Nordic combined have been found.

In summary, for competitive skiing and snowboarding it is only in snowboard where we have been able to identify two recent studies describing the injury incidence at the World Cup and national competitive level. In the other disciplines the handful of studies available are generally small with few participants, describe only one competition/event and are not of recent date. Therefore, to increase our knowledge of injuries to competitive skiing and snowboarding athletes, injuries in the different World Cup disciplines are described in Paper II. In addition, more detailed information of injury incidence is described for alpine skiing and freestyle skiing in Paper III & IV.

Injury location and type in skiing and snowboarding

In addition to knowing the injury rate, it is important to define the magnitude of the problem by describing the body part injured, injury type and severity of injuries. From the skiing and snowboarding literature it is mainly acute injuries that have been reported. To provide a current estimate, studies from the last 10 years including more than 100 injuries have been reviewed for recreational skiers and snowboarders (Table 6 & 7). However, as there is very little data from the Nordic disciplines and competitive skiing and snowboarding, all available studies have been included.

Table 6. *Injury locations in studies on alpine skiing (%).*

	Head/neck	Upper extremity	Shoulder/ clavicle	Wrist/ Hand	Lower extremity	Knee	Lower leg	Ankle	Abdomen/ chest	Spine/ back
Medical clinic/hospital										
(Boldrino & Furian 1999) USA, 1997 (n=160)	14	20	5	9	44	21	13		11	6
(Xiang et al,. 2005) USA, 2002 (n=77300)	15.7	33.2	15.6	11.0	37.6	22.7		8.7		6.1
(Sasaki et al,. 1999) Japan, 1991-1997 (n=10977)	15.5	25.9	12.5	9.4	52.5	31.0	7.5	8.7		6.1
(Dohjima et al,. 2001) Japan, 1988-2000 (n=5048)	10	26			40					
(Matsumoto et al,. 2002) Japan, 1995-2000 (n=2243)	29	19			35				17 (trunk)	6.1
(Corra et al,. 2004) Italy, 2001-2002 (n=1003)	17	24			31				10	13
Ski patrol/local clinic										
(Langran & Selvaraj 2002) Scotland, 1999-2000 (n=480)	15.7	24.2	6.9	14.8	53.1	36.7	4.8	8.1	3.2	
(Bridges et al,. 2003) Canada, 1999-2000 (n=823)	19	25	12	10	48	30	7	6	1	6
(Ekeland & Rødven 2009a) Norway, 2004-2006 (n=4575)	18	29	11	12	44	24	10	6	3	7

n=number of injuries

Table 7. *Injury locations in studies on snowboarding (%)*

	Head/neck	Upper extremity	Shoulder/ clavicle	Wrist/ Hand	Lower extremity	Knee	Lower leg	Ankle	Abdomen/ chest	Spine/ back
Medical clinic/hospital										
(Machold et al,. 2000) Austria, 1996-97 (n=152)	11.2	61	5.9	52 (incl lower arm)	21	7.9	3.3	6.6		2.0
(Boldrino & Furian 1999) USA, 1997 (n=102)	12	46	6	22	23	16			8	5
(Made & Elmqvist 2004) Sweden, 1989-1999 (n=568)	15.6	54.4		38.9	19.2	9.5	1.2	4.9	3.7	8.1
(Xiang et al,. 2005) USA, 2002 (n=62000)	16.6		14.7	21.9	18.5	6.4			11.6 (torso)	
(Sasaki et al,. 1999) Japan, 1991-1997 (n=1450)	13.4	51.3	16.7	23.5	27.2	8.0	4.2	11.3		
(Matsumoto et al,. 2002) Japan, 1995-2000 (n=2243)	23	40			14					23
(Dohjima et al,. 2001) Japan, 1988-2000 (n=2552)	8	55			17					
(Corra et al,. 2004) Italy, 2001-2002 (n=331)	18	44			17				4	17
(Yamagami et al,. 2004) Japan, 1992-1999 (n=3243)	18	38	12	16	18	6	4	6	7	7
Ski patrol/local clinic										
(Langran & Selvaraj 2002) Scotland, 1999-2000 (n=213)	19.7	46	8.9	29.7	21.6	12.2	0.5	7.0	4.2	3.3
(Bridges et al,. 2003) Canada, 1999-2000 (n=434)	17			25		7	1	6	1	10
(Ekeland & Rødven 2009a) Norway, 2004-2006 (n=2746)	18	53	12	31	17	6	3	6	4	9

n=number of injuries

Recreational skiing and snowboarding

Alpine skiing

Of all injuries sustained by recreational alpine skiers, 31-53% affects the lower extremities (Table 6). The knee is the most commonly injured body part with 21-37% of all injuries. Knee injuries have been described to have a MDBI in 2005/06 of 3101 (0.3 ACL injuries per 1000 SD) (Johnson et al,. 2009). The incidence rate for lower extremities has decreased by 50% since the late 1970s (Johnson et al., 2000) with the greatest decrease (83%) in lower leg injuries. This reduction has been ascribed to the improvement in release bindings and ski boots (Deibert et al,. 1998; Ettlinger et al., 2006; Ettlinger & Johnson 1982; Hauser 1989; Johnson et al., 1997). In recent years, however, there has been little change in the injury rate from 1988 to 1998 (Johnson et al., 2000). In the Vermont injury study (USA) (Johnson et al., 1997), the pattern has shown a 90 % decrease in twist-related injuries to the lower leg (below the knee) and an 83% decrease in bend-related injuries to the lower leg (tibia fractures). Ankle sprains, another component of the twist subgroup of lower leg injuries, decreased by 92%. Lower leg fractures presently represent 3-5% of all injuries (Ekeland et al., 2005; Langran & Selvaraj 2002), but the proportion is described to be much higher for children compared to teenagers and adults (Deibert et al,. 1998; Ekeland et al,. 1993, 2005; Laporte et al., 2000; Ungerholm et al,. 1985). Fractures of the lower extremity were up to nine times more common in children < 10 years of age than in adults (Ekeland et al,. 1993). Although the injury rate to the lower extremity has decreased significantly, the rate of severe knee sprains, usually involving the ACL has doubled from the 1970s to the 1990s (Johnson et al., 2000). On the other hand, there has been described a decrease in ACL injuries during the last years (1991 to 2006) (Johnson et al,. 2009). Hagel and co-workers (2004) reported an injury rate for lower leg injuries 0.43 injuries per 1000 SD, or 2.56 per 1000 skiers per year.

Injuries to the upper extremity account for 19-33% of all injuries and the most common injuries are to the shoulder and thumb. Trauma to the shoulder accounts for 5-16% of all injuries. Men have twice as many shoulder injuries as women (Ekeland & Rødven 2009a; Shealy & Ettlinger 1996). The most common injuries are rotator cuff strains or tears, anterior gleno-humeral dislocation, acromio-clavicular separation and clavicular fractures (Kocher & Feagin, Jr. 1996). The most common fracture of the shoulder for alpine skiers is a fracture of the clavicle (Kocher & Feagin, Jr. 1996). Radius fractures are not common among skiers (Davidson & Laliotis 1996). Injuries to the thumb account for between 4-10% of all skiing accidents (Davidson & Laliotis 1996; Johnson et al., 1997; Langran & Selvaraj 2002). These injuries are likely underreported by the ski patrol/medical facilities, as the skier might not seek medical attention at the injury site. A specific skiing injury, "skier's thumb" has been described as an acute injury to the first metacarpophalangeal joint, (MCP) with stretched or damaged ulnar collateral ligament of the thumb (Lamont 1991; Mogan & Davis 1982). Most of the thumb injuries in skiing are sprains (86%) (Carr et al,. 1981).

Head injuries account for 10 to 29% of all injuries. Sulheim and co-workers (2006) reported that approximately 25 % of the head injuries recorded by ski patrol were referred to a physician or hospital for further assessment or treatment (potentially severe injuries). Injuries to the head are mainly minor contusions and concussions (Lindsjö et al., 1985; Sulheim et al,. 2006). Spinal injuries seem to account for approximately 6% of all alpine injuries. The most frequent type of spinal injuries seen in a hospital is fracture, and burst fractures have been shown to be the most common fracture type (Tarazi et al,. 1999). Most of the fractures are located in the thoracolumbar spine (Reid & Saboe 1989; Tarazi et al,. 1999).

In summary, although some of the differences in distribution of injuries reflect the differences in injury recording, we have a fairly good picture of what the injuries to the recreational skiers are. The lower extremity is the most commonly injured body region, with the majority being severe knee sprains.

Snowboarding

In contrast to recreational alpine skiers, injuries to the upper extremity dominate in snowboarding with 38-61% of all injuries. The wrist is the most commonly injured body part with 12-26% of all injuries. A wrist fracture is the most commonly reported specific diagnosis (Idzikowski et al,. 2000; Matsumoto et al,. 2004). Extra-articular fractures dominate with 54% (Matsumoto et al,. 2004) although more experienced snowboarders sustained more severe and complex fractures. Wrist fractures are found to be more common in beginners (Idzikowski et al,. 2000; Made & Elmqvist 2004; Matsumoto et al,. 2004), women and younger age groups (Idzikowski et al,. 2000). This is the same for wrist sprains.

Hagel and co-workers (2004) reported from 5 years of ski patrol reports that snowboarders were more than 3 times as likely as skiers to have injuries of the upper extremity with an injury rate of 0.97 injures per 1000 SBD, or 6.60 injuries per 1000 snowboarders per year. Snowboarders have, however, a lower rate compared to skiers for injuries to the lower extremity (adjusted rate ratio (ARR) 0.79; 95% CI 0.66 to 0.95) with 0.36 injuries per 1000 SBD, 2.48 injuries per 1000 snowboarders per year. Injuries to the lower extremity, account for 14-27% of all injuries with the knee (6-16%) and ankle (5-11%) the most commonly of these. A rupture of the ACL, which is common in skiers, has been reported to account for only 0.6% of snowboarding injuries (Laporte et al., 2000). While severe knee sprains are common for recreational skiers, grade I or II are the most frequent for snowboarders; grade III injuries are rare (Bladin et al,. 1993). The injury rate for lower leg injuries in snowboarding was reported to 0.43 injuries per 1000 SBD, or 2.56 per 1000 snowboarders per year (Hagel et al,. 2004).

Head and neck injuries account for 8-23% of snowboarding injuries with an injury rate of 0.16 per 1000 SBD (1.06 per 1000 snowboarders per year) reported from ski patrol data (Hagel et al,. 2004). A survey among high school children reported 28% of the most serious injuries to be head injuries (Emery et al,. 2005). Compared to skiers, the rate of head/neck injury was 50 % higher in snowboarders and females had a lower rate compared to males (ARR 1.5, 95% CI 1.3 to1.8) (Hagel et al,. 2004).

Injuries to the spine and back ranged from 2-23%, with the highest percentages reported from hospital-based studies. For trunk injuries there was an injury rate of 0.16 per 1000 SBD (1.06 per 1000 snowboarders per year) and snowboarders are twice as likely to suffer injuries of the trunk compared to skiers (Hagel et al,. 2004).

Cross-country skiing

From cross-country skiing the studies available are 15-25 years old. Injuries to the lower extremity seem to vary from 31-53%, while injuries to the upper extremity account for 30-41% of all injuries (Boyle et al., 1985; Daljord & Maehlum 1986; Lereim 1999; Shealy 1985; Sherry & Asquith 1987). Wrist fractures have been described to be the most common fracture type treated at casualty department for injured cross-country skiers (Daljord & Maehlum 1986).

As described previously, ski jumping and Nordic combined are primarily competitive sports and we therefore lack data on the recreational level.

Freestyle skiing

The recreational freestyle skier, i.e. the skier going down the mogul course or try to ski the halfpipe would be described in the alpine population and we therefore do not have any separate data from freestyle skiing either. Freestyle skiing is nevertheless growing in popularity among recreational skiers with twin tip skies and the development of terrain parks. This leads to aerobic manoeuvres and challenging elements of jumps, turns and waves also to be performed by the younger recreational population.

Competitive skiing and snowboarding

Alpine skiing

For elite alpine skiers there is limited information available on injury site and injury type. There are three and four injuries reported in two studies from single-event competitions from World Junior Championship (Bergstrøm et al,. 2001) and the 1994 Olympic Winter Games (Ekeland et al,. 1996). An old study among 148 top-ranked FIS alpine athletes (Raas 1982) reported 171 severe injuries. The knee was the most commonly injured (22%) followed by the ankle (20%), lower leg (18%) and head (12%). Margreiter and co-workers (1976) reported 54 severe (absence >20 days) injuries to 40 female and 127 severe injuries to 74 male top racers from the international ski circuit 1972-74. Among the female racers, the lower leg was most commonly injured site 30% (16/54) followed by the knee 20% (11/54) and ankle 19% (10/54). For male racers the same pattern was seen with the lower leg 28% (35/127), knee 23% (29/127) and ankle 17% (21/127) being the most frequently injured body parts. Among alpine racers in national competitions in Norway, 40 injuries were recorded in 251 races during the 1981/82 season (Ekeland & Holm 1985). Leg injuries were most common (24%) followed by the knee (18%) and the back/buttocks (15%). Contusions were the most common injury type (38%) followed by sprain (30%) and fractures (20%). From 54 racers competing in the winter Olympic Games in 1994 reporting previous serious injuries (absence >20 days), the knee accounted for 43%, the lower leg 10% and the head 8% (Ekeland et al., 1997). Female racers had a significantly higher prevalence of previous ACL injuries. A study by Pujol and co-workers (2007) among French national team alpine racers followed from 1980 to 2005 reported an overall ACL injury rate of 8.5 per 100 skier-seasons.

In summary, knee injuries seem to be the most common injury location among competitive skiers, but most of the studies are not representative for the current level of performance at the World Cup level. They are in addition also mostly limited to only one event so there is a need for studies on competitive skiers.

Freestyle skiing

The only study from freestyle skiing describes injuries to competitors competing in the United States Ski and Snowboard Association sanctioned events from 1976 to 1980 (Dowling 1982). There were 29 injuries recorded where 24 contained sufficient analytical data and the most common injury locations were the knee (n=6), head (n=5) and spine (n=5). Ligament injuries were the most common injury type followed equally by fracture, muscle and contusion injuries (percentages not given).

Snowboarding

A recent study from World Cup snowboarding (Torjussen & Bahr 2006) found that the most common injury location was the knee (n=24; 18%), shoulder (n=18; 13%), back (n=17; 13%) and wrist (n=11; 8%). For national elite snowboarders, injuries to the back (22%), knee (16%), and hand/wrist injuries (9%) were the most common in a prospective study, while the knee (16%), back (13%), head (13%) and hand/wrist injuries (12%) were the most common acute injuries reported retrospectively (Torjussen & Bahr 2005). The injury pattern is therefore different from recreational snowboarders with fewer wrist injuries and more knee injuries.

Ski jumping

In ski jumping a study done with 133 active ski-jumpers in the USA, reporting injuries during the last 5 years found 211 medical attention injuries, where shoulder injuries were the most common, followed by head, ankle, knee, clavicle, face and leg injuries (Wright, Jr. et al,. 1991). Fractures were the most commonly reported injury type, with clavicle fractures being most frequent. Another study from 1985 (Wester 1985) reported at least 12 serious injuries (medical disability of at least 10%) to 2238 licensed ski jumpers from 1977-1981 based on hospital and insurance company registration. These were one cervical and two thoracolumbar fractures, one intracerebral haematoma and one eye injury, one hip, one leg and two ankle fractures, two leg amputations and one where information was not available. A follow-up to this study from 1982-86 among 2593 licensed ski jumpers (Wester 1988) found only three severe injuries, all to the head and face (one eye injury, one skull base fracture and one moderately severe head injury). Lereim (1999) reported that injuries in ski jumpers went down from 1346 in 1989 to 202 in official training and competitions in 1997 at the national level in Norway. The most commonly reported injured sites were the mid portion of the body (back, trunk, abdomen, pelvis), followed by the ankle/foot, thigh/leg and wrist/hand. Contusions were most frequent followed by sprain and laceration. In summary, there is great diversity in the recordings from ski jumping both in the terms of study quality, definitions and methodology. In addition the studies are up to 25 years old and likely not representative for the current injury rate, at least in World Cup ski jumping.

Cross-country skiing

A study among 833 participants in the American Birkebeiner cross-country ski marathon reported tendinitis/bursitis as the most common injury type directly after the race, followed by ligament sprains (Butcher & Brannen 1998). The same study found no significant difference between the two skiing techniques (skating and classic). Injuries to the ankle/foot were the most common race injuries, followed by injuries to the hand/wrist. Low back pain among competitive cross-country skiers has been described as a common complaint, with 65.4% of athletes at the national elite level reporting symptoms during the previous 12 months (Bahr et al,. 2004). The same finding was described among young competitive cross-country skiers (Eriksson et al,. 1996).

To sum up, there is no up-to date information on injury sites and types for competitive skiers, with the exception of snowboarding. Therefore, Paper II addresses the injury pattern within the different disciplines of alpine skiing, freestyle skiing, ski jumping, cross-country skiing, Nordic combined and snowboarding. Papers III & IV describe in greater detail the injury information for alpine and freestyle skiing.

Injury severity in skiing and snowboarding

As previously described, injury severity is a key variable in injury epidemiology. However, in skiing and snowboarding there is no consensus on how to report injury severity.

Recreational skiing and snowboarding

For the recreational skier and snowboarder, data on the severity of injury is limited. From recreational studies in any of the skiing and snowboarding disciplines, we know of none that have described the severity related to the number of days of absence from training and competition, as proposed in the consensus statement from football. Instead, the severity is described by clinical outcomes in different ways. From injury recordings among skiers and snowboarders 60-70% require medical care (Ekeland et al., 2005; Ekeland & Rødven 2000; Machold et al,. 2000). Two studies have also described that 4% of all skiing and snowboarding injuries require hospitalisation (Bladin et al,. 1993; Xiang et al,. 2005). One prospective study has described 58.7% of snowboarding injuries and 75.7% of skiing injuries to be moderate with need for at least one re-exam after the injury (Zacharopoulos et al,. 2009). In addition, 32.4% of snowboarding and 11.8% of skiing injuries were severe and needed hospitalisation and possible surgical treatment while 0.67% and 1.6% respectively were very severe/fatal.

Several studies have, however, described the incidence for catastrophic injuries that are either fatal or has extreme consequences for the patient, such as paralysis, irreversible loss of mental function or loss of a limb. The incidence for catastrophic skiing and snowboarding injuries from various studies is shown in table 8. Spinal cord injuries, severe brain injury and even fatal injuries occur regularly among alpine skiers and snowboarders.

Table 8. *Epidemiological studies of severe injuries in recreational skiers and snowboarders*

Reference Country, season, follow-up period	Population	Exposure	No of all injuries	Injury recording and definition	Injury incidence (per million SD, MSD)
(Sherry & Clout 1988) Australia 1956-87	Skiers (downhill or cross-country)	Estimation from lift tickets	29	Death certificate of sudden deaths occurred while skiing in Snowy Mountains	0.87
(Sacco et al,. 1998) United States, 1990-96	Skiers and snowboarders	Obtained from Vermont Ski Association data pool	26	Mortality data obtained from the Office of the Chief Medical Examiner of deaths.	1.02 0.23 (SB)
(Tarazi et al,. 1999) Canada, 1994-96	Skiers and snowboarders	Lift ticket data	56	Hospital recordings from specialized spine care unit of serious spinal injuries including fractures or neurologic deficit or both	10 40 (SB)
(Yamakawa et al,. 2001) Japan, 1988-2000	Skiers and snowboarders	Lift ticket data	26	Hospital recordings of spinal injuries[a] and spinal cord injuries[o]	6.9[a] 57 (SB)[a] 0.73[o] 4.2 (SB)[o]
(Fukuda et al,. 2001) Japan, 1994-99	Skiers and snowboarders	Information supplied by 15 of 34 ski resorts in one area	442	Hospital recordings from an authorized neurosurgical institute of injuries with neurological findings[1], intracranial organic lesions[2] or severe disability ≥ 6 months or fatalities[3]	9[1] 38 (SB) [1] 0.8 [2] 3.4 (SB) [2] 0.1 [3] 0.5 (SB) [3]
(Floyd 2001) United States, 1986-97	Alpine skiers and snowboarders	Estimation from ski resorts	41	Hospital recordings from level II trauma center of serious injuries with permanent neurological deficits or death	0.1
(Xiang & Stallones 2003) United States, 1980-2001	Skiers and snowboarders including cross-country skiers	Estimation from ticket sale	274	Death certificate from health statistics in Colorado	0.53-1.88*
(Shealy et al., 2006) United States, 1991-2005	Recreational skiers and snowboarders	Obtained from annual report from National Ski Areas Associations (NSAA)	562	Trauma deaths occurring while skiing or snowboarding within bounds of a ski resort. Fatality data from the US Consumer Product Safety Commission, the NSAA and public news.	0.71* 0.75 (skiing) 0.53 (SB)

SB=snowboarding, * million skier visits

In cross-country skiing, we only have a couple of 20-30 year old studies to describe the injury severity. One study reported the severity graded from one (minor injury such as mild knee sprain) to five (death or threat of loss of limb) with 40% of the injuries being grade 1, 35% grade 2, 16% grade 3 and 9% grade 4 (Sherry & Asquith 1987). Another study (Shealy 1985) used severity grading from 1 (mild injury to a small area of the body) to 8 (death) with 28% of the injuries being grade 1, 25% grade 2, 30% grade 3, 14% grade 4, 1% grade 5 and 1% grade 6. Three percent of cross-country skiing injuries seen in the emergency room in Oslo in 1981/82 required hospitalisation (Daljord & Maehlum 1986).

Competitive skiing and snowboarding

For the competitive athlete it is only in snowboarding where severity has been described according to the number of days of absence from training and competition. For acute time-loss injuries to World Cup and competitive national snowboarders , 41-47% are minor (1-7 days absence), 31% moderate (8-21 days absence) and 19-28% serious (>21 days absence) (Torjussen & Bahr 2005, 2006). AIS reported for injuries to the competitive national snowboarders were AIS 1; 38-47%, AIS 2; 47-60% and AIS 3; 2-6% (Torjussen & Bahr 2005).

Among competitive alpine skiers, 79.0% of female and 87.8% of male top-level skiers had sustained at least one severe injury (broken bones or injuries affecting the general health for >20 days) during their career (Margreiter et al,. 1976) and 72% of Olympic racers (82% of the women and 57% of the men) had previously suffered a severe skiing injury (severity not defined) (Ekeland et al., 1997). Another study reported that 83% of the 30 top-ranked skiers for the past three years had sustained injuries severe enough to impair health and ability to work for >20 days (Raas 1982). These studies are, however, limited by data that are decades old and the inclusion of few participants. Of the four injuries reported from the Junior World Championship and using ISS as the severity score, one had an ISS of 14, while the other three had an ISS of 1 (Bergstrøm et al,. 2001). In competitive cross-country skiing, based on a study with racers in the American Birkebeiner race (classified as expert skiers), most injuries were minor, with only 4.6% of skiers reporting lost training time due to injury and only 2.8% of all skiers reported that they required treatment (Butcher & Brannen 1998). In ski jumping, 81 of 133 (60.9%) retrospectively interviewed active athletes had in their career been injured sufficiently to require examination by a physician and 39 of these sustained a season-ending injury (Wright, Jr. et al,. 1991). One study based on approximately 2200 licensed jumpers in Norway from 1977-1981, found at least 12 injuries with a permanent medical disability of ≥10% (including four CNS lesions, two leg amputations and one blind eye) (Wester 1985).

As described above, it is only in snowboarding where the whole spectrum of injuries regarding severity has been addressed for competitive athletes, though only time-loss injuries. Knowledge is limited for the other disciplines. Therefore, we wanted to describe injury severity across all disciplines in Paper II and in more detail for the sub-disciplines within alpine and freestyle skiing (Papers III & IV).

Aims of the thesis

The aims of this thesis were to implement and validate an injury surveillance system in competitive skiing and snowboarding, and – based on this - to describe and compare the injury risk between alpine skiing, snowboarding, freestyle skiing, ski jumping, cross-country skiing and Nordic combined and compare them to other sports, if possible.

The specific aims were:

1. To establish and validate injury recording in competitive skiing and snowboarding based on three methods believed to be feasible; prospective recording by team medical staff, retrospective interviews with World Cup athletes and prospective reporting by technical delegates. The aim of Paper I was therefore to compare these three injury recording systems.

2. To assess the absolute injury rate (expressed as injuries per 100 athletes per season) for World Cup athletes in alpine skiing, freestyle skiing, snowboarding, ski jumping, cross-country skiing and Nordic combined (Paper II).

3. To estimate the relative injury rate (expressed as injuries per 1000 runs) within the different disciplines of World Cup alpine and freestyle skiing (Papers III-IV).

4. To describe the injury patterns among World Cup athletes in alpine skiing, freestyle skiing, snowboarding, ski jumping, cross-country skiing and Nordic combined (Papers II-IV).

5. To compare the injury rate between male and female athletes in different World Cup disciplines (Papers II-IV).

Methods

Study population and injury definition

The FIS ISS was developed prior to the 2006-07 winter season by the International Ski Federation in collaboration with the Oslo Sports Trauma Research Center. Its main objective was to provide current and reliable data on injury trends in international skiing and snowboarding.

This thesis is based on injury registration among World Cup athletes in the different FIS disciplines of alpine skiing, freestyle skiing, snowboarding, ski jumping, cross-country skiing and Nordic Combined during the first three competitive winter seasons (from 1 November or the first WC race of each season lasting until the World Cup finals/mid-March). The injury definition used was "all injuries that occurred during training or competition and required attention by medical personnel." This definition, as well as the classification of the type of injury and body part injured, was based on the recent consensus document on injury surveillance in football (Fuller et al,. 2006). Training included activities on snow and basic training not on snow. We classified the severity of injury according to the duration of absence from training and competition as slight (no absence); minimal (1 to 3 days), mild (4 to 7 days), moderate (8 to 28 days) and severe (>28 days) (see Appendix 1 – injury form).

Paper I

Study design and participants

Paper I is a methodological study comparing three different ways of injury recording during the 2006-07 winter season. Technical delegates from the FIS were asked to record injuries to any athlete participating in all events of the World Cup and World Ski Championships (WC/WSC) (including official training). We informed those responsible for the training of technical delegates in the different disciplines how to complete the injury forms during information meetings at the annual FIS spring and autumn meetings before the start of the season. We also produced a brochure with information about the project, as well as a description of roles and responsibilities and this brochure was distributed at the same meetings. Information was also distributed through the official FIS website as well as a sub-site of the Oslo Sports Trauma Research Center website dedicated to the project. The second registration method was a prospective injury recording by team medical personnel from six World Cup nations. The federations of Switzerland, Germany, France, Finland, Canada and Norway agreed to participate in this study during a meeting in the FIS Medical Committee in September 2006. Team contacts (preferably the doctor or physical therapist working and travelling with the team) were nominated by the federation for each discipline and these were asked to distribute information regarding the registration to all involved parties, as well as to ensure that all injuries to their World Cup athletes were documented. Regular communication was established with the team contacts through e-mail, telephone calls and text messages every 2-3 weeks throughout the season. The third registration method was retrospective interviews with World Cup athletes at the end of the competitive winter season. To facilitate athlete recall of participation and time loss due to injury, we used a form outlining the week-by-week schedule of the current World Cup program for each discipline (see Appendix 2, Season schedule). The same procedure was used for the interviews in Papers II-IV. For athletes not present at the interviews (due to injury or for other reasons), we interviewed their coaches/doctor/physical therapists to obtain the information needed. From the official FIS database we identified athletes who had started in at least one WC/WSC event and we also asked the team coaches to control and complete the list of athletes from their nations.

Data analyses

To compare the accuracy and completeness of the three registration methods, only injuries occurring in WC/WSC events (including official training) to World Cup athletes from the six selected nations were included.

Papers II-IV

Participants

World Cup athletes were interviewed retrospectively at one of the final World Cup events in alpine skiing, snowboarding, freestyle skiing, ski jumping, cross-country skiing and Nordic combined during the 2006-07 and 2007-08 seasons Papers II-III. The 2008-09 season was also included for freestyle skiing in Paper IV. From the official FIS database we identified athletes who had started in at least one WC/WSC event and we also asked the team coaches to control and complete the list of athletes from their nations. Athletes from 9 major nations; Switzerland, Germany, France, Finland, Canada, Norway, USA, Sweden and Italy were interviewed in all disciplines. These represent large teams in the different disciplines and we expected them to speak English fluently. In freestyle skiing and snowboarding, the athletes rarely compete in more than one of the sub-disciplines and the size of the teams varies. Therefore, to increase the number of participants, in some disciplines we also included additional World Cup teams provided that we could cover at least 80% of all team members with interviews. In this way, we added 11 World Cup teams in freestyle skiing and snowboarding in Paper II and IV.

At the event, we interviewed all athletes from the selected nations who were present in person. If the athlete was not present (due to injury or for other reasons), we interviewed their coaches. Some coaches directed us to their team physician/physical therapist in order to obtain the information required. We also asked the team coaches to control and complete the list of athletes from their nation. Athletes not defined as being on the World Cup team roster by the coaches were excluded (e.g. national athletes starting in races in that country on the national quota).

We explained the purpose and procedure of the interviews at the team captain's meeting in all disciplines where head coaches/team leaders from the different nations are present. We also asked the coaches at the same meetings to inform their athletes of the interviews. Letters describing the interviews were distributed by e-mail to all head coaches/team leaders in the different disciplines prior to the 2007-08 registration and 2008-09 registration. Research teams from the Oslo Sports Trauma Research Center consisting of physicians and physical therapists conducted the interviews. The research teams performed the interviews in the finishing area in connection with official training or competition, or, in some cases, at the team's hotel.

Statistics

The Statistical Package for Social Sciences (SPSS), version 15 was used to perform most of the analysis.

Injury incidence was expressed as the absolute injury rate (total number of injuries per 100 athletes per season) (Papers II-IV) for all disciplines and as the relative injury rate (corrected for exposure as the number of injuries per 1000 runs) for alpine and freestyle skiing (Papers III-IV), both with their corresponding 95% confidence intervals. When calculating the absolute injury rate we included all injuries during the season, in competition as well as during training. For calculating the relative injury rate we included only injuries from WC/WSC competitions, as these were the only where it was possible to relate injuries to the number of started runs (exposure) across the different disciplines. For each of the alpine skiers (Paper III) and freestyle skiers (Paper IV) we calculated their competition exposure as the exact number of started runs during the 2006-07 and 2007-08 winter seasons (including the 2008-09 winter season for Paper IV) based on information from the FIS database.

We based our calculations in Papers II-IV on the Poisson model and used a Z test for comparing injury risk between disciplines and computed the corresponding 95% confidence intervals (CI). We computed relative risks (RR) with their 95% CI to compare injury rate between male and female athletes for severity, distribution with regards to body part injured and the relative risk between the different disciplines for all injuries (and knee injuries in Papers III and IV). A two-tailed p-level of ≤ 0.05 was considered statistically significant.

In Paper I, Kappa (ϰ) correlation coefficients were calculated for agreement between methods (Altman 1991). Coefficients of 0.81–1.00 are generally interpreted as very good, 0.61–0.80 as good, 0.41–0.60 as moderate, 0.21–0.40 as fair, and less than 0.20 as poor (Altman 1991).

STATA (version 10, StataCorp, Lakeway Drive, Texas, USA) was used for test for trends over the first three seasons within alpine skiing, freestyle skiing and snowboarding using generalized estimation equations, GEE taking the dependency of multiple injuries and the same athlete being interviewed more than once into account.

Ethics

The studies were approved by the Regional Committee for Medical Research Ethics, Region Sør-Norge and by the Norwegian Social Science Data Services (see Appendix 3). For Paper I, written consent was obtained from the World Cup athletes from the six selected nations where the medical personnel sent in an injury form if an injury occurred during the season.

Results and discussion

Comparison of three different methods for injury surveillance in World Cup skiing and snowboarding (Paper I)

We found in the methodological study that retrospective interviews at the end of the winter season with World Cup athletes in skiing and snowboarding captured most injuries compared to prospective injury recording by medical staff and prospective recording by technical delegates. Of the 100 unique injuries which potentially could have been reported in all three registrations, 91 were recorded through the interviews, 47 by the medical team registration and 27 through the reports from technical delegates (Figure 3). Of the injuries not recorded through the medical team registration the majority (68%) were minor (no or 1-3 days absence), while 8 (15%) were severe (>28 days absence). For the injuries not reported by the technical delegates recording, 60% were minor and 15% severe. The results showed, however, that the injuries recorded through the three registration methods had a good to very good agreement for body part injured and injury type but varied from poor to good for severity (Table 9).

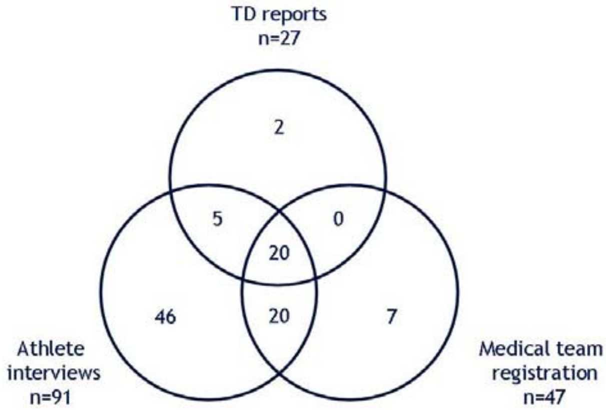

Figure 3. Injury rate expressed as injuries per 100 athletes for athlete interviews, medical team registration and reports from technical delegates (TD reports).

Table 9. *Kappa (ϰ) values with 95% CI for agreement between the different registration methods*

Variable	Registration method		
	TD reports vs. interview	Medical team vs. interview	TD reports vs. Medical team
Severity	0.14 (-0.19 to 0.47)	0.65 (0.46 to 0.84)	0.39 (-0.01 to 0.78)
Injury type	0.83 (0.65 to 1.00)	0.79 (0.63 to 0.94)	0.71 (0.46 to 0.96)
Body part	0.81 (0.63 to 0.98)	0.88 (0.77 to 0.99)	0.82 (0.63 to 1.00)

Sports Injury Surveillance - Retrospective vs. prospective recording

Consensus statements, previous studies and the general advice when recording injuries in sport is to perform a prospective, cohort study (Fonseca et al,. 2002; Fuller et al,. 2006, 2007; Junge & Dvorak 2000; Meeuwisse & Love 1998; Pluim et al,. 2009; Twellaar et al,. 1996). However, there are great differences from one sport to another as well as within a sport with regards to participants, level, organization and resources. Additionally, there are few methodological studies comparing different ways of injury reporting and to our knowledge none in skiing or snowboarding. We were somewhat surprised that the retrospective interviews with World Cup athletes at the end of the season turned out to be the best way to capture injuries compared to the two prospective recording methods. Recall bias is assumed to be the main limitation when using retrospective questionnaires, i.e. the athlete/coach may have forgotten some injuries. To minimize recall bias, we used week-by-week schedules of the 5- to 6- month winter season. A similar form was used in a study among beach volleyball players with good results (Bahr & Reeser 2003). However, a recent study among Norwegian elite football players found that 30% of injuries reported prospectively by team medical staff were not reported by retrospective player interviews at the end of the season (Bjørneboe et al,. 2010). Nevertheless, what needs to be appreciated when comparing these sports, is the difference in their organization. While there usually is one or two physiotherapists/physicians following an elite football team in Norway, there are teams in skiing and snowboarding that do not always travel with a physiotherapist or a physician. In fact, doctors and physiotherapists often take turns travelling with the team. We tried to have the medical person travelling with the team as the main responsible for the medical recording for each team in each discipline and kept regular contact with these. However, almost continuous travelling throughout the season might complicate the communication and reporting. The third registration, prospective reports from technical delegates had the lowest capture rate (except in freestyle skiing, where the technical delegates reported more than the medical team personnel). This was not totally unexpected since the technical delegates have a number of official tasks and probably do not learn of all injuries occurring during the race. It would nevertheless be an attractive option to use technical delegates to report injuries. If successful, injuries could be recorded at a low cost, worldwide and even at levels below the World Cup.

It is possible that other well-designed injury recording systems would be even more complete than the three described above for competitive skiing and snowboarding athletes. Having athletes and coaches record injuries prospectively during the season could be an alternative way of obtaining information from a broader group of athletes. However, as performance is the primary focus of elite athletes it may be unreasonable to expect them to comply fully with an injury recording protocol, especially as substantial numbers are needed to obtain valid results. A recent study on female football players from the top division in Norway has used a novel system based on weekly text messaging by players to report injuries. Team medical staff from the same football cohort also reported injuries prospectively, but missed approximately 2/3 of all injuries reported by the athletes and 50% of the severe injuries (personal communication Agnethe Nilstad 2010). The fact that the medical team knew about the athlete registration may have contributed to a low reporting from the medical team, but the data show that prospective registration by the medical team is not necessarily complete. Nevertheless, we do believe that it is essential to consider the sport in question for injury recording and examine carefully what the best registration method may be. In skiing and snowboarding, the retrospective interviews at the end of the season turned out to be the best way of reporting injuries among World Cup ski and snowboard athletes. This is therefore the method chosen to use for describing the injury incidence and pattern in the different disciplines (Papers II-IV).

Injury definition

We used the same injury definition and categories as the consensus report in football (Fuller et al,. 2006), which also have been adopted in other sports and organisations. With the same definitions and a consistent way of reporting injuries, meaningful comparisons with other sports are possible.

Capturing all injuries as described in the definition is the ultimate outcome with all injury registration. Medical attention is a key point in the injury definition used here. This obviously depends on how accessible medical assistance is. At the World Cup level in skiing and snowboarding, there are rules for event medical coverage. In addition, even though not all teams travel with medical personnel at all times, access to medical care should be readily available if needed. At lower levels, where medical coverage is more limited, it may be more likely that minor injuries will be missed. However, it is less likely that the level of care affects the rate of time-loss injuries reported. By using the medical attention definition we should also capture those injuries sustained during a race, where the athletes complete but suffer time loss afterwards due to an injury. Nevertheless, injuries might be missed and therefore the numbers should be regarded as minimum estimates.

Athlete and coach interviews

We interviewed all athletes present at the season-ending events (Papers I-IV). Almost without exceptions we had no problems of interviewing the athletes. It is essential to get a good cooperation from the athletes in order to capture all injuries as set by the definition. The athlete might as an example not report an injury if he/she is afraid that this information reaches their insurance company or their opponents. The purposes of the interviews were explained at compulsory team meetings and we repeated this to the athletes at the interviews, if necessary. If an athlete was not present at the interviews due to injury or other reasons, the coach was interviewed instead. The coaches are responsible for a limited number of athletes and they travel and live together almost the entire winter season. Our impression was that they had very good control over injuries to their athletes. In some cases they directed us to their physiotherapist or physician to obtain the information needed, but in most cases they provided us with the injury information during the 5-month competitive season.

The injury risk in World Cup skiing and snowboarding (Paper II)

The magnitude of the problem

In the largest cohort study to date, based on 2121 interviews of World Cup athletes, we recorded 705 injuries. Of these, 676 were on-snow injuries in the different disciplines of alpine skiing, snowboarding, freestyle skiing, ski jumping, cross-country skiing and Nordic combined. We found as many as 71.9% of on-snow injuries (71.5% of all injuries) to be time-loss injuries and for these injuries there was an increase in frequency towards the most severe injuries for alpine skiing, freestyle skiing and snowboarding (Figure 4).

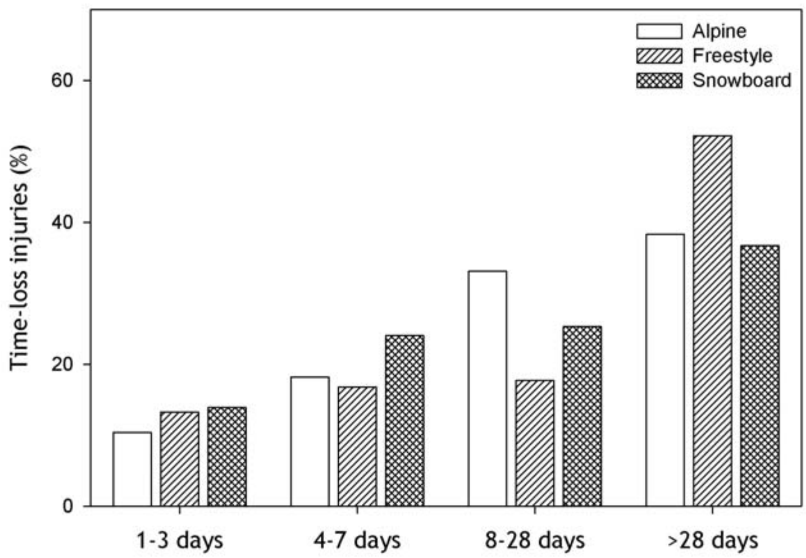

Figure 4. Percentage of time-loss injuries in the different severity categories for on-snow injuries in alpine skiing, freestyle skiing and snowboarding.

Using the number of injuries per 100 athletes per season to express the absolute injury rate during the 2006-07 and 2007-08 winter seasons, the risk of injury was significantly higher in alpine skiing, freestyle skiing and snowboarding than the Nordic disciplines (ski jumping, Nordic combined and cross-country skiing) (Figure 5). The risk was also significantly lower in cross-country compared to ski jumping and Nordic combined.

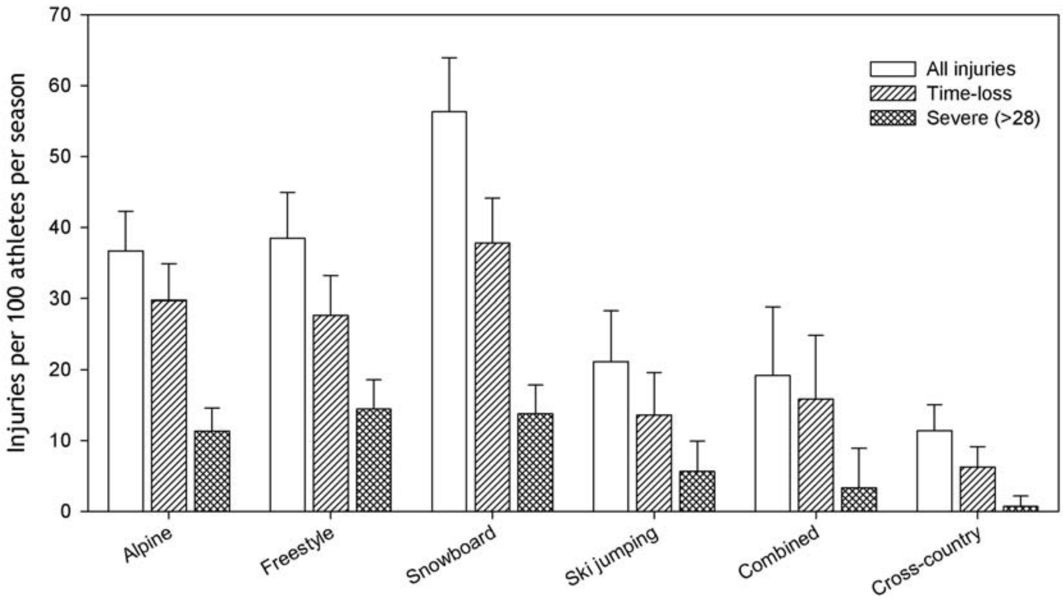

Figure 5. Injury rate expressed as the number of injuries per 100 athletes per season for all, time-loss and severe (>28 days) injuries in alpine skiing, freestyle skiing, snowboarding, ski jumping, Nordic combined and cross-country skiing. Combined data from the 2006-07 and 2007-08 winter seasons.

Our data suggest that in the alpine disciplines and snowboarding, frequency increases with injury severity. The main challenge with retrospective interviews is recall bias (Bahr & Reeser 2003) and it may be that it is easier to recall a severe injury than a minor injury. If this were the case, it could – at least in part – explain the observed relationship between frequency and severity shown in Figure 4. To minimize recall bias we had a restricted recall period (the World Cup season; 5 to 6 months) and used structured week-to-week interview formats to improve the athletes' recall of their competition and training schedule. It should be noted that in team sports like football, frequency is inversely related to severity. The logical explanation for the unique frequency-severity relationship observed is that as long as the skier stays on his skis/snowboard, the risk of (minor) injury is minimal. However, when there is a crash, it should not come as a surprise that injuries are often severe if we consider the challenges involved in these sports – alpine skiers manoeuvring down an icy, steep mountainside on a pair of skis or a board with minimal protection, often above the speed limit and freestyle skiers and snowboarders doing near-impossible aerial manoeuvres during high jumps.

As can be seen from Figure 4, about every third athlete suffers a time-loss injury each season, but how does this compare to other sports? Comparing sports with different levels of exposure is a challenge. Nevertheless, most of the athletes at the World Cup level are professional athletes training and competing as much as they can. This would be the same for professional athletes in many other sports. One interesting consequence of expressing injury rate in absolute terms, is that the data may be compared to non-snow sports such as professional football, where the injury risk has been documented to be unacceptably high when compared to other occupations (Drawer & Fuller 2002).

For comparing professional football with skiing and snowboarding we used studies where it was possible to calculate the number of injuries per 100 players per season (Figure 6). This comparison shows that football had a much higher rate of time-loss injuries than alpine skiing, freestyle skiing and snowboarding (94-205 injuries per 100 players per season) while the rate of severe injuries varied from 16-31 injuries per 100 players per season.

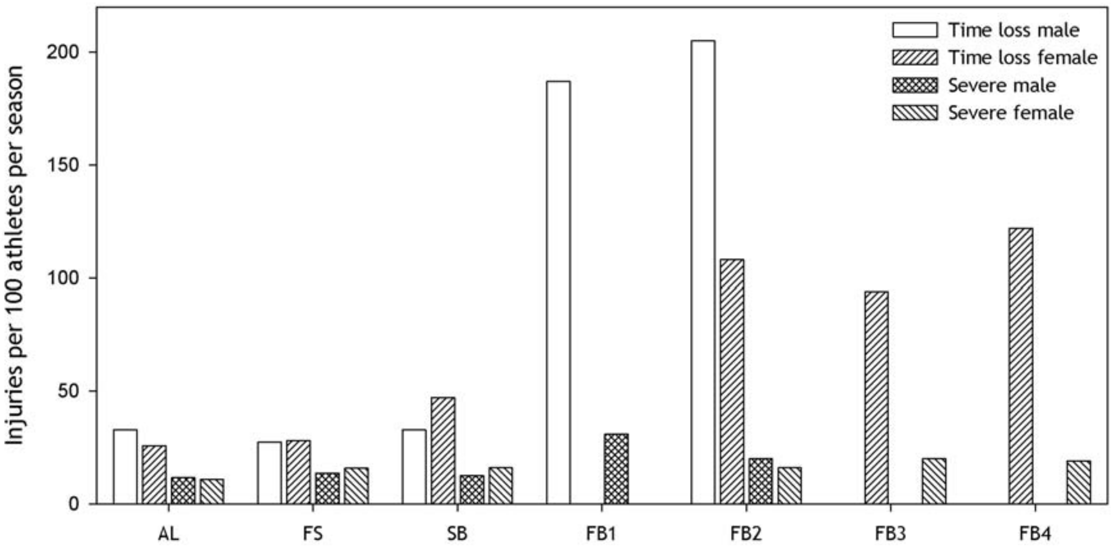

Figure 6. Injury rate expressed as injuries per 100 athletes per season for time-loss and severe injuries in alpine skiing (AL), freestyle skiing (FS), snowboarding (SB) and 4 football studies (FB1-4) for male and females.

Nevertheless, as a football season is about twice as long as the winter season in skiing and snowboarding it is difficult to make direct comparison. Therefore, data from Tippeligaen (the top division in Norwegian football for men) from a time period resembling the winter season in length and competition status were compared with World Cup alpine skiing, snowboarding and freestyle skiing (Flørenes et al., 2009). For acute time-loss injuries the risk in alpine skiing, freestyle skiing and snowboarding was only half of what found in Tippeligaen (Figure 7). However, for the severe injuries, the injury risk was the same in alpine skiing, snowboarding and football and even higher in freestyle skiing.

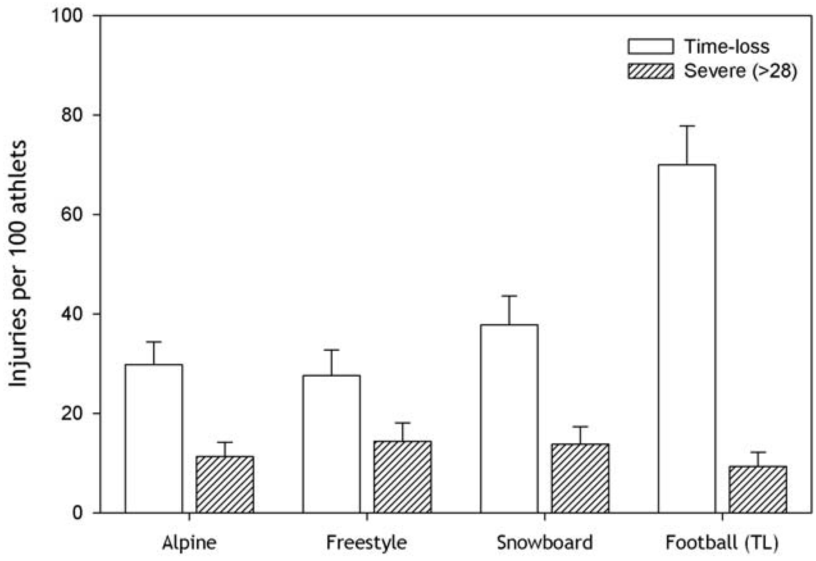

Figure 7. Injury rate expressed as injuries per 100 athletes per season for time-loss and severe injuries in World Cup alpine skiing, freestyle skiing, snowboarding (SB) and Football (Tippeligaen; top division in Norway). The season in football is estimated to the same length and competition schedule as for the World Cup sports.

Studies on recreational skiers and snowboarders typically report injuries per 1000 SD/SBD (Ekeland et al., 2005; Greenwald et al., 2003; Johnson et al,. 2009; Langran & Selvaraj 2002; Laporte et al., 2000). However, snow activity per day varies for competitive skiers and snowboarders (making SD/SBD difficult to use for this group). Some days they might have more than one training session on snow while during the competition day they may only do a few runs. In addition, SD/SBD does not necessarily reflect the relative risk of injury for these athletes e.g. per kilometer distance skied. Nevertheless, if we assume that there were two travel days and five training/competition days per week during the winter season, the injury rate can be estimated to 4.1, 4.3 and 6.3 injuries per 1000 SD/SBD for World Cup alpine skiing, freestyle skiing and snowboarding. These figures are two to three times as high as that reported from studies on recreational alpine skiers and snowboarders. This might not come as a surprise when we know that alpine racers can compete in up to 100-150 km/h, taking high risks to win while the average recreational skier and snowboarder behaves quite differently

Injury rates over three seasons (Papers II-IV)

One aim with sports injury surveillance is to monitor if injury risk changes over time. Sports change constantly and changes in rules and regulation, equipment, coaching technique or environmental factors may result in an increasing (or decreasing) injury rates. The FIS ISS data allows us to assess whether the injury risk in World Cup alpine skiing, freestyle skiing and snowboarding has changed since the surveillance was established during the 2006-07 winter season. Data from the first three seasons suggest that the injury rates have been reasonably consistent (Figure 8).

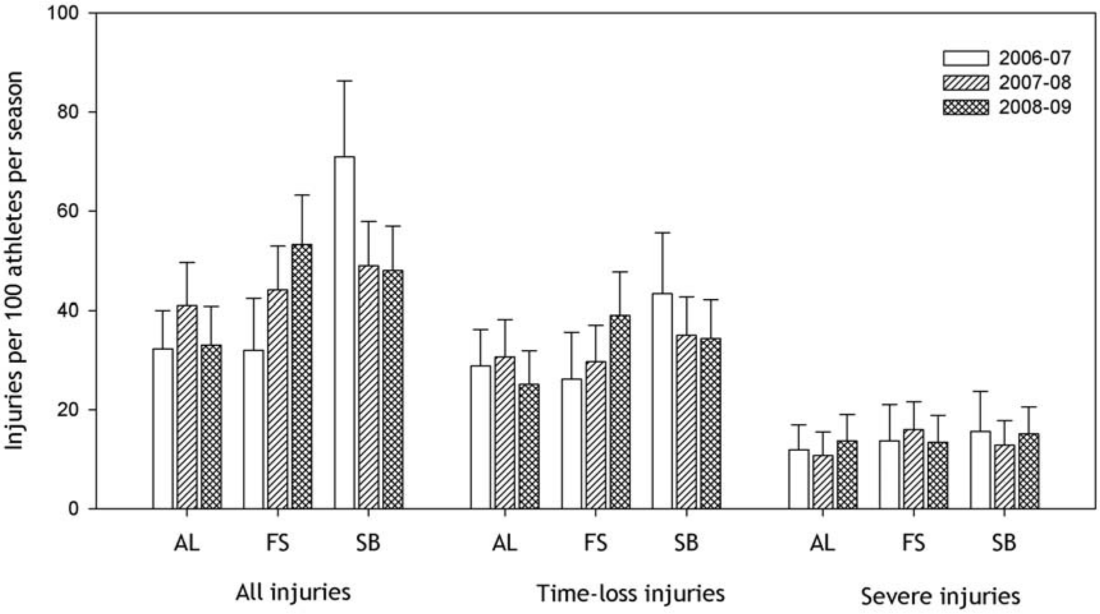

Figure 8. Injury rate expressed as injuries per 100 athletes per season (with 95% confidence intervals) for all, time-loss and severe injuries reported through the three seasons 2006-09 in alpine skiing (AL), freestyle skiing (FS) and snowboarding (SB).

However, a test for trends reveals that there has been an increase in freestyle skiing for all injuries (p=0.004) as well as time-loss injuries (p=0.029). There was also a decrease for all snowboarding injuries (p=0.007) but no differences for time-loss injuries. No changes were seen in alpine skiing over the three seasons. However, these results need to be interpreted with some cautions. We need to follow the injury rate in the different disciplines over time to determine if the increase in freestyle skiing is the beginning of a trend. The FIS ISS may help to assess whether changes and developments in the skiing and snowboarding disciplines lead to an increase in injury risk for the athletes or whether changes in rules and regulation, equipment and possibly future preventive measures decrease the injury risk.

Relative injury rates in World Cup alpine and freestyle skiing (Paper III & IV)

Alpine skiing (Paper III)

For injuries incurring in World Cup competitions, the exact exposure in total number of runs can be obtained from the FIS database. Thus, the relative risk for each discipline can be estimated as the number of injuries per 1000 runs. Among the 521 alpine skiers interviewed we recorded 8734 runs during the two World Cup seasons. The relative injury incidence for the 86 recorded World Cup injuries is shown in Figure 9, indicating that the incidence increased with increasing speed. The overall relative injury rate 9.8 (95% CI 7.8 to 11.9) was at least twice as high as previously described among competitive alpine skiers (1.4 – 4.0 injuries per 1000 runs) and for downhill skiing (1.1 – 8.3) (Bergstrøm et al,. 2001; Ekeland et al,. 1996). Even if the sport is developing continuously, e.g. with enhanced technology for faster equipment and skies, it is unknown whether the injury incidence has increased during the previous decade, as the two previous studies are small and from only one competition.

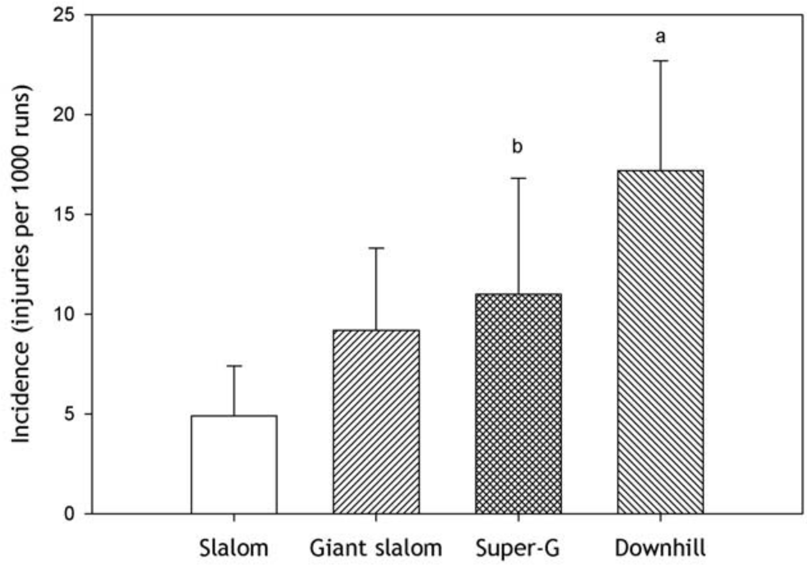

Figure 9. Injury incidence expressed as injuries per 1000 runs for the different disciplines in competitive alpine skiing (with 95% confidence intervals) for all injuries in WC/WSC competitions. [a]Downhill had a higher injury rate compared to slalom and giant slalom. [b]Super-G had a higher injury rate compared to slalom.

Freestyle skiing (Paper IV)

Based on three winter seasons with registration from World Cup competitions in freestyle skiing, the corresponding relative injury rate for the 106 injuries recorded across disciplines is shown in

Figure 10. The relative injury rate in freestyle World Cup competitions, 15.6 (95% CI 12.7 to 18.6) injuries per 1000 runs, was higher than the rate in alpine World Cup competitions (RR 1.59, 95% CI 1.20 to 2.11). It is not known whether the injury rate has changed during the previous decade, but the freestyle sport has changed considerably with new disciplines added (ski cross and halfpipe) and others removed (ballet).

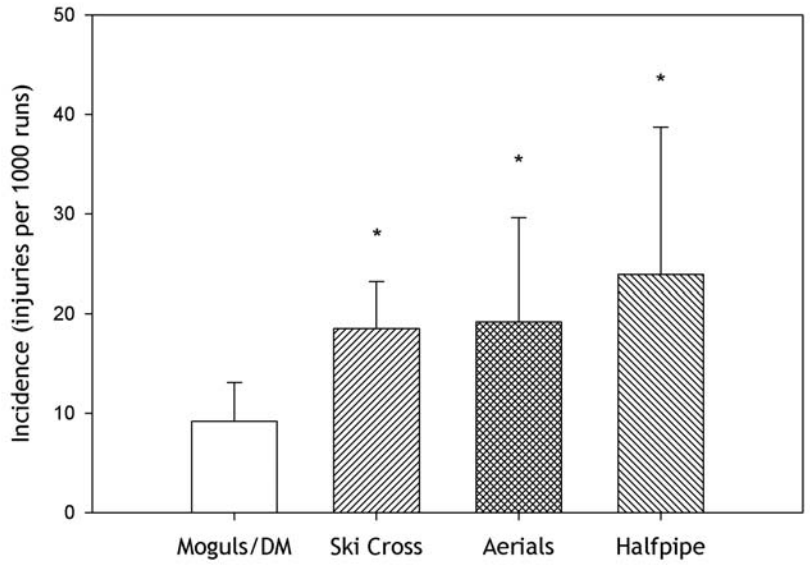

*Figure 10. Injury incidence expressed as injuries per 1000 runs for the different disciplines in competitive freestyle skiing (with 95% confidence intervals) for all injuries in WC/WSC competitions. *With moguls/dual moguls (DM) as the reference category, the other disciplines had a significantly higher injury rate.*

Injury patterns

Overall, injuries to the lower extremity dominated in all disciplines (Table 10). The knee was the most frequently injured body part (25.8% of all the 705 injuries in Paper II) and joint and ligament injuries the most frequently reported injury type in all disciplines, except in cross-country skiing (Papers II-IV). This is in accordance with other studies from the competitive level in alpine skiing and snowboarding. Knee injuries were shown to be most common among World Cup snowboarders (Torjussen & Bahr 2005, 2006). This is however, in contrast to the recreational snowboarder, who most commonly injures the wrist (Boldrino & Furian 1999; Ekeland & Rødven 2009a; Idzikowski et al,. 2000; Langran & Selvaraj 2002; Made & Elmqvist 2004; Xiang et al,. 2005).

Another common finding was a high proportion of head injuries with 58 of the 74 head injuries classified as concussions. Shoulder/clavicle injuries were also common, especially in snowboarding and freestyle skiing (Table 10).

Table 10. *Circumstances, severity, body part injuries and injury type for all (n=705) recorded injuries in the different disciplines during the 2006-07 and 2007-08 seasons.*

	Alpine skiing	Freestyle skiing	Snow-boarding	Ski jumping[1]	Nordic combined	Cross-country skiing	Total
Circumstances							
WC & WSC events	117 (61.2)	90 (56.3)	105 (44.3)	11 (24.4)	8 (34.8)	16 (32.6)	347 (49.3)
Other comp (incl FIS)	24 (12.6)	34 (21.3)	61 (25.7)	6 (13.2)	2 (8.7)	7 (14.2)	134 (19.1
Regular training on snow	48 (25.1)	33 (20.6)	67 (28.3)	15 (33.3)	7 (30.4)	25 (51.0)	195 (27.7)
Basic training not on snow	2 (1.0)	3 (1.9)	4 (1.7)	13 (28.9)	5 (21.7)	1 (2.0)	28 (4.0)
Information missing					1 (4.3)		1 (0.1)
Total	191 (100)	160 (100)	237 (100)	45 (100)	23 (100)	49 (100)	705 (100)
Severity							
Time-loss	155 (81.2)	115 (71.8)	159 (67.1)	29 (64.4)	19 (82.7)	27 (55.1)	504 (71.5)
Severe (>28 days)	59 (30.9)	60 (37.5)	58 (24.5)	12 (26.7)	4 (17.4)	3 (6.1)	196 (27.8)
Body part injured							
Head, neck, cervical	16 (8.4)	22 (13.8)	31 (13.1)	7 (15.6)	1 (4.3)	3 (6.1)	80 (11.4)
Chest, back, pelvis	26 (13.6)	23 (14.4)	34 (14.3)	2 (4.4)	5 (21.7)	14 (28.6)	104 (14.8)
Upper extremity	38 (19.9)	40 (25.0)	71 (30.0)	6 (13.2)	4 (21.6)	13 (26.5)	173 (24.6)
Lower extremity	111 (58.1)	75 (47.1)	101 (42.7)	29 (64.4)	12 (52.1)	19 (38.8)	347 (49.2)
Knee	68 (35.6)	47 (29.4)	44 (18.6)	12 (26.7)	7 (30.4)	4 (8.2)	182 (25.8)
Information missing				1 (2.2)			1 (0.1)
Total	191 (100)	160 (100)	237 (100)	45 (100)	23 (100)	49 (100)	705 (100)
Injury Type							
Fractures/bone stress	36 (18.8)	35 (21.9)	41 (17.3)	6 (13.3)	1 (4.3)		119 (16.9)
Joint/ligament	84 (44)	69 (43.1)	91 (38.4)	21 (46.7)	13 (56.5)	15 (30.6)	293 (41.6)
Muscle/tendon	20 (10.5)	20 (12.5)	28 (11.8)	2 (4.4)	5 (21.7)	19 (38.8)	94 (13.3)
Contusion	23 (12.0)	16 (10.0)	42 (17.7)	8 (17.8)	2 (8.7)	7 (14.3)	98 (13.9)
Skin/laceration	7 (3.7)	2 (1.3)	2 (0.8)	1 (2.2)	1 (4.3)	1 (2.0)	14 (2.0)
Nervous system/concussion	15 (7.9)	15 (9.4)	29 (12.2)	4 (8.9)		3 (6.1)	66 (9.4)
Other	6 (3.1)	3 (1.9)	4 (1.7)	3 (6.7)	1 (4.3)	4 (8.2)	21 (3.0)
Total	191 (100)	160 (100)	237 (100)	45 (100)	23 (100)	49 (100)	705 (100)

[1] Ski jumping includes two World Cup seasons for men and one Continental Cup season for women.

Knee injuries

As many as 37 of the 68 (54.4%) knee injuries in World Cup alpine skiing were severe (Paper III). There were 28 knee injuries during WC/WSC competitions, giving a knee injury incidence of 3.2 (95% CI 2.0 to 4.4) per 1000 runs. The incidence varied from the lowest in slalom (0.9, 95% CI -0.9 to 2.0) to the highest in downhill skiing (7.0 95% CI 3.4 to 10.5 injuries per 1000 runs). ACL injury was the most commonly reported specific diagnosis, accounting for 38% of knee injuries. This finding is in accordance with data from a recent study with a high frequency of ACL injuries among top-ranked French alpine skiers during a 25-year period (Pujol et al,. 2007).

The knee was also the most commonly injured body part in freestyle skiing with 77 (26.5%) of 291 injuries from three seasons (Paper IV). Of these, 38 (49.4%) were severe injuries. The head/face followed as the second most commonly injured body part with 39 injuries (13.4%) and the shoulder/clavicle with 32 injuries (11%). There were 31 knee injuries occurring in WC/WSC competitions, giving a relative injury rate for knee injuries of 4.6 (95% CI, 3.0 to 6.2) per 1000 runs. The incidence varied from 2.4 (95% CI -2.3 to 7.1) in halfpipe to 5.8 (95% CI 3.2 to 8.4) in ski cross. The results need to be interpreted with caution due to small numbers in some of the sub-disciplines. As for World Cup alpine skiers, ACL injury was the most common specific diagnosis in World Cup freestyle skiers, involving at least 38% of the knee injuries. This is probably a minimum estimate, as not all athletes/coaches could give a precise diagnosis. Nevertheless, our findings are supported by a study among participants in the FIS World Ski Championship in 2001 where 47% of the 95 participants had experienced at least one major knee injury with an absence of ≥20 days (Heir et al., 2003).

ACL injuries are by far the most commonly studied in sport. In skiing, three main injury mechanisms for ACL injuries have been described, albeit mainly in recreational skiers (Ettlinger et al,. 1995; Järvinen et al,. 1994; Johnson 1988; Johnson et al., 1997) (Figure 11). The valgus external lower-leg rotation mechanism (Figure 11a) occurs when the medial edge of the anterior part/tip of the ski catches the snow leading to a valgus-external rotation trauma of the knee (Johnson et al,. 1979; Marshall et al,. 1975). The skier falls forward and the lower leg is abducted and externally rotated in relation to the thigh. In addition, the ski acts as a moment arm and magnifies the torque. This mechanism leads primarily to a rupture in the medial collateral ligament followed by the ACL, which is torn in approximately 20% of cases. These patients may also have bone contusions (Johnson 1988). The "boot-induced anterior drawer" mechanism (Figure 11b) occurs when the skier lands on the tail of the ski in a hard landing, usually off balance with the knee fully extended and the contra-lateral arm rotated upward and rearward

(Ettlinger et al,. 1995; Johnson 1988). The top of the ski boot forces the tibia forward, leading to a boot-induced anterior drawer manoeuvre (anterior directed force on tibia relative to the femur) that causes an isolated disruption of the ACL. This mechanism is described to be common among freestyle and high level alpine skiers. The "phantom foot phenomenon" (Figure 11c) occurs when the skier is off balance to the rear attempting to regain control, with the weight on the inside edge of the tail of the downhill ski and the uphill ski unweighted (Ettlinger et al,. 1995; Johnson 1988). The inside edge of the downhill ski catches the snow and drives the leg into forced internal rotation with the knee hyper-flexed, resulting in an apparent isolated ACL injury. The term phantom foot, first introduced in 1986 (Ettlinger 1986), refers to the rear body of the carved ski which engages the inner edge and cause the ski to turn producing the torque leading to the injury. This mechanism is believed to be the most common and insidious ACL scenario in alpine skiing today and is the typical injury mechanism among recreational skiers.

a b c

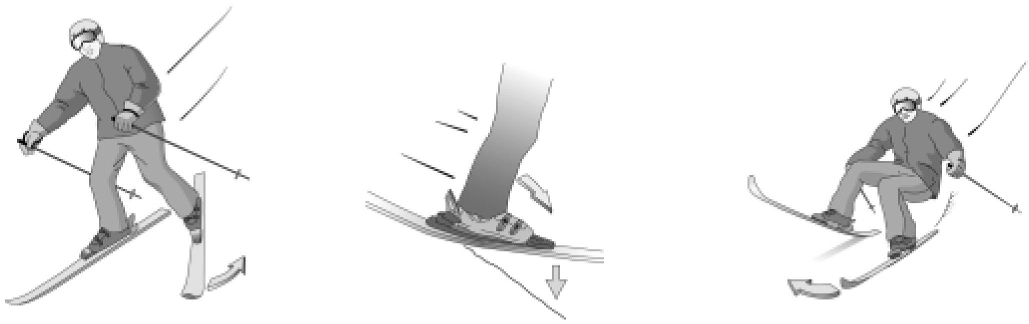

Figure 11. 3 common injury mechanisms for ACL injuries: (a) valgus-external rotation; (b) boot-induced anterior drawer; and (c) "phantom foot" mechanisms. The figure is reproduced from Koehle et al. (2002). Copyright 2008

Other mechanisms of ACL tears described include hyperextension and internal rotation of the tibia on the femur (Järvinen et al,. 1994; Kennedy et al,. 1974) or a combined loading mechanism with hyperflexion and weight on the tails of the skies with the ski tracking ahead, leading to a quadriceps eccentric contraction forcing the already stretched ACL to tear (McConkey 1986). There is however doubt as to weather a forceful quadriceps contraction can disrupt the ACL (Aune et al,. 1995).

Except for the BIAD mechanism we have, however, no information on the mechanism of ACL injuries for competitive skiers. Given the fact that there is a high knee injury incidence in downhill, this suggests that not only the high technical demands and forces involved in the technical disciplines can cause the ACL to tear, but also that high speed disciplines may be even more risky. Assessing the specific injury mechanism(s) for competitive alpine skiing is therefore of utmost importance and studies are urgently needed to provide more information.

Are there any differences in injury risk between men and women? (Papers II-IV)

Conflicting findings exist among the few studies available on whether there are sex differences in injury risk in competitive alpine skiing. Overall, we found no difference in the absolute injury rate between men and women for all injuries reported in the World Cup disciplines (Paper II). We found, however, as the first study, that males had a higher injury risk compared to females for all injuries in alpine skiing (RR 1.42, 95% CI, 1.06 to 1.91), while no significant sex difference was detected for time-loss injuries only (RR 1.28, 95% CI, 0.92 to 1.77). In WC/WSC competitions the relative injury rate was twice as high in males as in females for all injuries (RR 2.05, 95% CI 1.28 to 3.29) and time-loss injuries (RR 2.01, 95% CI 1.18 to 3.42) (Figure 12). However, slalom was the only discipline where we found a higher relative injury rate in males than females (RR 5.16, 95% CI 1.17 to 22.7). Nevertheless, when there are less than five cases (as was the case for women in slalom), the findings need to be interpreted with caution. Our results are in contrast to data from the Winter Olympic Games in Lillehammer (Ekeland et al,. 1996) and a World Junior Championship (Bergstrøm et al,. 2001), where females had a higher injury incidence than males. No sex differences were, however, reported among national competitive skiers during the winter season 1981-1982 in Norway (Ekeland & Holm 1985). We found no sex differences for knee injuries or ACL injuries (RR 1.08 95% CI 0.50 to 2.36) (Figure 12). Among competitive alpine skiers, the results are in correspondence with a study of elite French national team athletes during 25 years, where they found no sex difference in ACL injury risk (Pujol et al,. 2007). In contrast, another study reported a significantly higher percentage of previous ACL injuries in Olympic female alpine racers, although this study only had 54 competitors included (response rate of only 21%) (Ekeland et al,. 1996).

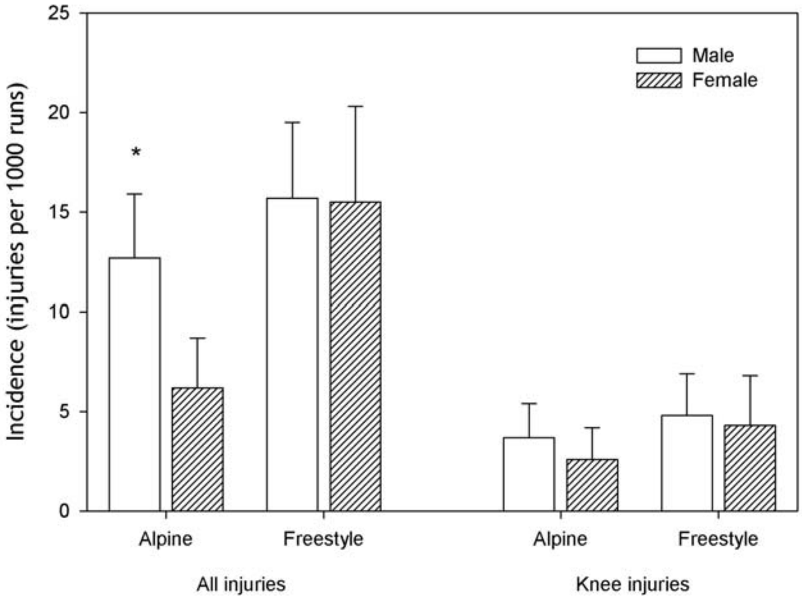

*Figure 12. Injury incidence expressed as injuries per 1000 runs for males and females in WC/WSC competitions in alpine skiing and freestyle skiing for all injuries as well as knee injuries. * Males had a higher injury risk in alpine skiing for all injuries in.*

In World Cup freestyle skiing, we found no sex difference in the absolute injury rate in any discipline or severity category. Also there was no difference for the injury incidence in WC/WSC competitions between males and females (RR 1.02, 95% CI 0.69 to 1.50) and no difference for knee (RR 1.12, 95% CI 0.54 to 2.33) or ACL injuries (RR 1.81, 95% CI 0.81 to 4.02) (Figure 12). Only for head injuries was there a difference, with a higher risk for females compared to males (RR 2.11, 95% CI 1.12 to 3.95). Only one previous study in freestyle skiing has looked at sex differences and found in contrast to the findings in Paper IV a significantly higher prevalence of previous, major knee injuries for women, but not for ACL injuries (Heir et al., 2003), as also found in Paper IV.

The findings of no difference for knee or ACL injuries between men and women in both World Cup alpine and freestyle skiing are in contrast to other sports like soccer, team handball and basketball, where females have a 4- to 6-fold higher rate of non-contact ACL injuries than men (Agel et al,. 2005; Arendt & Dick 1995; Bjordal et al,. 1997; Myklebust et al,. 1998). Several studies among recreational skiers have also reported a twofold greater risk of knee injuries among women compared to men (Ekeland et al., 2005; Ekeland & Rødven 2009b; Greenwald & Toelcke 1997; Johnson et al,. 2009; Laporte et al., 2000; Shealy & Ettlinger 1996). Even so, the competitive alpine and freestyle skiers might technically ski at the maximum of what is possible, involving such high forces that any vulnerability factors related to sex are overruled when an injury occurs. Another possibility could be that men ski more aggressively (and therefore gets injured at the same level as women despite being less vulnerable to begin with). In addition, we need to know more about injury mechanisms as we do not know if these are different for competitive male and female skiers. More data is also needed to look at potential sex differences for less frequent injury types. However, as there are no marked sex differences for time-loss injuries or severe injuries in alpine or freestyle skiing, men and women should both be targeted with injury prevention methods.

Limitations

There are some limitations with these studies that need to be borne in mind when interpreting the results. Firstly, recall bias is a known issue with retrospective study methods. Nevertheless, the methodological study found retrospective athlete and coach interview to be the best method to record injuries among World Cup ski and snowboard athletes. We have therefore used this as the recording methods in Papers II-IV. Nevertheless, as there seems to be no reason for athletes or coaches to "invent" injuries during the interviews, the incidence rates reported must be regarded as minimum estimates. Secondly, when we split injuries into the different sub categories we sometimes get too few cases to be conclusive about the results. This is especially the finding for the relative injury risk within the sub-disciplines in alpine and freestyle skiing. With less than five cases in any group, the results need to be interpreted with cautions. This mainly relates to the comparison between sexes and relative risks. Thirdly, the injuries recorded were from the competitive winter season only and we do not know what occurs the rest of the year. Another limitation is that when we have interviewed non-medical persons (athletes and coaches), it may be difficult to obtain the correct specific diagnosis in every case. However, we expect that the data obtained on the body part injured and the severity (the duration of absence from training and competition) is accurate. Nevertheless, the exact specific diagnosis, e.g. injuries to several structures in the knee, is probably not complete in all cases.

Conclusions

1. Retrospective interviews of athletes and coaches was the best method to capture injuries sustained during the season, considerably better than prospective registration by team medical personnel and prospective registration by technical delegates. This indicates that it is important to consider the characteristics and setting in each sport before establishing an injury registration system.

2. About every third alpine skier, freestyle skier and snowboarder sustained a time-loss injury each season, while the risk was much lower in the Nordic disciplines. Severe injuries were more common than moderate and minor in alpine skiing, freestyle skiing and snowboarding. Compared to professional footballers, the absolute injury risk was much lower among World Cup skiers and snowboarders; however, the risk of severe injuries was about the same.

3. The relative injury rate was almost twice as high in freestyle skiing compared to alpine skiing. Within freestyle skiing, the relative injury rate was lower in moguls compared to ski cross, aerials and halfpipe, while it increased with skiing speed within the alpine skiing disciplines (the lowest rate in slalom and the highest in downhill).

4. The knee was the most frequently injured body part (except in cross-country skiing) and severe knee ligament injuries dominated. Head injuries, mainly concussions, were also frequent.

5. We did not detect any sex differences for knee injuries in either alpine or freestyle skiing. However, the absolute and relative injury rates were higher among male alpine skiers compared to females, while there was no sex difference in freestyle skiing.

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Appendix 1-3

FÉDÉRATION INTERNATIONALE DE SKI
INTERNATIONAL SKI FEDERATION
INTERNATIONALER SKI VERBAND

Injury report / *Verletzungsmeldung / Rapport de blessure*

All injuries that occur during official training or competition and require attention by medical personnel should be reported/ *Alle Verletzungen, die während des offiziellen Trainings oder des Wettkampfes auftreten und Betreuung durch medizinisches Personal erfordern, sollten gemeldet werden/Toutes les blessures qui se produisent pendant l'entraînement officiel ou la compétition et qui necessitent l'attention du personnel médical doivent être rapportées*

Event information/
Informationen zum Bewerb/Information sur l'évènement

Discipline/ *Disziplin/Discipline*: ☐

Site/ *Ort/Lieu*: ☐

Country/ *Land/Pays*: ☐☐☐

Category/ *Kategorie/Catégorie*: ☐

Codex: ☐☐☐☐

Date (DD.MM.YYYY)/ *Datum/Date*: ☐☐.☐☐.☐☐☐☐

Athlete information/
Informationen zum Athleten/Données sur l'athlète

Name/ *Name/Nom*: ☐

FIS Code: ☐☐☐☐☐☐☐

Country/ *Land/Pays*: ☐☐☐

Gender/ *Geschlecht/ Sexe:*
- ☐ Male/ *Mann/Homme*
- ☐ Female/ *Frau/Femme*

Birth date (DD.MM.YYYY)/ *Geburtsdatum/ Date de naissance*: ☐☐.☐☐.☐☐☐☐

Injury information/
Information zur Verletzung/Information sur la blessure

To be completed in collaboration with event or team medical staff (if possible)/ *Bitte in Zusammenarbeit mit den medizinisch Verantwortlichen der Veranstaltung oder des Teams ausfüllen (wenn möglich)/Svp remplir en collaboration avec le personnel médical de l'événement ou de l'équipe (si possible)*

Note: Injuries occurring during warm-up, free skiing/snowboarding or between runs need NOT be recorded/ *Anmerkung: Verletzungen die während des Aufwärmens, bei freien Skifahren/Snowboarden oder zwischen zwei Läufen passieren müssen NICHT gemeldet werden/Note: Des blessures se produisant pendant l'echauffement, le ski/snowboarding libre ou entre les manche/runs n'ont pas besoin d'être enregistrés*

Body part injured/ *Verletzter Köperteil/Partie du corps blessée:*

- ☐ Head-face/ *Kopf-Gesicht/Tête-Face*
- ☐ Neck-cervical spine/ *Nacken-Halswirbel/Nuque-Vertèbre cervicale*
- ☐ Shoulder-clavicula/ *Schulter-Schlüsselbein/Epaule-Clavicule*
- ☐ Upper arm/ *Oberarm/Bras*
- ☐ Elbow/ *Ellbogen/Coudes*
- ☐ Forearm/ *Unterarm/Avant-bras*
- ☐ Wrist/ *Handgelenk/Poignet*
- ☐ Hand-finger-thumb/ *Hand-Finger-Daumen/Main-Doigt-Pouce*
- ☐ Chest (sternum-ribs-upper back)/ *Brustkasten (Brustbein-Rippen-Brustwirbelsäule)/Thorax (Sternum-Côtes-Haut du dos)*
- ☐ Abdomen/ *Bauch/Abdomen*
- ☐ Lower back-pelvis-sacrum/ *Lendenwirbelsäule-Becken-Kreuzbein/Bas du dos-Pelvis-Sacrum*
- ☐ Hip-groin/ *Hüfte-Leiste/Hanche-Aine*
- ☐ Thigh/ *Oberschenkel/Cuisse*
- ☐ Knee/ *Knie/Genoux*
- ☐ Lower leg-Achilles tendon/ *Unterschenkel-Achillessehne/Jambe-Tendon d'Achille*
- ☐ Ankle/ *Fussgelenk/Cheville*
- ☐ Foot-heel-toe/ *Fuss-Ferse-Zehen/Pied-Talon-Orteils*
- ☐ Information not available/ *Information nicht verfügbar/Information non disponible*

Side/ *Seite/Part*:
- ☐ Right/ *Rechts/Droite*
- ☐ Left/ *Links/Gauche*
- ☐ Not applicable/ *Nicht anwendbar/Non applicable*

Injury type/ *Art der Verletzung/Genre de la blessure:*

- ☐ Fractures and bone stress/ *Frakturen und Ermüdungsbrüche/Fracture et fracture de fatigue*
- ☐ Joint (non-bone) and ligament/ *Gelenke (nicht Knochen) und Bänder/Joint (articulation) et ligament*
- ☐ Muscle and tendon/ *Muskel und Sehnen/Muscle et tendon*
- ☐ Contusions/ *Quetschungen/Contusions*
- ☐ Laceration and skin lesion/ *Fleischwunden und Hautverletzung/Plaie et lésion de la peau*
- ☐ Nervous system including concussion/ *Nervensystem inkl. Gehirnerschütterung/Système nerveux y compris commotion cérébrale*
- ☐ Other/ *Andere/Autres*
- ☐ Information not available/ *Information nicht verfügbar/Information non disponible*

Expected absence from training and competition/ *Voraussichtliche Abwesenheit von Training und Wettkämpfen/Prévision d'absence à l'entrainement et en compétitions:*

- ☐ No absence/ *Keine Absenz/Pas d'absence*
- ☐ 1 to 3 days/ *1 bis 3 Tage/1 à 3 jours*
- ☐ 4 to 7 days/ *4 bis 7 Tage/4 à 7 jours*
- ☐ 8 to 28 days/ *8 bis 28 Tage/8 à 28 jours*
- ☐ >28 days/ *>28 Tage/>28 jours*
- ☐ Information not available/ *Information nicht verfügbar/Information non disponible*

Specific diagnosis (if available)/ *Genaue Diagnose (wenn verfügbar)/Diagnostic spécifique (si disponible):*

☐

Note: If there are multiple injuries resulting from the same accident, please describe the most serious injury above and the less serious injuries here/ *Anmerkung: Wenn aus dem gleichen Unfall mehrere Verletzungen resultieren, bitte beschreiben sie die schwereren Verletzungen oben und die leichteren Verletzungen hier/Note: S'il y a des blessures multiples résultant du même accident, veuillez décrire les blessures les plus sérieuses ci-dessus et les blessures moins sérieuses ci-dessous:*

☐

Contact information to obtain further medical information/ *Kontakt für weitere medizinische Informationen/Contact pour obtenir des informations médicales supplémentaires:*

Name/ *Name/Nom:* ☐

Mobile telephone/ *Mobiltelefonnummer/ Numéro mobile:* ☐

E-mail: ☐

Please complete page 2/ *Bitte vervollständigen Sie Seite 2/Svp remplir page 2*

Injury circumstances/
Umstände der Verletzung/Circonstances de la blessure:

- ☐ Competition/ *Wettkampf/Compétition*
- ☐ Official training/ *OffiziellesTraining/Entraînement officiel*

Type of snow/ *Schneeart/Genre du neige:*

- ☐ Natural snow/ *Naturschnee/Neige naturelle*
- ☐ Artificial snow/ *Kunstschnee/Neige artificiel*
- ☐ Plastic/ *Plastik/Plastique*

Course conditions (multiple choices possible)/ *Streckenzustand (mehrere Antworten möglich)/Condition de la piste (choix multiples possibles):*

- ☐ Ice/ *Eis/Glace*
- ☐ *Soft/ Weich/Doux*
- ☐ Compact/ *Kompakt/Compact*
- ☐ Injected snow/ *Wasserbehandelter Schnee/Neige traitée par l'eau*
- ☐ Chemicals used(salt, snow solidifier, others)/ *Gebrauchte Chemikalien(Salz, Schneeverfestiger, andere)/Produit chimique utilisé (sel, solidification de neige, autres)*

Weather conditions (multiple choices possible)/ *Wetterbedingen (mehrere Antworten möglich)/Conditions météorologiques (choix multiples possibles):*

- ☐ Sunny-clear/ *Sonnig-klar/Beau temps-clair*
- ☐ Cloudy/ *Bewölkt/Couvert*
- ☐ Raining/ *Regnerisch/Pluvieux*
- ☐ Snowing/ *Schneefall/Chute de neige*
- ☐ Foggy/ *Nebel/Brouillard*
- ☐ Flat light/ *Diffuses Licht/Mauvaise visibilité*
- ☐ Artificial light/ *Künstliche Beleuchtung/Illumination artificielle*

Wind conditions/ *Windkonditionen/Condition de vent:*

- ☐ No wind/ *Kein Wind/Pas de vent*
- ☐ Some wind/ *Etwas Wind/Peu de vent*
- ☐ High wind/ *Starker Wind/Vent fort*

Video/ Video/Vidèo:

Video available from accident (multiple choices possible)/ *Video vom Unfall verfügbar (mehrere Antworten möglich)/Vidéo de l'accident disponible (choix multiples possibles):*

- ☐ No/ *Keines/No*
- ☐ TV broadcast/ *Fernsehanstalt/Chaines TV*
- ☐ Other video/ *Anderes Video/Autres video:*

Explain/ *Erklärung/Expliquez:*

Contact information to obtain copy of video/ *Kontakt um das Video zu erhalten/Contact pour obtenir une copie de la vidéo:*

Name/ *Name/Nom:*

E-mail:

Mobile telephone/ *Mobiltelefonnummer/ Numéro mobile:*

Other comments/
Weitere Bemerkungen/Autres commentaires:

Please send this injury report as soon as possible to/
Bitte schicken Sie diese Verletzungsmeldung so rasch als möglich an/
Veuillez envoyer ce rapport de blessure le plus vite possible à la:

FIS, Blochstrasse 2, CH-3653 Oberhofen, SUI

Fax: +41 33 244 61 71

E-mail: **Alpine: luessy@fisski.ch** **Freestyle/Snowboard: hostettler@fisski.ch**
Cross Country/Telemark: lessing@fisski.ch **Ski Jumping/Nordic Combined: friedrich@fisski.ch**

Injury Surveillance Study - Interview

FIS World Cup Alpine, male, 2008/09

FIS PARTNER FIS INJURY SURVEILLANCE SYSTEM

Oslo Sports Trauma RESEARCH CENTER

Athlete Name: ______________________________ ☐ Trainer: ____________________

Nation: __________ Discipline: __________ ☐ MD/PT: ____________________

Contact (e-mail/cell): ______________________________ ☐ Athlete

Week	Date	Site	Race / Competition	Start: Yes	Injury: Yes	If "yes" on injury, fill out form Other notes
43 20.-26./10	26.10.2008	Solden, AUT	GS	☐	☐ ☐	
44	27.-2./10				☐	
45	3.-9./11				☐	
46 10.-16./11	16.11.2008	Levi, FIN	SL	☐	☐ ☐	
47	17.-23./11				☐	
48 24.-30./11	29.11.2008 30.11.2008	Lake Louise, CAN Lake Louise, CAN	DH SG	☐ ☐	☐ ☐ ☐	
49 1.-7./12	05.12.2008 06.12.2008 07.12.2008	Beaver Creek, USA Beaver Creek, USA Beaver Creek, USA	DH SG GS	☐ ☐ ☐	☐ ☐ ☐ ☐	
50 8.-14./12	12.12.2008 12.12.2008 13.12.2008	Val d`Isere Val d`Isere Val d`Isere	SC (SL) SC (SG) GS	☐ ☐ ☐	☐ ☐ ☐ ☐	
51 15.-21./12	19.12.2008 20.12.2008 21.12.2008	Val Gardena, ITA Val Gardena, ITA Alta badia, ITA	SG DH GS	☐ ☐ ☐	☐ ☐ ☐ ☐	
52 22.-28./12	22.12.2008 28.12.2008	Alta badia, ITA Bormio, ITA	SL DH	☐ ☐	☐ ☐ ☐	
1 29.-4./1	05.01.2009 06.01.2009	Adelboden, SUI Adelboden, SUI	GS SL	☐ ☐	☐ ☐ ☐	
2 5.-11./1	06.01.2009 10.01.2009 11.01.2009	Zagreb, CRO Adelboden, SUI Adelboden, SUI	SL GS SL	☐ ☐ ☐	☐ ☐ ☐ ☐	

3	16.01.2009	Wengen, SUI	SC (DH)	☐	☐	
	16.01.2009	Wengen, SUI	SC (SL)	☐	☐	
	17.01.2009	Wengen, SUI	DH	☐	☐	
	18.01.2009	Wengen, SUI	SL	☐	☐	
12.-18./1					☐	
4	23.01.2009	Kitzbuehel, AUT	SG	☐	☐	
	24.01.2009	Kitzbuehel, AUT	DH	☐	☐	
	25.01.2009	Kitzbuehel, AUT	SC (DH)	☐	☐	
	25.01.2009	Kitzbuehel, AUT	SC (SL)	☐	☐	
19.-25./1					☐	
5	27.01.2009	Schladming, AUT	SL	☐	☐	
	01.02.2009	Garmisch, GER	SL	☐	☐	
26.-1./2					☐	
6	04.02.2008	Val d`Isere, FRA	SG	☐	☐	
	07.02.2009	Val d`Isere, FRA	DH	☐	☐	
	09.02.2009	Val d`Isere, FRA	SC (DH)	☐	☐	
	09.02.2009	Val d`Isere, FRA	SC (SL)	☐	☐	
	11.02.2009	Val d`Isere, FRA	Team	☐	☐	
	13.02.2009	Val d`Isere, FRA	GS	☐	☐	
	15.02.2009	Val d`Isere, FRA	SL	☐	☐	
2.-8./2					☐	
7	17.02.2009	Zagreb-Sljerne, CRO	SL	☐	☐	
9.-15./2					☐	
8	21.02.2009	Sestriere, ITA	GS	☐	☐	
	22.02.2009	Sestriere, ITA	SC (SG)	☐	☐	
	22.02.2009	Sestriere, ITA	SC (SL)	☐	☐	
16.-22./2					☐	
9	28.02.2009	Kranjska Gora, SLO	GS	☐	☐	
	01.03.2009	Kranjska Gora, SLO	SL	☐	☐	
23.-1./3					☐	
10	06.03.2009	Kvitfjell, NOR	DH	☐	☐	
	07.03.2009	Kvitfjell, NOR	DH	☐	☐	
	08.03.2009	Kvitfjell, NOR	SG	☐	☐	
2.-8./3					☐	
11	11.03.2009	Åre, SWE	DH	☐	☐	
	12.03.2009	Åre, SWE	SG	☐	☐	
	13.03.2009	Åre, SWE	GS	☐	☐	
	14.03.2009	Åre, SWE	SL	☐	☐	
	15.03.2009	Åre, SWE	Team	☐	☐	
9.-15./3					☐	

Number of injuries: ____________

Number of injury forms: ____________

UNIVERSITETET I OSLO
DET MEDISINSKE FAKULTET

Professor dr.med. Roald Bahr
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Sør- Norge (REK Sør)
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NO-0318 Oslo

Telefon: 228 50 670
Telefaks: 228 44 661
E-post: juliannk@medisin.uio.no
Nettadresse: www.etikkom.no

Dato: 12.10.06
Deres ref.:
Vår ref.: S-06356b

S-06356b Overvåking av skiskader på elitenivå - FIS Injury Surveillance System

Komiteen behandlet søknaden i sitt møte torsdag 05.10.06

Prosjektet oppfattes som en kvalitetssikring av FIS' skadeovervåkingssystem (ISS). Søknaden omfattes derfor ikke av komiteens mandat om fremleggelsesplikt.

Med vennlig hilsen

Tor Norseth
Leder

Julianne Krohn-Hansen
Sekretær

Kopi: Stipendiat Tonje Wåle Flørenes, Senter for idrettskadeforskning, Norges Idrettshøgskole, Pb. 4014 Ullevål Stadion, 0806 Oslo

Norsk samfunnsvitenskapelig datatjeneste AS
NORWEGIAN SOCIAL SCIENCE DATA SERVICES

NSD

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Norway
Tel: +47-55 58 21 17
Fax: +47-55 58 96 50
nsd@nsd.uib.no
www.nsd.uib.no
Org.nr. 985 321 884

Tonje Wåle Flørenes
Norges idrettshøgskole
Postboks 4014 Ullevål Stadion
0806 OSLO

Vår dato: 23.10.2006 Vår ref: 15355/KS Deres dato: Deres ref:

TILRÅDING AV BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 13.09.2006. Meldingen gjelder prosjektet:

15355	*Validering av FIS Injury Surveillance System*
Behandlingsansvarlig	*Norges idrettshøgskole, ved institusjonens øverste leder*
Daglig ansvarlig	*Tonje Wåle Flørenes*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, eventuelle kommentarer samt personopplysningsloven/-helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/endringsskjema. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://www.nsd.uib.no/personvern/database/

Personvernombudet vil ved prosjektets avslutning, 01.01.2008 rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Bjørn Henrichsen

Katrine Utaaker Segadal

Kontaktperson: Katrine Utaaker Segadal tlf: 55 58 35 42

Vedlegg: Prosjektvurdering

Paper I

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Recording injuries among World Cup skiers and snowboarders: a methodological study

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No long-term injury surveillance programs exist for competitive skiing or snowboarding. The objective of this study was, therefore, to compare different methods to record injuries among World Cup athletes in alpine, freestyle, and cross-country skiing, snowboarding, ski jumping and Nordic combined. Information regarding injuries sustained during the 2006–2007 winter season was recorded through three separate and independent systems: prospective injury reports by technical delegates (TD) from the International Ski Federation, prospective medical team registration by selected teams, and retrospective athlete interviews at the end of the season. A total of 100 unique injuries to 602 World Cup athletes were identified from any of the three recording methods. Of these, 91% were registered through the athlete interviews, 47% by the medical team registration and 27% by the TD reports. Only 20 injuries (20%) were captured by all three methods. A total of 64 time-loss injuries were registered. The interviews captured 60 (94%), the medical team registration 39 (61%), and the TD reports 23 (36%) time-loss injuries, while 18 (28%) were registered by all three systems. Retrospective interviews with athletes/coaches regarding injuries during the last 6 months gave the most complete picture of injuries to World Cup skiers and snowboarders.

Skiing and snowboarding are popular sports and it has been estimated that there are approximately 200 million skiers worldwide (Hunter, 1999). Skiing and snowboarding are also popular as competitive sports and the different disciplines of alpine skiing, freestyle skiing, snowboarding, ski jumping, cross-country skiing, and Nordic combined (combination of cross-country skiing and ski jumping) account for more than half of all participants in the winter Olympic Games. According to the International Ski Federation (FIS), 5393 FIS races were held during the 2006–2007 winter season in these disciplines (FIS, personal communication, April 2008). Of these, 298 races were at the World Cup level.

However, in contrast to recreational alpine skiing and snowboarding, where there are several regional (Johnson et al., 2000; Dohjima et al., 2001; Langran & Selvaraj, 2002; Made & Elmqvist, 2004) and even national (Laporte et al., 2000; Ekeland & Rødven, 2006) prospective ski injury recording systems, no long-term injury surveillance programs exist for competitive skiing or snowboarding. Therefore, we only have limited data available on the injury profile of the elite skier or snowboarder. Although there are some studies from competitive alpine skiing (Ekeland & Holm, 1985; Ekeland et al., 1996; Bergstrom et al., 2001), snowboarding (Torjussen & Bahr, 2005, 2006), freestyle skiing (Dowling, 1982), and ski jumping (Wright, Jr. et al., 1986; Yamamura et al., 1993), these are generally small and often limited to one competition. Except for snowboarding, there are no recent studies available reflecting the current performance level of elite athletes in these disciplines. No data is available from elite cross-country skiing or Nordic combined. Consequently, as prospective injury recording systems do not exist, the risk of being injured for top-level skiers or snowboarders is unknown.

Establishing reliable systems for injury surveillance is a key risk management tool. Such recording systems also represent the important first step in the sequence of injury prevention research (van Mechelen et al., 1992). Prospective cohort studies are recommended to monitor injury patterns and risk over time (Fuller et al., 2006). To date, injury surveillance systems have been established for major sports events such as World Championships in individual sports like athletics (Alonso et al., 2009) and team sports such as football (Junge et al., 2004) and rugby (Stephenson et al., 1996), as well as multi-sport competitions such as the Olympic Games (Junge et al., 2006, 2008) and the US college sports (National Collegiate Athletic Association Injury Surveillance System) (Dick et al., 2007).

Before the 2006–2007 winter season, FIS took an initiative to establish a continuous injury reporting system for all FIS events. In recreational skiing and snowboarding different methods, reports from ski patrols, physicians at base-lodge clinics, hospital reports or self-reports have been used to record injuries. However, as it was not known which method would yield the most complete and accurate record of injuries to elite ski and snowboard athletes, we wanted to evaluate what would be the best method to register injuries in this population of athletes. The information sources potentially available were the athletes themselves, their medical staff or FIS personnel responsible for running the event, namely the technical delegate (TD) and his local staff, including the official race doctor. Thus, the aim of this study was to compare three different methods to record injuries among World Cup skiers and snowboarders, prospective reporting by the TD, prospective reporting by the medical staff of selected World Cup teams and retrospective interviews with World Cup athletes at the end of the World Cup season.

Materials and methods

Study design and population

Injuries to World Cup athletes in the different disciplines of alpine skiing (downhill, super-G, giant slalom, slalom, combined and super combined), freestyle skiing (moguls, dual moguls, halfpipe, skicross, aerials), snowboarding (halfpipe, snowboardcross, parallel giant slalom, parallel slalom, big air), ski jumping, cross-country skiing and Nordic combined were registered through three independent and separate methods during the 2006–2007 winter season (November 1 until the end of the respective World Cup season): (1) prospective injury reports by the TD from FIS (TD reports), (2) prospective injury reporting throughout the season by medical staff from selected World Cup teams ("Medical team registration"), and (3) retrospective athlete interviews at the end of the season ("Athlete interviews"). Athletes from one of six major skiing nations who had participated in at least one World Cup event during the season were eligible for inclusion in this study. The study was approved by the Regional Committee for Medical Research Ethics, Region Øst-Norge and by the Norwegian Social Science Data Services.

Injury definition

The injury definition communicated to all parties involved in the three registration methods was: "All injuries that occurred during training or competition and required attention by medical personnel." Training included activities on snow and basic training not on snow. The three registration systems used an injury form containing the same information regarding event and injury (Fig. 1). The classification of the type of injury and body part injured were based on a recent consensus document on injury surveillance in football (Fuller et al., 2006). Severity of injury was classified according to the duration of absence from training and competition as slight (no absence); minimal (1–3 days), mild (4–7 days), moderate (8–28 days) and severe (>28 days). Expected time loss was recorded in the TD reports, as the actual time loss was not known at the time of registration. A specific diagnosis was also recorded. If multiple injuries resulted from the same event, all of these were described on the same form.

Injury registration by the TD reports

A TD is the official FIS representative and is always present at FIS races, with the responsibility of ensuring that the athletes, coaches and organizers are satisfied with the outcome of the competition (FIS, 2005). The primary duties of the TD are to make sure that the rules and directions of the FIS are adhered to, to see that the event runs smoothly, to advise the organizers within the scope of their duties and to be the official representative of the FIS (FIS, 2008). TDs were asked to report injuries to any athlete participating in all events of the World Cup and World Championships (including official training). We informed those responsible for TD training in the different disciplines how to complete the injury forms during information meetings at the annual FIS spring and autumn meetings before the start of the season. We also produced a brochure with information about the project, as well as description of roles and responsibilities and this brochure was distributed at the same meetings. Information was also distributed through the official FIS website as well as a sub site of the Oslo Sports Trauma Research Center website dedicated to the project. To report an injury, TDs were asked to complete a specific injury form (Fig. 1). The injury form described each injury in detail with regards to the injury type, body part injured, the injured side, specific diagnosis, and expected duration of time loss from training/competition. The TDs were asked to enlist the help of a medically trained person at the event, preferably the official race doctor, to complete the specific medical information. The TDs completed the forms manually or electronically and faxed or sent them by e-mail or regular mail to the FIS office.

Medical team registration

The second registration method was a prospective reporting by the medical staff for six selected World Cup teams. The federations of Switzerland, Germany, France, Finland, Canada and Norway agreed to participate in this study during a meeting in the FIS Medical Committee in September 2006. Each of these federations nominated a contact person for each World Cup team in the disciplines of alpine, freestyle, snowboard, ski jumping, Nordic combined and cross-country skiing, preferably the doctor or physical therapist working and travelling with the team. We sent a letter describing the purposes and procedures of the medical team registration to the team contacts. The team contacts were asked to ensure that all injuries to their World Cup athletes during team activities and competitions were documented by their medical personnel. The team contacts were asked to pass on information material to all athletes, trainers, medical personnel and other support staff to inform about the registration. In addition, written consent was obtained from the athletes. The team contacts were physicians, physical therapists or

FÉDÉRATION INTERNATIONALE DE SKI
INTERNATIONAL SKI FEDERATION
INTERNATIONALER SKI VERBAND

Injury report / *Verletzungsmeldung / Rapport de blessure*

All injuries that occur during official training or competition and require attention by medical personnel should be reported/ *Alle Verletzungen, die während des offiziellen Trainings oder des Wettkampfes auftreten und Betreuung durch medizinisches Personal erfordern, sollten gemeldet werden/Toutes les blessures qui se produisent pendant l'entraînement officiel ou la compétition et qui necessitent l'attention du personnel médical doivent être rapportées*

Event information/
Informationen zum Bewerb/Information sur l'évènement

Discipline/ *Disziplin/Discipline*:

Site/ *Ort/Lieu*:

Country/ *Land/Pays*:

Category/ *Kategorie/Catégorie*:

Codex:

Date (DD.MM.YYYY)/ *Datum/Date*:

Athlete information/
Informationen zum Athleten/Données sur l'athlète

Name/ *Name/Nom*:

FIS Code:

Country/ *Land/Pays*:

Gender/ *Geschlecht/ Sexe*:
- ☐ Male/ *Mann/Homme*
- ☐ Female/ *Frau/Femme*

Birth date (DD.MM.YYYY)/ *Geburtsdatum/ Date de naissance*:

Injury information/
Information zur Verletzung/Information sur la blessure

To be completed in collaboration with event or team medical staff (if possible)/ *Bitte in Zusammenarbeit mit den medizinisch Verantwortlichen der Veranstaltung oder des Teams ausfüllen (wenn möglich)/Svp remplir en collaboration avec le personnel médical de l'événement ou de l'équipe (si possible)*

Note: Injuries occurring during warm-up, free skiing/snowboarding or between runs need NOT be recorded/ *Anmerkung: Verletzungen die während des Aufwärmens, bei freien Skifahren/Snowboarden oder zwischen zwei Läufen passieren müssen NICHT gemeldet werden/Note: Des blessures se produisant pendant l'echauffement, le ski/snowboarding libre ou entre les manche/runs n'ont pas besoin d'être enregistrés*

Body part injured/ *Verletzter Köperteil/Partie du corps blessée:*
- ☐ Head-face/ *Kopf-Gesicht/Tête-Face*
- ☐ Neck-cervical spine/ *Nacken-Halswirbel/Nuque-Vertèbre cervicale*
- ☐ Shoulder-clavicula/ *Schulter-Schlüsselbein/Epaule-Clavicule*
- ☐ Upper arm/ *Oberarm/Bras*
- ☐ Elbow/ *Ellbogen/Coudes*
- ☐ Forearm/ *Unterarm/Avant-bras*
- ☐ Wrist/ *Handgelenk/Poignet*
- ☐ Hand-finger-thumb/ *Hand-Finger-Daumen/Main-Doigt-Pouce*
- ☐ Chest (sternum-ribs-upper back)/ *Brustkasten (Brustbein-Rippen-Brustwirbelsäule)/Thorax (Sternum-Côtes-Haut du dos)*
- ☐ Abdomen/ *Bauch/Abdomen*
- ☐ Lower back-pelvis-sacrum/ *Lendenwirbelsäule-Becken-Kreuzbein/Bas du dos-Pelvis-Sacrum*
- ☐ Hip-groin/ *Hüfte-Leiste/Hanche-Aine*
- ☐ Thigh/ *Oberschenkel/Cuisse*
- ☐ Knee/ *Knie/Genoux*
- ☐ Lower leg-Achilles tendon/ *Unterschenkel-Achillessehne/Jambe-Tendon d'Achille*
- ☐ Ankle/ *Fussgelenk/Cheville*
- ☐ Foot-heel-toe/ *Fuss-Ferse-Zehen/Pied-Talon-Orteils*
- ☐ Information not available/ *Information nicht verfügbar/Information non disponible*

Side/ Seite/Part:
- ☐ Right/ *Rechts/Droite*
- ☐ Left/ *Links/Gauche*
- ☐ Not applicable/ *Nicht anwendbar/Non applicable*

Injury type/ *Art der Verletzung/Genre de la blessure:*
- ☐ Fractures and bone stress/ *Frakturen und Ermüdungsbrüche/Fracture et fracture de fatigue*
- ☐ Joint (non-bone) and ligament/ *Gelenke (nicht Knochen) und Bänder/Joint (articulation) et ligament*
- ☐ Muscle and tendon/ *Muskel und Sehnen/Muscle et tendon*
- ☐ Contusions/ *Quetschungen/Contusions*
- ☐ Laceration and skin lesion/ *Fleischwunden und Hautverletzung/Plaie et lésion de la peau*
- ☐ Nervous system including concussion/ *Nervensystem inkl. Gehirnerschütterung/Système nerveux y compris commotion cérébrale*
- ☐ Other/ *Andere/Autres*
- ☐ Information not available/ *Information nicht verfügbar/Information non disponible*

Expected absence from training and competition/ *Voraussichtliche Abwesenheit von Training und Wettkämpfen/Prévision d'absence à l'entrainement et en compétitions:*
- ☐ No absence/ *Keine Absenz/Pas d'absence*
- ☐ 1 to 3 days/ *1 bis 3 Tage/1 à 3 jours*
- ☐ 4 to 7 days/ *4 bis 7 Tage/4 à 7 jours*
- ☐ 8 to 28 days/ *8 bis 28 Tage/8 à 28 jours*
- ☐ >28 days/ *>28 Tage/>28 jours*
- ☐ Information not available/ *Information nicht verfügbar/Information non disponible*

Specific diagnosis (if available)/ *Genaue Diagnose (wenn verfügbar)/Diagnostic spécifique (si disponible):*

Note: If there are multiple injuries resulting from the same accident, please describe the most serious injury above and the less serious injuries here/ *Anmerkung: Wenn aus dem gleichen Unfall mehrere Verletzungen resultieren, bitte beschreiben sie die schwereren Verletzungen oben und die leichteren Verletzungen hier/Note: S'il y a des blessures multiples résultant du même accident, veuillez décrire les blessures les plus sérieuses ci-dessus et les blessures moins sérieuses ci-dessous:*

Contact information to obtain further medical information/ *Kontakt für weitere medizinische Informationen/Contact pour obtenir des informations médicales supplémentaires:*

Name/ *Name/Nom:*

Mobile telephone/ *Mobiltelefonnummer/ Numéro mobile:*

E-mail:

Please complete page 2/ *Bitte vervollständigen Sie Seite 2/Svp remplir page 2*

Fig. 1. Injury form with the standard injury information used in all three registration methods.

athletic trainers, depending on the organization of the different teams. Regular communication was established with the team contacts through e-mail, telephone calls and text messages every 2–3 week throughout the season and they sent injury reports either by e-mail, fax or mail continuously during the season.

FIS PARTNER FIS INJURY SURVEILLANCE SYSTEM

Injury Surveillance Study - Interview

Oslo Sports Trauma RESEARCH CENTER

FIS World Cup Alpine, male, 2006/07

Athlete Name: ______________________

Nation: ____________ Discipline: ____________

Contact (e-mail/cell): ______________________

Week	Date	Site	Race / Competitio n	Start: Yes	Injury: Yes	If "yes" on injury, fill out form Other notes
44	1.-5./11				☐	
45 (6.-12./11)	12.11.2006	Levi, FIN	SL	☐	☐ ☐	
46	13.-19/11				☐	
47 (20.-26./11)	25.11.2006	Lake Louise, CAN	DH	☐	☐	
	26.11.2006	Lake Louise, CAN	SG	☐	☐ ☐	
48 (27.-3./12)	30.11.2006	Beaver Creek, USA	SC (DH)	☐	☐	
	30.11.2006	Beaver Creek, USA	SC (SL)	☐	☐	
	01.12.2006	Beaver Creek, USA	DH	☐	☐	
	02.12.2006	Beaver Creek, USA	GS	☐	☐	
	03.12.2006	Beaver Creek, USA	SL	☐	☐ ☐	
49 (4.-10./12)	10.12.2006	Reiteralm, AUT	SC (SG)	☐	☐	
	10.12.2006	Reiteralm, AUT	SC (SL)	☐	☐ ☐	
50 (11.-17./12)	15.12.2006	Gardena/Groeden, ITA	SG	☐	☐	
	16.12.2006	Gardena/Groeden, ITA	DH	☐	☐	
	17.12.2006	Alta Badia, ITA	GS	☐	☐ ☐	
51 (18.-24./12)	18.12.2006	Alta Badia, ITA	SL	☐	☐	
	20.12.2006	Hinterstoder, AUT	SG	☐	☐	
	21.12.2006	Hinterstoder, AUT	GS	☐	☐ ☐	
52 (25.-31./12)	28.12.2006	Bormio, ITA	DH	☐	☐	
	29.12.2006	Bormio, ITA	DH	☐	☐ ☐	
1 (1.-7./1)	06.01.2007	Adelboden, SUI	GS	☐	☐	
	07.01.2007	Adelboden, SUI	SL	☐ ☐	☐ ☐	
2 (8.-14./1)	13.01.2007	Wengen, SUI	DH	☐	☐	
	14.01.2007	Wengen, SUI	SC (DH)	☐	☐	
	14.01.2007	Wengen, SUI	SC (SL)	☐	☐ ☐	

Fig. 2. Example of an interview form with week-by-week schedule. Part of the form from alpine skiing.

Athlete interviews

The third registration method was a retrospective interview with World Cup athletes and/or their team managers/doctors/physical therapists at the end of the 2006–2007 winter season regarding injuries the athletes had sustained during the season. Athletes having started in at least one World Cup/World Championship event in each of the disciplines of alpine, freestyle, snowboard, ski jumping, Nordic combined and cross-country skiing from the same six nations participating in the medical team registration were identified from the official FIS database. The interviews were carried out at one of the season-ending World Cup events for each discipline. At these events, all athletes who were present from the selected nations were interviewed in person. For those athletes who were not present (due to injury or other reasons), their coaches and/or team physicians/physical therapists were interviewed. Information regarding the purpose and procedures of the interviews was given at the team captain's meeting, where head coaches from all nations are required to be present, and they were asked to inform their athletes. Research teams from the Oslo Sports Trauma Research Center (physicians, physical therapists and medical students) conducted the interviews, normally in the finishing area in connection with official training or competition for the different disciplines, in some cases at their hotel. Athletes from the freestyle discipline halfpipe and the snowboard disciplines big air, parallel giant slalom and parallel slalom were not interviewed because of event cancellations and scheduling conflicts. The interviews were structured based on a form outlining the week-by-week schedule of the World Cup program for each respective discipline, to facilitate athlete recall of missed participation due to injury (Fig. 2). If an injury was recorded, an injury form was completed.

During the registration period, neither the TDs nor the team medical staff was aware that we would perform athlete interviews at the end of the season.

Data analyses

To compare the accuracy and completeness of the three registration methods, injuries recorded to any athlete from the six nations covered by all three methods were compared. The comparison was limited to injuries occurring during World Cup/World Championships (including official training), as the TD reports did not cover training injuries outside these events. Injuries reported during the season-ending event were not included in the comparison between the different methods. We defined the information reported by the athletes themselves regarding injury type and the duration of absence from competition and training as the reference to which the other methods were compared. If an injury was not reported in the athlete interview, we then used the report from the team medical personnel as the reference.

Statistics

Kappa (κ) correlation coefficients were calculated for agreement between methods (Altman, 1991). Coefficients of 0.81–1.00 are generally interpreted as very good, 0.61–0.80 as good, 0.41–0.60 as moderate, 0.21–0.40 as fair and <0.20 as poor (Altman, 1991).

Results

During the 2006–2007 winter season, 3297 athletes competed in the FIS World Cup according to the official FIS database; 455 in alpine skiing, 1475 in cross-country skiing, 79 in Nordic combined, 459 in freestyle skiing, 141 in ski jumping and 620 in snowboarding. Of these, 612 were from the World Cup teams of the six countries covered by all three registration methods and we were able to obtain interview information about 602 athletes (98%); 141 from alpine skiing, 153 from cross-country skiing, 41 from Nordic combined, 117 from freestyle skiing, 50 from ski jumping and 100 from snowboarding.

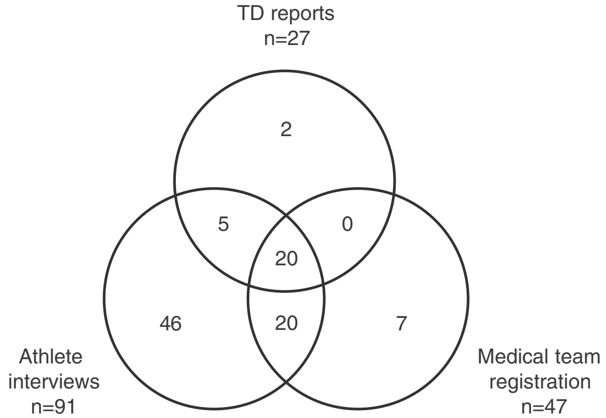

Fig. 3. Venn diagram of injuries reported through the three registration methods within the cohort covered by all three methods ($n = 100$).

A total of 100 unique injuries, which potentially could have been reported in all three registrations were identified (injuries to the 602 athletes interviewed occurring in World Cup/World Championship events until the date of the interviews). Of these, 91 injuries were recorded through the athlete interviews, 47 by the medical team registration and 27 by the TD reports. Only 20 injuries were recorded by all three registration methods (Fig. 3).

For the time-loss injuries (injuries leading to an absence of ≥ 1 day), a total of 64 unique injuries were identified from at least one of the three recording systems. Sixty injuries were reported from the athlete interviews, 39 by the medical team registration and 23 through the TD reports. Eighteen injuries were recorded by all three registration methods (Fig. 4).

Of the 100 unique injuries recorded through the three recording systems, 29 were in alpine skiing, 12 in cross-country skiing, four in Nordic combined, 25 in freestyle skiing, six in ski jumping and 24 in snowboarding. Among the 29 alpine skiing injuries, 10 (34%) were detected by the TD reports and 21 (72%) through the medical team registration. The corresponding figures for cross-country skiing were 0 and 4 (33%), for Nordic combined 0 and 3 (75%), for freestyle skiing 11 (44%) and 10 (40%), for ski jumping 2 (33%) and 4 (67%) and for snowboarding 4 (17%) and 5 (21%) for the TD reports and medical team registration, respectively.

As shown in Table 1, 44 (60%) of the 73 injuries that the TDs did not record were minor injuries with no absence or a 1–3 day time loss from training and

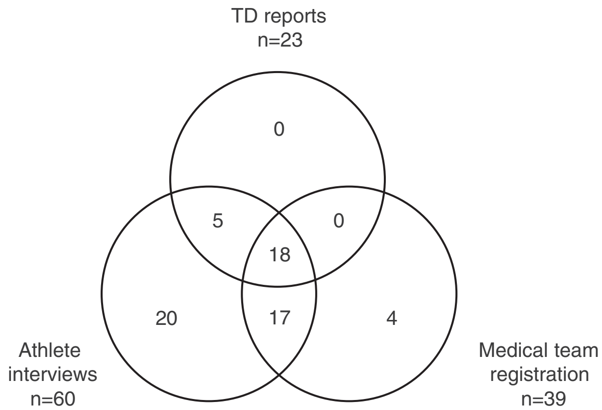

Fig. 4. Venn diagram of time-loss injuries (absence ≥ 1 day) reported through the three registration methods within the cohort covered by all three methods ($n = 64$).

Table 1. Comparison of reported severity between technical delegates (TD) reports and all recorded injuries ($n = 100$)

TD reports	All recorded injuries						Total
	0	1–3 days	4–7 days	8–28 days	>28 days	Unknown	
0	3			1			4
1–3 days			1				1
4–7 days	1	1		1	2		5
8–28 days					2		2
>28 days				1	5		6
Unknown		1	1	1	6		9
Not recorded	32	12	3	14	11	1	73
Total	36	14	5	18	26	1	100

Results are shown as the number of cases in each severity category, classified according to the number of days of absence from training and competition (0: no time loss, 1–3 days, 4–7 days, 8–28 days and >28 days).

Table 2. Comparison of reported severity between medical team registration and all recorded injuries ($n = 100$)

Medical team registration	All recorded injuries						Total
	0	1–3 days	4–7 days	8–28 days	>28 days	Unknown	
0	8						8
1–3 days		4	1	1			6
4–7 days		2	1	3			6
8–28 days			2	7	1		10
>28 days					16		16
Unknown					1		1
Not recorded	28	8	1	7	8	1	53
Total	36	14	5	18	26	1	100

Results are shown as the number of cases in each severity category, classified according to the number of days of absence from training and competition (0: no time loss, 1–3 days, 4–7 days, 8–28 days and >28 days).

competitions, while 14 injuries (19%) were moderate injuries with an absence of 8–28 days and 11 (15%) severe injuries (>28 days). In one case, we did not have any information about the duration of time loss.

When comparing the medical team reports to the athlete interviews as the reference, 36 (68%) of the 53 injuries they did not record were minor with no or 1–3 days of absence from training and competition, while 7 (13%) were moderate (8–28 days) and 8 (15%) severe (>28 days) (Table 2).

In the athlete interviews, 9 injuries reported by the TDs or medical staff were missed, and, of these, 5 did not lead to any absence, 2 to 1–3 days of missed training and competition, while 2 were moderate (8–28 days).

When comparing the information on injury type reported by the TDs with the reference, the information was accurate in all but 3 cases (two fractures and one joint/ligament injury) (Table 3). More than half of the fractures were reported by the TDs, while muscle, tendon and contusion injuries were only reported in 13–14% of the cases.

When the information provided by the medical team was compared with the athlete interviews, the same injury type was reported in 40 of the 47 cases reported by both registration methods, while there was a discrepancy in seven cases (15%) (Table 4). Through the medical team reporting six of eight (75%) fractures were reported and six of 11 (55%) nervous system/concussion injuries were reported. On the other hand most of the muscle and tendon (10 of 14 cases, 71%), as well as contusion injuries (17 of 24 cases, 71%) were not reported by the medical team.

The TDs reported the correct body part injured for 23 of 27 (85%) injuries, while the team medical registration information on body part was correct in 43 of 47 (91%) reported cases.

κ correlation coefficients are shown in Table 5. There was good to very good agreement for the body part injured and injury type, while agreement for severity varied from poor to good.

Discussion

The main finding of this study was that retrospective athlete interviews with athletes/coaches was the best method to detect injuries sustained during one World Cup season, better than prospective registration by team medical staff and better than prospective TD reporting. This was unexpected, as previous studies from football (Junge & Dvorak, 2000), physical education students (Twellaar et al., 1996) and pre-school children (Fonseca et al., 2002) have shown that prospective registration recorded more injuries than retrospective registration. Junge & Dvorak (2000) found in a study of 264 football players that

Table 3. Comparison of reported injury type between technical delegates (TD) reports and all recorded injuries ($n = 100$)

TD reports	All recorded injuries							Total
	Fracture	Joint/ ligament	Muscle/ tendon	Contusion	Skin/ laceration	Nervous system/ concussion	Other	
Fracture	5							5
Joint/ligament	1	10						11
Muscle/tendon			2					2
Contusion		1		3				4
Skin/laceration								
Nervous system/ concussion	1					4		5
Other								
Not recorded	1	30	12	21	1	7	1	73
Total	8	41	14	24	1	11	1	100

Table 4. Comparison of reported injury type between medical team registration and all recorded injuries ($n = 100$)

Medical team registration	All recorded injuries								Total
	Fracture	Joint/ ligament	Muscle/ tendon	Contusion	Skin/ laceration	Nervous system/ concussion	Other	Unknown	
Fracture	6					1			7
Joint/ligament		19		1					20
Muscle/tendon		1	3			1			5
Contusion			1	5					6
Skin/laceration									
Nervous system/concussion				1		6			7
Other							1		1
Unknown		1							1
Not recorded	2	20	10	17	1	3			53
Total	8	41	14	24	1	11	1		100

Table 5. Kappa (κ) values with 95% CI for agreement between the different registration methods

Variable	Registration method		
	TD reports vs interview	Medical team vs interview	TD reports vs medical team
Severity	0.14 (− 0.19 to 0.47)	0.65 (0.46–0.84)	0.39 (− 0.01 to 0.78)
Injury type	0.83 (0.65–1.00)	0.79 (0.63–0.94)	0.71 (0.46–0.96)
Body part	0.81 (0.63–0.98)	0.88 (0.77–0.99)	0.82 (0.63–1.00)

TD, technical delegates.

retrospective interviews with the players for the previous 2 months reported only 1/3 of injuries compared with a prospective follow-up every week. Fonseca et al. (2002) compared the incidence of injuries in preschool children obtained from diaries filled in by the children's caretakers with injuries reported by interviews of the same caretakers covering the last 30 days. They found that diaries captured a higher number of injuries during these 30 days than did retrospective interviews. Twellaar et al. (1996) prospectively recorded information on sports injuries every 3 weeks for 4 years in a group of 136 physical education students and retrospectively asked 59 students to recall all injuries. They concluded that even in a well-supervised population, prospective injury registration is not complete and the reliability of retrospective injury registration is even poorer.

The current results demonstrate that the suitability of injury recording methods depends on the setting where they are applied. The main limitation of retrospective injury reporting is recall bias, as described by Twellaar et al. (1996). To help athletes and coaches remember participation and injuries sustained throughout the season, we used interview forms outlined as week-by-week schedules of the World Cup program in each respective discipline in the same way as in a previous study on injuries among beach volleyball players (Bahr & Reeser, 2003). The athlete interviews recorded 91% of all the injuries identified by any of the three methods and 94% of all time-loss injuries. Thus, it seems that recall bias was minimal when recording injuries to elite ski and snowboard athletes during a limited period of one World Cup season. The explanation for this may be the setting; highly committed professional athletes may be expected to remember injuries that have affected their performance during the competitive season. The fact that 40% of the interviews were carried out with coaches (for athletes not present at the event where interviews were performed) did not seem to affect the capture rate significantly. Our impression was that the coaches had a very good recall of injuries to their racers, which is perhaps not surprising considering that each coach is responsible for a limited number of athletes and that the World Cup teams travel and live together during the entire competitive season. Performing the interviews the way we did, based on forms outlining the competition schedule, therefore seems to have facilitated recall of injuries by athletes and coaches. Still, we can not rule out the possibility that there were injuries that were not captured by any of the recording systems used. The interviews were mainly performed after an official training session or race and athletes may still have been focused on the race or simply did not want to share their injury history with the researchers.

The two prospective registration methods in this study captured 61% (Medical team registration) and 36% (TD) of time-loss injuries. Only a few studies have compared prospective injury registration previously. One study (Olsen et al., 2006) compared two prospective registration methods of injury reporting in youth team handball; match reporting by scorekeepers at each match and coach reporting. They found that coach reports were the best method. Another study (Emery et al., 2005) found for 21 adolescent soccer teams (age 12–18) in Canada (317 participating players) a high rate of completion of injury report forms (96.2%) by a team designate (a volunteer coach or parent) and therapist assessment forms (85.9%) but a low rate for physician diagnosis forms (36.4%).

We were somewhat surprised to see the low capture rate of the medical team registration in this setting. The six nations participating in our study were picked because they had the necessary medical staff and organization to carry out the registration. Also, we were in close contact with the selected contact persons for each discipline in each nation throughout the season. Despite this, there are a number of factors that can explain the low capture rate. First, in some cases the doctor or physiotherapist did not always travel with the team. Second, some teams had a number of doctors and physiotherapists sharing responsibility and taking turns travelling with the team, which may have hindered communication about the registration system and injuries sustained within the team. Third, the teams travel almost continuously during the winter season and it may have been a challenge to send in the injury form, e.g. because of poor internet access and a busy schedule. Finally, it is possible that athletes did not even seek help for injuries, especially minor injuries with no or 1–3 days of absence time loss, as also described by Olsen et al. (2006). We do not know which of these factors were the most important, but the findings suggest that an injury registration system based on medical staff reports is unreliable in this setting.

The low capture rate of the TD registration was not unexpected. We included TD registration as a third injury recoding system because – if successful – this would be an attractive option whereby injuries could be recorded at low costs using an available resource. The TD is the official FIS representative, who is always present at FIS events, and not just at the World Cup level. A number of steps were taken to inform the TDs of their responsibility to record injuries and the procedures to be followed, including training sessions with FIS representatives and those responsible for educating TDs, TD training seminars and distribution of a presentation and brochure with information about the registration and the roles and responsibilities of the TD. However, the results show that the TD registration captured only 1/3 of the time-loss injuries. There are several possible explanations for the low capture rate. First, even if TDs have a supervisory role, they were probably not aware of all injuries occurring during the race. We recommended that TDs involved the race doctor at each event to help complete forms for injuries seen by the event medical staff. This probably did not happen in all cases, and some athletes sustaining an injury may have elected to seek medical care from their own medical team without involving the event medical staff. TDs also have a number of official tasks and forms to complete, and we do not know how they prioritized the injury recording.

The disciplines differ with regards to race settings, environment and task requirements, as well as characteristics of the injuries and their mechanisms. These are factors that could complicate the use of one system for all the different disciplines. We found, however, that the retrospective interviews captured most injuries across all disciplines (75–100%). The capture rate by the medical team registration varied from 21% to 75%, but was higher than the capture rate from the TD registration in all disciplines except in freestyle skiing (TDs 44% vs 40% for the medical team registration). The caveat is that there are few injuries for a valid comparison for some disciplines, but our results strongly indicate that retrospective interviews best reflect the injury rate across all disciplines.

We found that there was good to very good agreement between the three registration methods for body part injured and injury type, while agreement was from poor to good for severity. If the information from two methods differs, we cannot know for sure which is correct. However, the results for body part and injury type are encouraging, suggesting that the information provided is quite accurate, regardless of the recording method. In contrast, while agreement for severity was good between the athlete interviews and the medical team registration, the severity estimates provided by the TD registration differed widely with those reported by the other methods. The simple explanation for this is that severity was reported as the duration of absence from training and competition, and while the TDs were asked to *estimate* this at the time of injury, the athletes and medical staff generally reported injuries after the athlete had returned to compete and the duration of time loss was *known*. We also noted that in 36% of the cases reported by the TDs they were unable to include information on the estimated duration of absence from sports, i.e. injury severity. This may not be surprising, considering that they may not have had access to a qualified medical opinion when completing the forms. Consequently, our results demonstrate that inaccurate or missing severity estimates represent an additional limitation of the TD reporting method. This is interesting, as the surveillance systems established in football (Junge et al., 2004), athletics (Alonso et al., 2009) and the Olympic Games (Junge et al., 2006, 2008) are also based on severity estimates provided at the time of injury, albeit by a team physician.

As outlined above, there are a number of factors that may explain the difference in performance between the three different recording systems. However, it should be noted that the study was carried out of a subgroup of athletes and teams, and we do not know if the results are representative for the entire population of World Cup skiers. We included a clearly defined population of six nations and obtained information on 98% of their World Cup athletes. They represented large teams in the different disciplines, chosen because they were thought to have adequate resources and well-organized medical teams to complete the registration. Consequently, it seems likely that a registration system based on medical staff reports would function even worse if smaller nations with fewer resources were involved. On the other hand, smaller teams are more reliant on the event medical staff if they suffer injuries, which could increase the capture rate of the TD registration. We would expect interviews to function equally well among all World Cup teams, regardless of level.

Perspectives

According to the consensus statement from football (Fuller et al., 2006), one should aim at prospective study designs when establishing injury registration systems in sports. However, our study indicates that it is important to consider the characteristics of the setting in each sport before constituting an injury registration system and that retrospective interview with athletes/coaches may represent a better alternative. Our experience with this and a previous study (Bahr & Reeser, 2003) also indicates that when performing retrospective interviews, using a structured form based on the week-by-week schedule of the competition calendar (as shown in Fig. 2) may be an important tool to secure a high compliance and reduce recall bias.

Establishing a continuous recording system for elite skiing and snowboarding is an important priority to be able to monitor injury risk and pattern over time. One purpose of such a system is to document the consequences of changes in equipment (e.g. carving skis) or competition rules (e.g. new disciplines, course designs). Motivation among everyone involved; organizers, officials, members of the different teams and especially those required to provide information is essential to obtain complete data in injury recording. The current findings show that the best reporting system is retrospective interviews with a sample of athletes/coaches. Medical team registration did not function as expected, probably because medical coverage is less consistent than in professional team sports such as FIFA competitions or professional hockey or basketball. As mentioned above, TD registration is an attractive option, as injuries could be recorded from all regions around the world at low costs using an available resource and at all FIS events, not just at the World Cup level. However, it is not known whether it is possible – with improved TD training and more active involvement of event medical staff – to improve the capture rate to acceptable levels. Also, another limitation of the TD recording system is the inaccurate severity estimates provided.

In conclusion, retrospective interviews with athletes/coaches regarding injuries sustained during one World Cup season (5–6 months) gave the most complete picture of injuries to elite ski and snowboard athletes.

Key words: skiing, snowboarding, snow sports, athletic injuries, epidemiology.

Acknowledgements

We would like to thank the athletes, coaches, medical team personnel and TDs who participated in this study and the FIS staff and officials for all practical support. This project has been established through a generous grant from DJO and the FIS. The Oslo Sports Trauma Research Center has been established at the Norwegian School of Sport Sciences through grants from the Royal Norwegian Ministry of Culture and Church Affairs, the South-Eastern Norway Regional Health Authority, the Norwegian Olympic Committee & Confederation of Sport and Norsk Tipping AS.

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Paper II

INJURIES AMONG WORLD CUP SKI AND SNOWBOARD ATHLETES

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Running head: World Cup skiing and snowboarding injuries

Key words: skiing, snowboarding, athletic injuries, epidemiology

ABSTRACT

There is little information available on injuries to World Cup skiers and snowboarders. The aim of this study was to describe and compare the injury risk to World Cup athletes in alpine skiing, freestyle skiing, snowboarding, ski jumping, Nordic combined and cross-country skiing. We performed retrospective interviews with FIS World Cup athletes from selected nations during the 2006-07 and 2007-08 winter seasons and recorded all acute injuries occurring during the seasons. We interviewed 2121 athletes and recorded 705 injuries. There were 520 (72%) time-loss injuries and 196 (28%) severe injuries (absence >28 days). In freestyle skiing, alpine skiing and snowboarding there were 27.6, 29.8 and 37.8 time-loss and 14.4, 11.3 and 13.8 severe injuries per 100 athletes per season, respectively. In Nordic combined, ski jumping and cross-country skiing there were 15.8, 13.6 and 6.3 time-loss and 3.3, 5.6 and 0.7 severe injuries per 100 athletes per season, respectively. Conclusions: About 1/3 of the World Cup alpine, freestyle and snowboard athletes sustain a time-loss injury each season, while the risk is low in the Nordic disciplines. A particular concern was the high proportion of severe injuries observed among alpine, freestyle and snowboard athletes, which is in contrast to most other sports.

INTRODUCTION

Skiing and snowboarding are popular sports. According to the International Ski Federation (FIS), 2362 athletes started in World Cup competitions in 2006-07 and 2177 in 2007-08 in the different disciplines of alpine skiing, freestyle skiing, snowboard, ski jumping, cross-country skiing and Nordic combined (combination of ski jumping and cross-country skiing).

The sports of skiing and snowboarding are exciting and represent a source of enjoyment, not just for the athletes but for spectators and TV-viewers worldwide. However, the spectacular crashes and significant injuries seen regularly remind us of the risks associated with the sports. However, there are only a handful of studies that have examined the risk for injury to the elite skier and snowboarder and these are generally small, often limited to one competition, or not representative for the current level of performance at the World Cup level. In alpine skiing, one study from the 1994 Olympic Winter Games (Ekeland et al., 1996), one from a World Junior Championships (Bergström et al., 2001) and one season-long study from 1985 (Ekeland & Holm 1985) have estimated the injury rate to be between 1.9 and 4 injuries per 1000 runs. In freestyle skiing, a discipline which has undergone major changes during recent years, a study from 1976-80 has estimated the injury rate to 2.8 injuries per 1000 skier days (Dowling 1982). In snowboard, studies on World Cup athletes and athletes competing at the national level report injury rates of 1.3 and 4.0 injuries per 1000 runs, respectively (Torjussen & Bahr 2006; Torjussen & Bahr 2005). In ski jumping, we have found only one 5-year study from Lake Placid, USA, reporting 1.2 injuries per 1000 skier days for World Cup competitions and training (Wright, Jr. et al., 1986). There is no information available on the injury risk associated with elite cross-county skiing or Nordic combined. Therefore, except for snowboarding, the risk of being a World Cup athlete in the various FIS disciplines is not known.

FIS therefore established an injury surveillance system (the FIS ISS) prior to the 2006-2007 winter season. The objective of the FIS ISS is to provide data on injury trends in international skiing and snowboarding at the elite level with the long-term goal of reducing injury risk. The aim of the current paper was to describe the injury risk and injury pattern among World Cup athletes in alpine skiing, freestyle skiing, snowboarding, ski jumping, cross-country skiing and Nordic combined based on data from the FIS ISS.

MATERIALS AND METHODS

Study design and population

We conducted retrospective interviews at the end of the 2006-07 and the 2007-08 winter seasons. A methodological study (Flørenes et al., 2009) comparing prospective injury reporting by team medical personnel, prospective injury reporting by FIS technical delegates and retrospective athlete/coach interviews showed that retrospective interviews were the most accurate in this setting. We therefore chose this method to record injuries among World Cup ski and snowboard athletes. We defined the winter season as starting on November 1, or the first race of the season, lasting until the interviews took place. We conducted the interviews in March during one of the final events in each discipline each year. From the official FIS database we identified athletes who had started in at least one World Cup/World Championship event in each of the sub-disciplines of alpine skiing (downhill, super-G, giant slalom, slalom, combined and super combined), freestyle skiing (moguls, dual moguls, halfpipe, skicross, aerials), snowboard (halfpipe, snowboardcross, parallel giant slalom, parallel slalom, big air), ski jumping, cross-country skiing and Nordic combined. In all disciplines we included athletes from nine major skiing nations: Germany, Switzerland, Canada, Finland, France, Norway, Italy, Sweden and Austria. These represent large teams in the different disciplines and we expected most athletes to speak English fluently. In freestyle skiing and snowboarding the athletes rarely compete in more than one of the sub-disciplines (halfpipe, skicross, moguls/dual moguls, aerials, snowboardcross and big air) and the size of the teams vary. Therefore, to increase the number of participants, in some disciplines we also included additional World Cup-teams from other English speaking nations, provided that we could cover at least 80% of all team members with the interviews. In this way, we added 11 World Cup teams in freestyle skiing and snowboarding.

At the event, we interviewed all athletes from the selected nations who were present in person. If the athletes were not present (due to injury or for other reasons), we interviewed their coaches. Some coaches directed us to their team physician/physical therapist to get the information needed. We also asked all team coaches to control and complete the list of athletes from their nation. Athletes not defined as being on the World Cup team roster by the coaches were excluded (e.g. national athletes starting in races in that country on the national quota).

Injury recording and injury definition

We explained the purpose and procedures of the interviews at the team captain's meetings, where head coaches from all nations are required to be present. At these meetings, we also encouraged the coaches to inform their athletes of the interviews. A letter describing the interviews was distributed by e-mail to all head coaches/team leaders prior to the 2007-08 registration. Research teams from the Oslo Sports Trauma Research Center consisting of physicians, physical therapists and medical students conducted the interviews. The research teams performed the interviews in the finishing area in connection with official training or competition, or in some cases, at the team's hotel. Athletes from the freestyle skiing sub-discipline halfpipe and the snowboard sub-disciplines big air, parallel giant slalom/slalom were not interviewed at the end of the 2006-07 winter season due to event cancellations and scheduling conflicts. There is no World Cup in ski jumping for women, and we therefore included the Continental Cup (the highest level) for the 2007-08 winter season. There are only male participants in Nordic combined. To facilitate athlete recall of participation and time loss due to injury we used a form outlining the week-by-week schedule of the current World Cup program for each discipline. We asked if they had started in each of the events from the first week of the season to the next for the whole season (Flørenes et al., 2009). For each injury the athlete reported, we completed an injury form with information on where and when the injury had occurred, what kind of injury it was (body part, injury type and injured side) and how long they were out of training and/or competition. We also asked for a specific diagnosis for each injury. For the interviews with the coaches for athletes not present we used the same method. Each coach is responsible for a limited number of athletes. The World Cup teams travel and live together for almost the entire competitive season and a methodological study found the coaches to have a good recall of injuries to their racers (Flørenes et al., 2009).

The injury definition was: "All injuries that occurred during training or competition and required attention by medical personnel." This definition as well as the classification of the type of injury and body part injured was based on a recent consensus document on injury surveillance in football (Fuller et al., 2006). We classified the severity of injury according to the duration of absence from training and competition as slight (no absence); minimal (1 to 3 days), mild (4 to 7 days), moderate (8 to 28 days) and severe (>28 days) (Fuller et al., 2006). If multiple injuries resulted from the same accident, we described all of these on the same injury form. We also recorded information of where the injury happened, during World

Cup/World Ski Championship competition/official training, other competitions/official training, other training activity on snow (i.e. regular training) or basic training not on snow (i.e. running, weightlifting, soccer etc.). For describing the injury rate we use all recorded injuries, while only "on-snow" injuries (including competitions, official training and regular training on snow) are included when describing the injury severity, injury type and injured body part.

The study was approved by the Regional Committee for Medical Research Ethics, Region Sør-Norge and by the Norwegian Social Science Data Services.

Statistics

To estimate the risk of injuries to World Cup athletes and allow a comparison between the different World Cup disciplines, we have used the number of injuries per 100 athletes per season with their corresponding 95% confidence intervals (95% CI) to report injury rate. We based our calculation on the Poisson model and used a Z test for comparing injury risk between disciplines and computing the corresponding 95% CI. We computed relative risks (RR) with their corresponding 95% CI to compare injury risk between male and female athletes, as well as the risk of the most severe injuries and knee injuries between the different disciplines. A two-tailed p-level of ≤ 0.05 was considered statistically significant.

RESULTS

Of the 2149 World Cup athletes eligible, 2121 (98.7%) were interviewed during the 2006-07 and 2007-08 winter seasons (Table 1). Fifteen and 11 athletes from two teams in the sub-disciplines of freestyle skiing and snowboarding, respectively, were excluded because of low team response rates (47% and 9%, respectively). Of the 2121 interviewed athletes, 1145 (54%) were interviews with the athletes in person and 976 (46%) with the coach/medical staff (Table 1).

[insert Table 1 near here]

Of the 705 injuries recorded, there were 676 (95.9%) "on-snow" injuries (occurring during competitions, official training or regular training on snow). As many as 49.3% of all injuries occurred during World Cup/World Ski Championship events including official training (Table 2). For alpine skiing, freestyle skiing, snowboarding and Nordic combined, the majority of injuries occurred during World Cup/World Ski Championship events, while training on snow was the activity where most injuries occurred for ski jumping and cross-country skiing (Table 2). Only 4 % of all injuries occurred during basic training not on snow; however, for ski jumping and Nordic combined this was the second and third most common activity during which an injury occurred (28.9% and 21.7%, respectively).

[insert Table 2 near here]

As many as 121 of 448 injuries among males (27.4 %) and 75 of 257 among females (29.2 %) were severe injuries (time loss >28 days) (Figure 1). A similar proportion of injuries reported by males (125 of 448, 28.0%) and females (68 of 257, 26.5%) did not lead to any absence from training and competition. For all injuries, we found no difference in injury rate between males and females (female vs. male RR 1.05, 95% CI 0.89 to 1.25).

[insert Figure1 near here]

The injury rate during the World Cup season, estimated as the number of injuries per 100 athletes, is shown in Table 3. For time-loss injuries there was a higher rate in snowboarding compared to the other disciplines (RR: 1.27, 95% CI 1.02 to 1.58 vs. alpine skiing; RR: 1.37, 95% CI 1.08 to 1.74 vs. freestyle skiing; RR: 2.77, 95% CI 1.87 to 4.12 vs. ski jumping; RR: 2.39, 95% CI 1.48 to 3.84 vs. Nordic combined; RR: 6.02, 95% CI 4.00 to 9.05 vs. cross-country skiing). We also observed a lower rate in cross-country skiing compared to all the other disciplines (RR: 0.21, 95% CI 0.14 to 0.32 vs. alpine skiing; RR: 0.23, 95% CI 0.15 to 0.35 vs. freestyle skiing; RR: 0.46, 95% CI 0.27 to 0.78 vs. ski jumping; RR: 0.40, 95% CI 0.22 to 0.71 vs. Nordic combined). For severe injuries there was a higher rate for alpine skiing, freestyle skiing and snowboarding compared to the three Nordic disciplines of ski jumping, Nordic combined and cross-country skiing (alpine skiing vs. ski jumping RR: 2.01, 95% CI 1.08 to 3.74; alpine skiing vs. Nordic combined RR: 3.40, 95% CI 1.23 to 9.35; alpine skiing vs. cross-country skiing RR: 16.2, 95% CI 5.09 to 51.8; freestyle skiing vs. ski jumping RR: 2.56, 95% CI 1.38 to 4.76; freestyle skiing vs. Nordic combined RR: 4.33, 95% CI 1.57 to 11.9; freestyle skiing vs. cross-country skiing RR: 20.7, 95% CI 6.48 to 65.9; snowboarding vs. ski jumping RR: 2.45, 95% CI 1.31 to 4.55; snowboard vs. Nordic combined RR: 4.13, 95% CI 1.50 to 11.4; snowboard vs. cross-country skiing RR: 19.7, 95% CI 6.19 to 63.0). We also observed a higher rate for severe injuries in ski jumping than cross-country skiing (RR: 8.08, 95% CI 2.28 to 28.6), and Nordic combined compared to cross-country skiing (RR: 4.78, 95% CI 1.07 to 21.3).

[insert Table 3 near here]

The distribution of injury severity for “on-snow” injuries in each discipline is shown in Table 4. Time-loss injuries accounted for 486 (71.9%) of all “on-snow injuries” reported and 189 (28.0%) were severe injuries. There was no difference in the risk for a severe injury between alpine skiing, freestyle skiing and snowboarding (freestyle skiing vs. alpine skiing RR: 1.25, 0.87 to 1.80, freestyle skiing vs. snowboarding RR: 1.03, 0.72 to 1.48, snowboarding vs.

alpine skiing RR: 1.22, 0.85 to 1.75), while the risk for the severe injuries was lower in cross-country skiing than the other disciplines (RR ranging from 0.05 to 0.06). Ski jumping had also a higher risk of severe injuries compared to cross-country skiing for the severe injuries (RR: 5.38, 1.43 to 20.3).We also observed a higher risk for severe injuries in freestyle skiing, alpine skiing and snowboarding compared to ski jumping and Nordic combined (freestyle skiing vs. ski jumping RR: 3.78, 1.80 to 7.90; freestyle vs. Nordic combined RR: 8.51, 2.08 to 34.8; alpine skiing vs. ski jumping RR: 3.02, 1.44 to 6.31; alpine skiing vs. Nordic combined RR: 6.80, 1.66 to 27.8; snowboarding vs. ski jumping RR: 3.67, 1.75 to 7.68; snowboarding vs. Nordic combined RR: 8.27, 2.02 to 33.8).

[insert Table 4 near here]

For injuries incurred on snow (including competitions, official trainings and regular training on snow) the most common injury type for all disciplines was joint and ligament injuries (37.5% to 52.9%), except in cross-country skiing, where the most common injury type was muscle and tendon injuries (Table 5). Fractures were the second most common in alpine and freestyle skiing, contusions in ski jumping, muscle and tendon injuries in Nordic combined while joint and ligament injuries were second most common in cross-country skiing. In snowboarding fractures/bone stress and contusions were equally the second most common injury types. (Table 5).

[insert Table 5 near here]

Overall, 26 % of the injuries incurred on snow were knee injuries and the knee was the most frequently injured body part in all disciplines (18.9% to 36.0 %), except for cross-country skiing, where injuries to the lower back/pelvis/sacrum were the most common (Table 6). There was no difference in the rate for knee injuries between alpine skiing, freestyle skiing and snowboarding (alpine skiing vs. freestyle skiing RR: 1.18, 0.81 to 1.72; alpine skiing vs. snowboarding RR: 1.25, 0.86 to 1.83; freestyle skiing vs. snowboarding RR: 1.06, 0.70 to 1.60). The risk for knee injuries was higher in alpine skiing (RR: 3.48, 1.67 to 7.23) and freestyle skiing (RR: 2.94, 1.39 to 6.24) compared to ski jumping. In alpine skiing the second most commonly injured body parts were the lower back/pelvis/sacrum and lower leg, in freestyle skiing and ski jumping head/face while the second most commonly injured body part in snowboarding, Nordic combined and cross country skiing was the shoulder/clavicle.

[insert Table 6 near here]

DISCUSSION

This study is the first large cohort study to examine the injury risk and pattern in elite skiing and snowboarding and also the first to compare the different World Cup disciplines. The principal finding was that the risk of injuries in snowboarding, freestyle skiing and alpine skiing is high, with a high frequency of the most severe injuries. The knee was the most commonly injured body part across all disciplines except cross-country skiing.

As outlined by Torjussen and Bahr (Torjussen et al., 2006), choosing the appropriate method to report the risk of injury in skiing and snowboarding is a challenge if the objective is to compare risk between different skiing populations or disciplines where exposure may differ considerably. Epidemiological studies on recreational skiers and snowboarders typically report the number of injuries per 1000 skier days. If we assume that World Cup skiers and snowboarders during the season (4.5 months from November through mid-March) on average have two travel days each week and train and compete during the remaining five days, we find that there were 4.1, 4.3 and 6.3 injuries per 1000 days for alpine skiing, freestyle skiing and snowboarding. These estimates are probably low, as we have not corrected for missed exposure for injury or other reasons. Nevertheless, it appears that the injury risk is two to three times as high as that reported from previous studies on recreational alpine skiers (ranging from 1.1 to 3.2 across different studies) (Ekeland et al., 2005; Johnson et al., 2009; Langran 2005; Laporte et al., 2000) and snowboarders (2.3 to 4.1) (Ekeland et al., 2005; Greenwald et al., 2003; Langran & Selvaraj 2002), if injury rate is expressed per 1000 skier/snowboarder days.

Most of the few previous studies available on elite skiing and snowboarding have reported injury incidence as the number of injuries per 1000 runs (Bergström et al., 2001; Ekeland et al., 1996; Ekeland et al., 1985; Torjussen et al., 2006; Torjussen et al., 2005), as this has been argued to be the most accurate measure of injury risk. In alpine skiing and snowboarding 1 to 4 injuries per 1000 runs has been reported (Bergström et al., 2001; Ekeland et al., 1996; Ekeland et al., 1985; Torjussen et al., 2006; Torjussen et al., 2005), However, when comparing injury risk between different disciplines, run distance and the number of runs during a competition differ widely. For example, one run in ski jumping, snowboard-cross, and halfpipe is much shorter than a run in downhill skiing, and a cross-country skiing race can be up to 50 km long. And while there are four runs in freestyle halfpipe, five runs in snowboard-cross, two in ski jumping, there is only one in downhill skiing. It has previously been argued that the most precise measure for injury risk estimation for snow sports is per distance skied (Ronning et al., 2000). One limitation of this approach is that it may be difficult to collect precise data on the number of runs and the length of each run performed by each skier over the course of the season, at least during training. Moreover, the question is whether it is appropriate to correct for such exposure differences when comparing injury risk across disciplines, for example to compare the risk between a downhill skier and a ski jumper.

In team sports such as football and rugby, injury incidence is usually reported as the number of injuries per 1000 hours of training or match exposure (Fuller et al., 2006; Fuller et al., 2007). However, compared to other sports, e.g. football, where athletes are active more or less continuously during an entire training and match, alpine or snowboard athletes spend a lot of time in the ski lift or waiting to start during training and they are active for only a short period of time during a competition. Froholdt and co-workers (Froholdt et al., 2009) recently discussed the importance of using both relative injury risk (i.e. where the injury risk is expressed as a rate corrected for exposure) as well as the absolute injury risk (i.e. expressed as the total number of injuries during a season for a team or player/athlete) when comparing injury risk between different levels of play in football. We would argue that absolute injury risk is highly relevant and in this study we have therefore chosen to express injury risk as the number of injuries per 100 athletes per season. This allows us to compare the overall risk of being injured for top level skiers and snowboarders between the different disciplines directly, as this seems more relevant than comparing the relative risk associated with one ski jump to one downhill race. Most of these athletes are full-time professional and during the season they perform the maximal amount of training and competition possible within the constraints of their discipline.

We found that the risk for injury in alpine skiing, freestyle skiing and snowboarding was high, while there was a lower risk associated with the Nordic disciplines ski jumping, cross-country skiing and combined. This does not come as a surprise when we consider the high speed on icy surfaces, spectacular jumps and the combination of speed and jumps with minimal protection these athletes are exposed to during training and competition. However, the question is, how high is high? One interesting consequence of expressing injury rate in absolute terms, is that the data may be compared to non-snow sports such as professional football, where the injury risk has been documented to be unacceptably high when compared to other occupations (Drawer & Fuller 2002). We used data from two studies on male elite football to estimate the number of injuries per 100 athletes per season, one (Ekstrand et al., 2009) where injuries was reported for seven seasons among 23 Champions League teams and one (Hägglund et al., 2009) covering 11 teams in the Swedish premier league. Based on these, we estimated that there were 187 and 205 acute time-loss injuries per 100 athletes per season, respectively. Similar calculations based on studies in female elite players from Sweden (Hägglund et al., 2009), Germany (Faude et al., 2005) and Norway (Tegnander et al., 2008) yielded estimates of 108, 122 and 94 injuries per 100 athletes per season. In other words, the injury risk in elite football appears to be much higher than our estimates of 30, 28 and 38 acute time-loss injuries per 100 athletes per season in alpine skiing, freestyle skiing and snowboarding, respectively, even if we account for the fact that the competitive season is about twice as long in football as in the World Cup.

A consistent finding across most sports is that the frequency of injuries decreases with severity. In other words, slight injuries are the most common, followed by minor and moderate, and with severe injuries the least common. It should be noted that our results were the reverse; severe injuries were the most frequent. Almost 1/3 of all injuries to male and female World Cup skiing and snowboarding athletes were severe, leading to an absence for more than 28 days, similar to a previous study among World Cup snowboarders (Torjussen et al., 2006). Cross-sectional studies among active World Cup snowboard and freestyle athletes have also reported a high prevalence of severe knee injuries (Dowling 1982; Torjussen et al., 2006). The majority (57-88%) of top level skiers reported to have suffered at least one serious injury during their career (Ekeland et al., 1997; Margreiter et al., 1976; Raas 1982). A study on French world-class alpine skiers showed that 50% had sustained at least one ACL injury (Pujol et al., 2007). We found that the risk for sustaining a severe injury was highest in alpine skiing, freestyle skiing and snowboarding, mainly because of knee ligament injuries. Compared to cross-country skiing, these disciplines had a 16- to 20-fold increased risk of such injuries.

So, although it seems that the overall injury rate is higher in professional football than on the World Cup circuit, what about the risk for severe injuries? We estimate that among male players on Champions League teams and Swedish premier league teams there were 31 and 20 severe injuries (>28 days) per 100 athletes per season, respectively (Ekstrand et al., 2009; Hägglund et al., 2009). For female elite players in Sweden, Germany and Norway (Faude et al., 2005; Hägglund et al., 2009; Tegnander et al., 2008) we estimate that there were 16, 19 and 20 severe injuries per 100 athletes per season, respectively. Our findings from alpine skiing, freestyle skiing and snowboarding show that there were 11, 14 and 14 severe injuries per 100 athletes per season respectively, If we take into account that the football season is about twice as long as the World Cup season, it seems as if the annual risk for severe injuries is about the same for professional skiers, snowboarders and footballers.

There are some limitations that must be kept in mind when interpreting the results from this study. First, when using retrospective interviews as the method for recording injuries, recall bias is as a challenge (Bahr & Reeser 2003). However, in a methodological study we found that retrospective athlete interviews gave the most complete picture compared to prospective injury recording by team medical personnel or FIS technical delegates (Flørenes et al., 2009). Nevertheless, there is a possibility that some injuries have not been captured through the injuries. If so, the injury risk will have been underestimated. Having athletes and coaches record injuries prospectively is potentially an alternative way of recording injuries more accurately. However, as performance is the primary focus of elite athletes it may be unreasonable to expect them to comply fully with an injury recording protocol, especially as substantial numbers are needed to obtain valid results.

A second limitation is that we have only interviewed the athletes for injuries happening during the competition period of the winter season and we have no data regarding injuries they may have sustained during pre-season training on snow or basic training the rest of the year. This limitation needs to be kept in mind when comparing to other sports with a longer competitive season, like football

PERSPECTIVES

Surveillance systems established at the elite level in sports such as football, athletics, handball and the Olympics (Alonso et al., 2009; Dvorak et al., 2007; Junge et al., 2006; Langevoort et al., 2007) have provided important information of injury risk and injury patterns, which in turn has helped researchers direct their focus to develop methods to prevent injuries. Limited data have been available to quantify the risk of injury to our best skiers and snowboarders. This study found that about 1/3 of the athletes in World Cup alpine skiing, freestyle skiing and snowboarding sustain a time-loss injury during the competitive winter season, while the rate is low in the Nordic disciplines. Although the overall risk is much lower among professional skiers and snowboarders compared to professional footballers, the high proportion of severe injuries, mainly knee injuries, is a concern. This is where future research to prevent skiing and snowboarding injuries should be directed.

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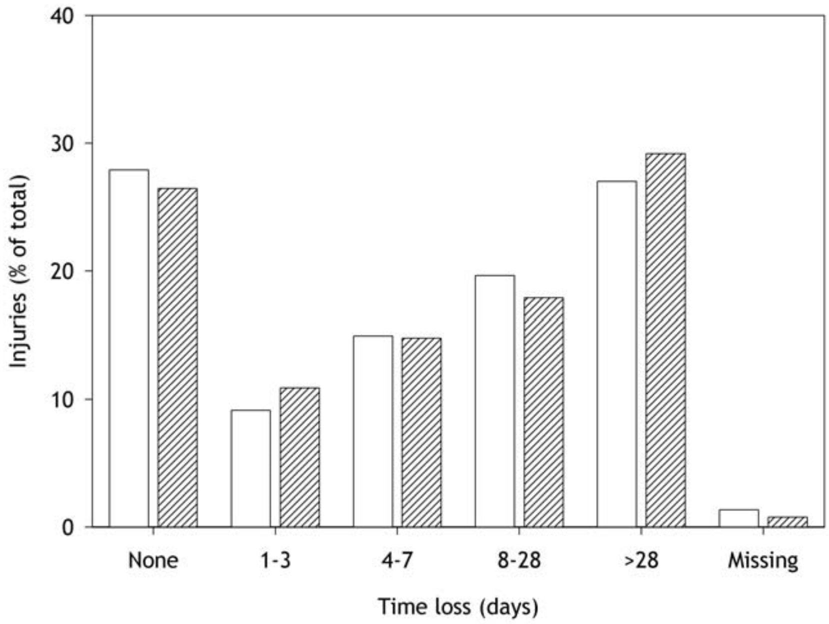

Figure 1. Injuries according to severity (expressed as the number of days of absence from training and competitions) for all recorded injuries (n=705) among males (n=448; open bars) and females (n=257; hatched bars).

Table 1. The number of athletes included in the study (All) and the number of athletes where information was obtained through interviews (T) either with the athletes themselves (A) or their coaches or medical staff (C/M).

	Male								Female								Total			
	2006-07 season				2007-08 season				2006-07 season				2007-08 season				Both seasons			
	All	**Interview**			**All**	**Interview**			**All**	**Interview**			**All**	**Interview**			**All**	**Interview**		
		A	C/M	T		A	C/M	T		A	C/M	T		A	C/M	T		A	C/M	T
Alpine skiing	144	47	97	144	148	78	70	148	116	38	78	116	113	44	69	113	521	207	314	521
Freestyle skiing	107	70	37	107	192	67	110	177	46	33	13	46	86	38	48	86	431	208	208	416
Snowboarding	91	61	30	91	198	106	80	186	50	39	11	50	95	66	28	94	434	272	149	421
Ski jumping[1]	67	30	37	67	76	46	30	76					70	38	32	70	213	114	99	213
Nordic combined[2]	57	39	18	57	63	45	18	63									120	84	36	120
Cross-country skiing	134	70	64	134	124	75	49	124	90	56	34	90	82	59	23	82	430	260	170	430
Total	600	317	283	600	801	417	357	774	302	166	136	302	446	245	200	445	2149	1145	976	2121
(% interviewed)				(100.0)				(97)				(100.0)				(99.8)				(98.7)

[1] Ski jumping includes two World Cup seasons for men and one Continental Cup season (2007-08) for women.
[2] There are only male participants in Nordic combined.

Table 2. Description of activity during which injuries occurred for World Cup athletes in alpine skiing, freestyle skiing, snowboarding, ski jumping, Nordic combined and cross-country skiing. Combined data from the 2006-07 and 2007-08 winter seasons expressed as the number of injuries (percentages in parentheses).

	Alpine skiing	**Freestyle skiing**	**Snowboarding**	**Ski jumping**[1]	**Nordic combined**	**Cross-country skiing**	**Total**
World Cup and World Championship events	86 (45.0)	50 (31.3)	64 (27.0)	5 (11.1)	6 (26.1)	15 (30.6)	226 (32.1)
Official training to WC/WSC	31 (16.2)	40 (25.0)	41 (17.3)	6 (13.3)	2 (8.7)	1 (2.0)	121 (17.2)
Other competitions	3 (1.6)	26 (16.3)	37 (15.6)	2 (4.4)		1 (2.0)	69 (9.8)
Other FIS comp	20 (10.5)	5 (3.1)	19 (8.0)	2 (4.4)	2 (8.7)	6 (12.2)	54 (7.7)
Official FIS training	1 (0.5)	3 (1.9)	5 (2.1)	2 (4.4)			11 (1.6)
Other training activity on snow (regular training)	48 (25.1)	33 (20.6)	67 (28.3)	15 (33.3)	7 (30.4)	25 (51.0)	195 (27.7)
Basic training not on snow	2 (1.0)	3 (1.9)	4 (1.7)	13 (28.9)	5 (21.7)	1 (2.0)	28 (4.0)
Information missing					1 (4.3)		1 (0.1)
Total	191 (100)	160 (100)	237 (100)	45 (100)	23 (100)	49 (100)	705 (100)

[1]Ski jumping includes two World Cup seasons for men and one Continental Cup season for women.

Table 3. Injuries per 100 athletes per season (with 95% confidence intervals) for injuries recorded during the 2006-07 and 2007-08 winter seasons in alpine skiing, freestyle skiing, snowboard, ski jumping, Nordic combined and cross-country skiing.

	Injuries per 100 athletes per season		
	All injuries	Time-loss injuries (≥1 day absence)	Severe injuries (>28 days absence)
Alpine skiing	36.7 (31.5 to 41.9)	29.8 (25.1 to 34.4)	11.3 (8.4 to 14.2)
Freestyle skiing	38.5 (32.5 to 44.4)	27.6 (22.6 to 32.7)	14.4 (10.8 to 18.1)
Snowboarding	56.3 (49.1 to 63.5)	37.8 (31.9 to 43.6)	13.8 (10.2 to 17.3)
Ski jumping[1]	21.1 (15.0 to 27.3)	13.6 (8.7 to 18.6)	5.6 (2.4 to 8.8)
Nordic combined	19.2 (11.3 to 27.0)	15.8 (8.7 to 23.0)	3.3 (0.1 to 6.6)
Cross-country skiing	11.4 (8.2 to 14.6)	6.3 (3.9 to 8.6)	0.7 (-0.1 to 1.5)

[1]Ski jumping includes two World Cup seasons for men and one Continental Cup season for women.

Table 4. Injury severity distribution for "on-snow" injuries (including competitions, official training and regular training on snow) for alpine skiing, freestyle skiing, snowboarding, ski jumping, Nordic combined and cross-country skiing during the 2006-07 and 2007-08 winter seasons expressed as the number of injuries (percentages in parentheses).

Time loss	**Alpine skiing**	**Freestyle skiing**	**Snow-boarding**	**Ski jumping**[1]	**Nordic combined**	**Cross-country skiing**	**Total**
No time loss	35 (18.5)	42 (26.8)	71 (30.5)	12 (37.5)	2 (11.8)	20 (41.7)	182 (26.9)
1-3 days	16 (8.5)	15 (9.6)	22 (9.4)	3 (9.4)	3 (17.6)	9 (18.8)	68 (10.1)
4-7 days	28 (14.8)	19 (12.1)	38 (16.3)	6 (18.8)	4 (23.5)	6 (12.5)	101 (14.9)
8-28 days	51 (27.0)	20 (12.7)	40 (17.2)	3 (9.4)	5 (29.4)	9 (18.8)	128 (18.9)
>28 days	59 (31.2)	59 (37.6)	58 (24.9)	8 (25.0)	2 (11.8)	3 (6.3)	189 (28.0)
Not available		2 (1.3)	4 (1.7)		1 (5.9)	1 (2.1)	8 (1.2)
Total	189 (100)	157 (100)	233 (100)	32 (100)	17 (100)	48 (100)	676 (100)

[1] Ski jumping includes two World Cup seasons for men and one Continental Cup season for women.

Table 5. Injury type per discipline for "on-snow" injuries (including competitions, official training and regular training on snow) recorded during the 2006-07 and 2007-08 winter seasons expressed as number of injuries (percentages in parentheses) for each discipline (n=676).

	All injuries						
Injury Type	Alpine skiing	Freestyle skiing	Snow-boarding	Ski jumping[1]	Nordic combined	Cross-country skiing	Total
Fractures/bone stress	35 (18.5)	34 (21.7)	41 (17.6)	3 (9.4)	1 (5.9)		114 (16.9)
Joint/ligament	84 (44.4)	68 (43.3)	90 (38.6)	12 (37.5)	9 (52.9)	15 (31.3)	278 (41.1)
Muscle/tendon	20 (10.6)	19 (12.1)	27 (11.6)	1 (3.1)	3 (17.6)	18 (37.5)	88 (13.0)
Contusion	23 (12.2)	16 (10.2)	41 (17.6)	8 (25.0)	2 (11.8)	7 (14.6)	97 (14.3)
Skin/laceration	7 (3.7)	2 (1.3)	2 (0.9)	1 (3.1)	1 (5.9)	1 (2.1)	14 (2.1)
Nervous system/concussion	14 (7.4)	15 (9.6)	29 (12.4)	4 (12.5)		3 (6.3)	65 (9.6)
Other	6 (3.2)	3 (1.9)	3 (1.3)	3 (9.4)	1 (5.9)	4 (8.3)	20 (3.0)
Total	189 (100)	157 (100)	233 (100)	32 (100)	17 (100)	48 (100)	676 (100)

[1] Ski jumping includes two World Cup seasons for men and one Continental Cup season for women.

Table 6. Body part injured for each discipline expressed as number of injuries (percentages in parentheses) for "on-snow" injuries (including competitions, official training and regular training on snow) during the 2006-07 and 2007-08 winter seasons.

	All injuries						
Body part injured	Alpine skiing	Freestyle skiing	Snow-boarding	Ski jumping[1]	Nordic combined	Cross-country skiing	Total
Head/face	16 (8.5)	20 (12.7)	30 (12.9)	7 (21.9)		1 (2.1)	74 (10.9)
Neck, cervical spine		2 (1.3)	1 (0.4)		1 (5.9)	1 (2.1)	5 (0.7)
Shoulder, clavicula	13 (6.9)	16 (10.2)	31 (13.3)	2 (6.3)	3 (17.6)	7 (14.6)	72 (10.7)
Upper arm	1 (0.5)	1 (0.6)					2 (0.3)
Elbow	3 (1.6)	5 (3.2)	9 (3.9)	2 (6.3)		4 (8.3)	23 (3.4)
Forearm	1 (0.5)	3 (1.9)	6 (2.6)	1 (3.1)		1 (2.1)	12 (1.8)
Wrist	3 (1.6)	3 (1.9)	13 (5.6)		1 (5.9)		20 (3.0)
Hand, finger, thumb	17 (9.0)	11 (7.0)	12 (5.2)		1 (5.9)	1 (2.1)	42 (6.2)
Chest (sternum, ribs, upper back)	4 (2.1)	10 (6.4)	6 (2.6)	1 (3.1)		2 (4.2)	23 (3.4)
Abdomen		1 (0.6)	3 (1.3)				4 (0.6)
Lower back, pelvis, sacrum	21 (11.1)	11 (7.0)	24 (10.3)	1 (3.1)	3 (17.6)	12 (25.0)	72 (10.7)
Hip, groin	4 (2.1)	10 (6.4)	10 (4.3)	1 (3.1)		3 (6.3)	28 (4.1)
Thigh	4 (2.1)	3 (1.9)	7 (3.0)	1 (3.1)	1 (5.9)	2 (4.2)	18 (2.7)
Knee	68 (36.0)	46 (29.3)	44 (18.9)	8 (25.0)	6 (35.3)	4 (8.3)	176 (26.0)
Lower leg, Achilles tendon	21 (11.1)	6 (3.8)	7 (3.0)	3 (9.4)	1 (5.9)	5 (10.4)	43 (6.4)
Ankle	10 (5.3)	7 (4.5)	22 (9.4)	3 (9.4)		3 (6.3)	45 (6.7)
Foot, heel, toe	3 (1.6)	2 (1.3)	8 (3.4)	1 (3.1)		2 (4.2)	16 (2.4)
Not available				1 (3.1)			1 (0.1)
Total	189 (100)	157 (100)	233 (100)	32 (100)	17 (100)	48 (100)	676 (100)

[1] Ski jumping includes two World Cup seasons for men and one Continental Cup season for women.

Paper III

EDITOR'S CHOICE

Injuries among male and female World Cup alpine skiers

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ABSTRACT

Background: Limited knowledge exists on injuries among professional alpine skiers.

Objective: To describe the risk of injury and the injury pattern among competitive World Cup alpine skiers during the competitive season.

Methods: Retrospective interviews were performed with all World Cup athletes from 10 nations at the end of the 2006–7 and 2007–8 winter seasons, and all acute injuries occurring during the 4.5-month competitive season were recorded. If the athlete was not present, their coaches or medical personnel were interviewed.

Results: A total of 191 acute injuries were recorded among 521 World Cup alpine skiers. As many as 86 injuries (45%) occurred during World Cup/World Ski Championship competitions, corresponding to an injury rate of 9.8 injuries per 1000 runs (95% CI 7.8 to 11.9). The injury rate was found to increase with increasing speed (slalom 4.9 injuries per 1000 runs, 95% CI 2.5 to 7.4—giant slalom 9.2, 5.1 to 13.3—super-G 11.0, 5.2 to 16.8—downhill 17.2, 11.6 to 22.7). The most frequently injured body part was the knee, with 68 injuries (36%), and 37 of these were severe. The overall injury rate was higher in males than in females, but not for knee injuries.

Conclusions : The risk of injury among World Cup athletes in alpine skiing is even higher than previously reported. The knee is the most commonly injured body part and with many severe injuries. Injury rate increased with a higher speed and was higher among males than in females.

Alpine skiing has been on the Olympic programme since 1936. The first World Cup ski race was held in 1967, and today the World Cup alpine skiing events include downhill, super-G (super giant slalom), giant slalom and slalom. The International Ski Federation (FIS) arranged 3087 and 3625 alpine races internationally during the 2006–7 and 2007–8 season, respectively. The number of races for the alpine skiing World Cup was 71 and 74 for the same two seasons and 453 and 443 athletes competed in these competitions. The alpine World Cup is popular, and TV audiences of up to 250 million watch an event (FIS, personal communication, 2009).

While the injury risk for recreational skiers has been well documented based on prospective injury recording systems since the early 1970s,[1–3] there are almost no data published on the injury pattern and injury risk for competitive alpine skiers. Recent data on professional skiers competing in diverse disciplines from downhill with high speed, long jumps and minimal protection to slalom with technical demands are limited to two single-event studies (Olympic Games 1994 and Junior World Championships 1995).[4 5] However, several cross-sectional studies among active skiers have shown that 72–83% of world class skiers have sustained at least one previous serious injury.[6–9] Although these studies are decades old, they indicate that the risk of injuries is high.

The aim of this study was therefore to describe the risk of injury and the injury pattern among competitive World Cup alpine skiers during the competitive season.

METHODS

Study design and population

We conducted retrospective interviews with World Cup alpine skiers from 10 nations at the end of the 2006–7 and the 2007–8 winter seasons because a methodological study[10] found this to be the best method available to record injuries among World Cup ski and snowboard athletes. We defined the winter season as starting on 1 November or, if earlier, the first World Cup race of the season, lasting until the interviews took place. For the 2006–7 season, the first World Cup alpine event was in Levi, Finland on 11–12 November. The first races scheduled in Sölden, Austria 28–29 October were cancelled because of a lack of snow. Therefore, the injury registration started on 1 November in this season, and we conducted the interviews at the two final World Cup events in Kvitfjell, Norway (8–10 March 2007) and Lenzerheide, Switzerland (14–18 March 2007). For the 2007–8 season, the first World Cup alpine event was in Sölden, Austria on 27–28 October, and the registration for this season started there. We conducted the interviews at the two final World Cup events in Kvitfjell, Norway (27 February to 2 March 2008) and Bormio, Italy (10–16 March 2008).

From the official FIS database, we identified athletes who had started in at least one World Cup (WC)/World Ski Championship (WSC) event in downhill, super-G, giant slalom, slalom, combined or super combined. We included all athletes from the teams of Germany, Switzerland, Canada, Finland, France, Norway, Italy, Sweden, Austria and Slovenia (2007–8 only). These represent large teams in the different disciplines, and we expected most of their athletes to speak English fluently.

At the events, we interviewed the athletes from the selected nations who were present in person. If the athlete was not present (due to injury or for other reasons), we interviewed their coaches. Some coaches directed us to their team physician/ physical therapist to obtain the information needed. We also asked the team coaches to control and complete the list of athletes from their nation.

Athletes not defined as being on the World Cup team roster by the coaches were excluded (eg, national athletes starting in races in that country on the national quota).

We explained the purpose and procedure of the interviews at the team captain's meeting, where head coaches from all nations were required to be present. At this meeting, we also asked the coaches to inform their athletes of the interviews. A letter describing the interviews was distributed by email to all head coaches/team leaders in the alpine World Cup prior to the 2007–8 registration. Research teams from the Oslo Sports Trauma Research Center consisting of physicians and physical therapists conducted the interviews. The research teams performed the interviews in the finishing area in connection with official training or competition, or, in some cases, at the team's hotel. To facilitate athlete recall of participation and time loss due to injury, we used a form outlined as the week-by-week calendar of the alpine World Cup season as an interview tool.[10]

The Regional Committee for Medical Research Ethics, Region Øst-Norge and the Norwegian Social Science Data Services approved the study.

Injury definition

The injury definition was "All injuries that occurred during training or competition and required attention by medical personnel." This definition, as well as the classification of the type of injury and body part injured, was based on a recent consensus document on injury surveillance in football.[11] Training included activities on snow, and basic training not on snow. We classified the severity of injury according to the duration of absence from training and competition as slight (no absence); minimal (1 to 3 days), mild (4 to 7 days), moderate (8 to 28 days) and severe (>28 days) as also recommended in the consensus report.[11] For each injury, we recorded the body part injured, the injury type, as well as the specific diagnosis. If multiple injuries resulted from the same event, we described all of these on the same form. We also recorded information on where the injury happened, during World Cup/World Ski Championship competition/official training, other competition/official training, other training activity on snow (ie, regular training) or basic training not on snow (ie, running, weightlifting, soccer, etc). For injuries recorded during the interviews, the interviewer completed an injury form containing the above-mentioned information.[10]

Statistics including injury incidence and exposure

To present the most complete picture of injury risk, we have expressed injury incidence as the absolute injury rate (expressed as the total number of injuries per 100 athletes per season) as well as the relative injury rate (expressed corrected for exposure as the number of injuries per 1000 runs), both with their corresponding 95% CIs. When calculating the absolute injury rate we included all injuries during the season, in competition as well as during training. To calculate the relative injury rate, we included injuries in World Cup/World Ski Championship competitions, as these were the only competitions where it was possible to relate injuries to the number of started runs (exposure) across the different disciplines. For each of the skiers, we calculated their competition exposure as the exact number of started runs during the 2006–7 and 2007–8 winter seasons based on information from the FIS database. The database includes information on race completion, and we included the run if the athlete was disqualified afterwards but counted only one run if the athlete was disqualified after the first run in slalom and giant slalom (where there are two runs per event).

We based our calculation on the Poisson model and used a Z test for comparing injury risk between disciplines and computing the corresponding 95% CI. We computed relative risks (RR) with their 95% CIs to compare injury rates between male and female athletes for severity, distribution with regard to body part injured and the relative risk between the different disciplines for all injuries and knee injuries. A two-tailed p level of $\leqslant 0.05$ was considered statistically significant.

RESULTS

In total, 521 alpine athletes (292 males and 229 females) were interviewed during the 2006–7 and the 2007–8 winter seasons from the selected nations. Of these, 207 interviews (40%) were done with the athletes and 314 (60%) with coaches/medical personnel. Five athletes were interviewed via the telephone/email within 4 weeks after the interviews. This represents a 100% response rate for athletes on the World Cup teams selected for the study.

A total of 191 acute injuries (123 among males and 68 among females) were recorded. The absolute injury rate, expressed as the number of injuries per 100 athletes per season, is shown for all injuries within the different severity categories for males and females in table 1. There was a higher risk for males compared with females for all injuries, while no significant gender difference was detected for time-loss injuries only.

As many as 155 (81.1%) of the injuries recorded were time-loss injuries; the majority of these were moderate and severe injuries. Overall, 111 (58.1%) were located in the lower extremity. The most commonly injured body part was the knee (n = 68, 35.6%), and 37 (54.4%) of these were severe with an absence of >28 days (table 2). The second most frequently injured body parts were the lower leg, where 31.8% were severe injuries, and the lower back region, where only 4.5% were severe (table 2). The injury distribution is shown separately for males and females in fig 1. There was no difference in the absolute rate

Table 1 Absolute injury rates with 95% CIs for all recorded injuries (n = 191) among males and females related to injury severity

	Incidence (injuries/100 athletes per season)			Relative risk
Absence	Male	Female	Total	Males versus females
None	9.2 (5.8 to 12.7)	3.9 (1.4 to 6.5)	6.9 (4.7 to 9.2)	2.35 (1.11 to 5.00)
1–3 days	3.4 (1.3 to 5.5)	2.6 (0.5 to 4.7)	3.1 (1.6 to 4.6)	1.31 (0.48 to 3.60)
4–7 days	6.5 (3.6 to 9.4)	4.4 (1.7 to 7.1)	5.6 (3.5 to 7.6)	1.49 (0.69 to 3.21)
8–28 days	11.3 (7.4 to 15.2)	7.9 (4.2 to 11.5)	9.8 (7.1 to 12.5)	1.44 (0.81 to 2.55)
>28 days	11.6 (7.7 to 15.6)	10.9 (6.6 to 15.2)	11.3 (8.4 to 14.2)	1.07 (0.64 to 1.79)
Total	42.1 (34.7 to 49.6)	29.7 (22.6 to 36.8)	36.7 (31.5 to 41.9)	1.42 (1.06 to 1.91)

Relative risk with 95% CIs between males and females is shown for each severity category.

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Table 2 Distribution of all recorded injuries (n = 191) with respect to body part injured and severity category (classified according to the number of days of absence from training and competition)

Body part injured	No time loss	1–3 days	4–7 days	8–28 days	>28 days	Total (%)
Head/face	3	2	2	4	5	16 (8.4)
Neck, cervical spine						
Shoulder, clavicula	3	1	3	4	2	13 (6.8)
Upper arm				1		1 (0.5)
Elbow		2			1	3 (1.6)
Forearm					1	1 (0.5)
Wrist	1			1	1	3 (1.6)
Hand, finger, thumb	11	2	2	1	1	17 (8.9)
Chest (sternum, ribs, upper back)		1	2	1		4 (2.1)
Abdomen						
Lower back, pelvis, sacrum	2		13	6	1	22 (11.5)
Hip, groin	1	1			2	4 (2.1)
Thigh	1	1		2		4 (2.1)
Knee	8	2	4	17	37	68 (35.6)
Lower leg, Achilles tendon	5	3		7	7	22 (11.5)
Ankle	1	1	3	4	1	10 (5.2)
Foot, heel, toe				3		3 (1.6)
Total (%)	36 (18.8)	16 (8.4)	29 (15.2)	51 (26.7)	59 (30.9)	191 (100)

for knee injuries between males and females (RR 1.06, 95% CI 0.65 to 1.71).

The most common injury type in alpine skiing was joint and ligament injuries (44.0%) followed by fractures and bone stress (18.8%) (table 3). For both injury types, the majority were severe injuries (42.9% for joint and ligament injuries and 41.7% for fractures and bone stress). As shown in table 4, the knee accounted for 57 (67.9%) of all joint and ligament injuries, and knee ligament injuries were the most frequent injury type (table 4). Of these, ACL injuries was the most frequent specific diagnosis (n = 26). We found no difference between males and females in the risk for ACL injuries (RR 1.08, 95% CI 0.50 to 2.36). Concussions followed as the second most common specific injury type (n = 11).

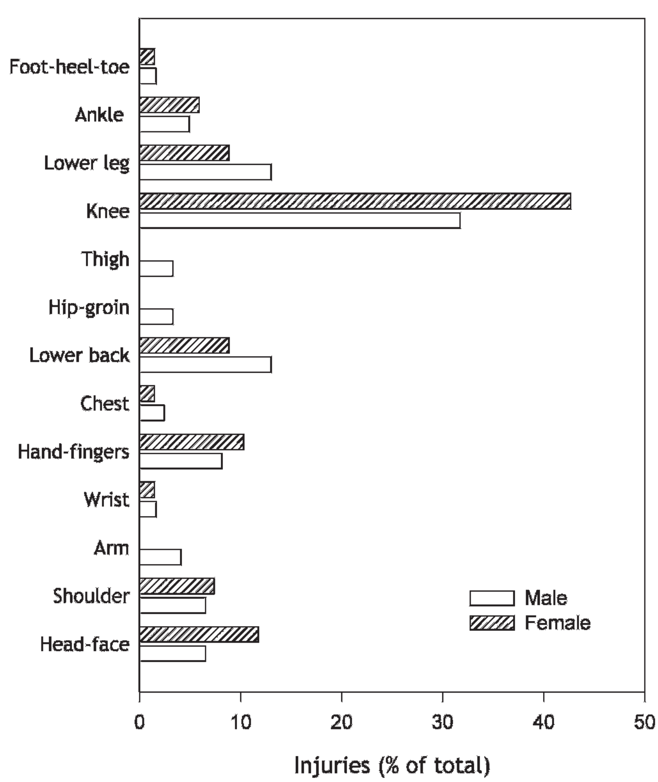

Figure 1 Distribution by body region of all reported injuries (n = 191) expressed as the percentage of the total number reported for males (n = 123; open bars) and females (n = 68; hatched bars).

Of the 191 injuries, 86 (45.0%) occurred during World Cup/World Ski Championship competitions, 31 (16.2%) during official training for these competitions, while 48 (25.1%) injuries occurred during regular training on snow. Of the remaining injuries, 24 (12.6%) occurred during other competitions/official training and 2 (1.0%) during basic training not on snow. Based on the FIS database, we estimated the total exposure during World Cup/World Ski Championship competitions for the athletes interviewed to be 8734 runs (table 5). The relative injury rate, estimated as the number of injuries per 1000 runs, was 9.8 (95% CI 7.8 to 11.9). Of the 86 injuries, 67 led to time loss from training/competition, corresponding to a relative rate of 7.7 injuries per 1000 runs for time-loss injuries. The relative injury rate across the different disciplines for all injuries (n = 86) as well as knee injuries (n = 28) is shown for males and females in table 5. For all injuries, the highest incidence was found for downhill followed by super-G and giant slalom, while the incidence was lowest in slalom. There was a significant difference between downhill (RR 3.48, 95% CI 1.93 to 6.25) and super-G (RR 2.23, 95% CI 1.09 to 4.56) compared with slalom, as well as for downhill compared with giant slalom (RR 1.87, 95% CI 1.07 to 3.25). Slalom was the only discipline where there was a difference in relative injury rate between males and females (RR 5.16, 95% CI 1.17 to 22.7). However, there was no difference in the relative rate for knee injury between males and females in any discipline.

DISCUSSION

This is the first large cohort study to examine the overall injury risk and detailed injury pattern among World Cup alpine skiers during the competitive season. The main findings were that the injury rate for elite alpine skiers was higher than reported previously, that the injury rate increased with skiing speed and that the absolute and relative injury rate was higher among males compared with females. The knee was the most commonly injured body part, with a majority of severe injuries.

Table 3 Distribution of all recorded injuries with respect to injury type and severity category (classified according to the number of days of absence from training and competition)

	No time loss	1–3 days	4–7 days	8–28 days	>28 days	Total (%)
Injury type						
Fractures/bone stress	9	2	3	7	15	36 (18.8)
Joint/ligament	11	5	8	24	36	84 (44.0)
Muscle/tendon	3	3	8	6		20 (10.5)
Contusion	8	4	5	6		23 (12.0)
Skin/laceration	2		1	2	2	7 (3.7)
Nervous system/concussion	1	2	4	3	5	15 (7.9)
Other	2			3	1	6 (3.1)
Total	36	16	29	51	59	191 (100)

To describe overall injury risk and enable a comparison with other studies and sports, we have estimated both the absolute rate (per season) and relative rate (per run). Through the FIS database, we could extract a complete record of the exact numbers of runs during World Cup/World Ski Championship competitions for each of the athletes interviewed. Therefore, the relative rate of 9.8 injuries per 1000 runs (7.7 injuries per 1000 runs for time-loss injuries) represents a reliable estimate. There are only two previous studies available on World Cup alpine skiers, which reported an incidence of 1.9 and 4.0 injuries per 1000 runs, respectively.[4 5] However, these studies were based on data from just one major event with few injuries recorded, and the injury definition, with regard to severity, was not clearly defined. Our findings indicate that the injury risk in WC/WSC competition is at least twice as high as previously suggested. One limitation of our approach is that exact exposure data were only available for World Cup/World Ski Championship competitions, not training outside these competitions. Obtaining documentation on the number of runs performed or the time spent in active training is challenging, and much of the technical training cannot be attributed to one specific discipline.

When comparing the injury risk between disciplines, it should also be borne in mind that the length of a run varies between disciplines. Downhill consists of only one run and has the longest course (ranging from around 2000 to 4500 m), the largest vertical drop (800 to 1100 m for males, 450 to 800 m for females) and hence the highest speed (average 95 to 105 km/h, maximal speed can exceed 140 km/h).[12] At the other end of the spectrum is slalom, with two runs, the shortest course, the lowest vertical drop (180 to 220 m for men, 140 to 220 m for women), and frequent turns (on average 60 gates) designed to combine speed with neat execution and precision of turns.[12] Another difference is that ski and safety equipment varies between disciplines, although crash helmets are compulsory in all competitions. One study from the 1980s showed that two-thirds of the injuries were reported to have occurred downhill,[7] and two more recent single-event studies have an incidence of 1.1 and 8.3 injuries per 1000 runs, respectively.[4 5] Our results confirm that downhill is associated with the highest injury risk but also document that the incidence, 17.2 injuries per 1000 runs, is much higher than previously reported. We also found that the risk of injury increased with increasing speed, from the lowest in slalom to the highest in downhill. Notably, among World Cup alpine skiers the injury rate increases with severity; as many as 38% of all time-loss injuries cause an absence of > 28 days. This is in contrast to most other sports, where severe injuries are the least frequent. If we consider the challenges involved—manoeuvring down an icy, steep mountainside on a pair of skies with minimal protection, often above the speed limit—these findings are not surprising. However, whether there has been an increase in severe injuries or in downhill

Table 4 Distribution of all recorded injuries (n = 191) with respect to body part injured and injury type

Body part	Fractures and bone stress	Joint and ligament	Muscle and tendon	Contusions	Lacerations and skin lesions	Nervous system/ concussion	Other	Total (%)
Head, face	2			1	2	11		16 (8.4)
Neck, cervical spine								
Shoulder, clavicle	2	8	2	1				13 (6.8)
Upper arm	1							1 (0.5)
Elbow		3						3 (1.6)
Forearm	1							1 (0.5)
Wrist	2	1						3 (1.6)
Hand, finger, thumb	11	4	1	1				17 (8.9)
Chest (sternum, ribs, upper back)	1			3				4 (2.1)
Abdomen								
Lower back, pelvis, sacrum	1	2	7	6	1	4	1	22 (11.5)
Hip, groin			2		1		1	4 (2.1)
Thigh			4					4 (2.1)
Knee	3	57	2	3	3			68 (35.6)
Lower leg, Achilles tendon	8	2	2	8			2	22 (11.5)
Ankle	3	7						10 (5.2)
Foot, heel, toe	1						2	3 (1.6)
Total	36	84	20	23	7	15	6	191 (100)

Table 5 Number of all injuries (n = 86) and exposure (the total number of runs, n = 8734) in the different disciplines during World Cup/World Ski Championship competitions

Discipline	Injuries (n)		Exposure (runs)		Incidence (injuries per 1000 runs)			Relative risk	Knee injury incidence (injuries per 1000 runs)			Relative risk
	Male	Female	Male	Female	Male	Female	Total	Males vs females	Male	Female	Total	Males vs females
Downhill	25	12	1292	863	19.3 (11.8 to 26.9)	13.9 (6.0 to 21.8)	17.2 (11.6 to 22.7)	1.39 (0.70 to 2.77)	8.5 (3.5 to 13.5)	4.6 (0.1 to 9.2)	7.0 (3.4 to 10.5)	1.84 (0.59 to 5.77)
Super-G	9	5	620	653	14.5 (5.0 to 24.0)	7.7 (0.9 to 14.4)	11.0 (5.2 to 16.8)	1.90 (0.64 to 5.66)	1.6 (−1.5 to 4.8)	1.5 (−1.5 to 4.5)	1.6 (−0.6 to 3.7)	1.05 (0.07 to 16.8)
Giant slalom	14	5	1090	977	12.8 (6.1 to 19.6)	5.1 (0.6 to 9.6)	9.2 (5.1 to 13.3)	2.51 (0.90 to 6.97)	3.7 (0.1 to 7.3)	4.1 (0.1 to 8.1)	3.9 (1.2 to 6.6)	0.90 (0.22 to 3.58)
Slalom	14	2	1864	1375	7.5 (3.6 to 11.4)	1.5 (−0.6 to 3.5)	4.9 (2.5 to 7.4)	5.16 (1.17 to 22.7)	1.1 (−0.4 to 2.6)	0.7 (−0.7 to 2.2)	0.9 (−0.1 to 2.0)	1.48 (0.13 to 16.3)
Total	62	24	4866	3868	12.7 (9.6 to 15.9)	6.2 (3.7 to 8.7)	9.8 (7.8 to 11.9)	2.05 (1.28 to 3.29)	3.7 (2.0 to 5.4)	2.6 (1.0 to 4.2)	3.2 (2.0 to 4.4)	1.43 (0.66 to 3.10)

Injury incidence is shown for all injuries (n = 86) in the different disciplines among male and female skiers as well as for knee injuries only (n = 28), and the relative risk for males versus females.

because of the development of the sport and its equipment, or the actual risk has been higher than previously reported, is difficult to know. Continuous injury surveillance is needed to follow such trends.

While several studies have shown that the knee is the most commonly injured body part among adult recreational skiers,[13–16] there is less evidence on elite alpine skiers. One study among top-ranked skiers from the 1980s found knee ligament injury to be the most frequent injury type, while a lateral ligament ankle sprain was the most frequent specific diagnosis.[7] We also found the knee to be the most commonly injured body part among World Cup skiers, accounting for 36% of all injuries, while ankle sprains were rare. ACL injury was the most commonly reported specific diagnosis, accounting for 38% of knee injuries. Moreover, we have most likely underestimated the number of ACL injuries, as the person interviewed in several cases could not give a precise diagnosis. However, about half of the knee injuries were severe, causing >28 days of time loss from sports. Our findings are supported by a recent study by Pujol and coworkers,[17] who observed a high frequency of ACL injuries among top-ranked French alpine skiers during a 25-year period. Preventing severe knee injuries should therefore be a priority.

Several mechanisms have been described to cause ACL injuries in alpine skiing,[18–24] but as most of this research has been done on recreational skiers, we do not know if these are relevant for alpine skiers at the World Cup level. The boot-induced anterior drawer mechanism, which occurs during hard landings in deep knee flexion after a jump, has been described to be more common among high-level skiers.[24] Our data show that the incidence of knee injuries was highest in downhill and lowest in slalom. This suggests that not only can the high technical demands and forces involved in the technical disciplines (giant slalom and slalom) cause the ACL to tear, but also the high-speed disciplines may be even more risky. However, at present we do not even know if the injuries are caused by loads occurring while the athlete is still skiing, or if the ACL is torn in crashes where the athlete tumbles down the slope, with the heavy ski acting as a lever. Before preventive measures can be suggested, the injury mechanisms need to be characterised.

Our data suggest that the injury risk is higher for male than female elite skiers. The injury incidence in World Cup/World Ski Championship competitions was twice as high in males. The overall injury risk during the winter season was also higher in male skiers. Our results are in contrast with data from the 1994 Olympic Games[4] and the 1995 World Junior Championships,[5] where females had a significantly higher injury incidence than males. No sex differences were, however, reported among national competitive skiers during the 1981/2 season.[25] The present study is the first to report a higher injury incidence among males, although it should be noted that we found no significant differences when only time-loss injuries were included.

For knee injury risk, however, we detected no sex differences. Our findings are in line with Pujol and coworkers,[17] who found no sex differences in ACL injury risk among elite French national team athletes during 25 years. Ekeland and coworkers,[4] on the other hand, reported a significantly higher percentage of previous ACL injuries in Olympic female alpine racers, but this was a study of 54 competitors[4] with a response rate of only 21%. Several studies among recreational skiers have reported a twofold greater risk of knee injuries among women compared with men.[1 3 26–28] In team sports like soccer and team handball, women have a four- to sixfold higher rate of non-contact ACL

What is already known on this topic

- There are no data from large cohort studies on the injury risk and pattern among elite alpine skiers.
- There are conflicting study findings regarding sex differences in injury risk among competitive alpine skiers.

What this study adds

- The injury rate among World Cup alpine skiers during the competitive season is high, particularly for severe knee injuries.
- Injury rate across disciplines increases with increasing speed.
- Males have an increased risk compared with females.

injuries than men.[29–32] Perhaps the speed, technical demands and high forces associated with World Cup skiing over-rule any vulnerability factors related to sex.

Some limitations must be kept in mind when interpreting the results from this study. Recall bias is a challenge with retrospective interviews. However, we did find this to be the best method available to record injuries among skiers and snowboarders.[10] If not all injuries were captured through the interviews, the injury rate in alpine skiing will have been underestimated. However, this is the most comprehensive survey conducted among World Cup skiing athletes to date. Another limitation is that we have recorded injuries only through the World Cup winter season, and we do not know what occurs in the training season. Although the athletes do much of their training on snow all year round, some changes in the overall pattern and injury risk would be likely if we had been able to include the entire year.

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Paper IV

Injuries among World Cup freestyle skiers

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Running head: Injuries among freestyle skiers

Key words: Epidemiology, athletic injuries, skiing

Abstract

Background: Limited knowledge exists on injuries among professional freestyle skiers.

Objective: To describe the risk of injury and injury patterns among competitive World Cup freestyle skiers during the competitive season.

Methods: We conducted retrospective interviews with World Cup freestyle skiers from 20 nations in a cohort study at the end of the 2006-07, 2007-08 and 2008-09 winter seasons and recorded all acute injuries occurring during the 4.5-month competitive season. If the athlete was not present, we interviewed their coaches or medical personnel.

Results: A total of 291 acute injuries were recorded among 662 World Cup freestyle skiers. Ninety-three injuries (32%) were severe in nature, defined as >28 days absence from training/competition. This corresponds to 14 (95% CI 11.2 to 16.9) injuries per 100 athletes per season.. The most frequently injured body part was the knee with 77 injuries (27%) and 37 of these were severe. The head was the next most commonly injured body part with 39 (13%) injuries. As many as 106 injuries (36%) occurred during World Cup/World Ski Championship competitions, corresponding to an injury rate of 15.6 injuries per 1000 runs (95% CI 12.7 to 18.6). There were no significant differences between males and females in either the injury rate or the rate for knee injuries seen. **Conclusions**: The injury rate among World Cup athletes in freestyle skiing is high especially for the severe injuries. Knee injuries are the most commonly injured body part, also dominated by severe injuries. We found no significant difference in the injury rate related to sex.

Introduction

Freestyle skiing is a relatively recent addition to the traditional Olympic winter sports — combining speed, showmanship and the ability to perform aerial manoeuvres while skiing.[1] Today, the freestyle skiing events at the World Cup level consist of five disciplines; moguls, dual moguls, aerials, halfpipe and ski cross.

In mogul skiing, the athlete skis down a 200-250 m long course uniformly covered with moguls and also containing two jumps. In dual moguls, competitors compete head to head on parallel mogul courses. In aerials, the athletes perform high jumps where they are scored according to the difficulty of the manoeuvre performed and its execution. In halfpipe, the skiers ski down a 100-140 m long snow-constructed pipe with 3-4.5 m high walls, performing a series of manoeuvres skiing off the walls into the air, landing back into the pipe again. Ski cross has the longest course of the freestyle disciplines (900-1200 m). The skiers, in groups of four to six, race head to head past several freestyle skiing challenges (e.g. turns, jumps and waves) in several elimination heats until the final settles the podium positions.[2]

Dowling et al.[3] monitored injuries in United States Ski Association events during the 1978-79 and 1979-80 seasons, estimating that there were 2.8 injuries per 1000 skier-days, with knee, head and spine injuries the most frequent. However, the freestyle skiing sport has evolved considerably from the early 80s and halfpipe and ski cross have been added as new disciplines to the World Cup program.

Thus, the aim of this study was to describe the risk of injury and the injury pattern among competitive World Cup freestyle skiers during the competitive winter season and examine sex and discipline as risk factors.

Material and methods

Study design and population

We conducted retrospective interviews in a cohort of World Cup freestyle skiers from pre-defined teams at the end of the 2006-07, 2007-08 and 2008-09 winter seasons. A methodological study[4] comparing prospective injury reporting by team medical personnel, prospective injury reporting by FIS technical delegates and retrospective athlete/coach interviews showed that retrospective interviews were the most accurate in this setting. We therefore chose this method to record injuries among World Cup freestyle skiers. We defined the winter season as starting on November 1. We conducted the interviews at the two final events in Voss, Norway (March 2 to 3, 2007) and Madonna di Campiglio, Italy for the first season, the final World Cup events in Valmalenco, Italy (March 12 to 16, 2008) for the second season and the final World Cup events in La Plagne, France (March 18 to 19, 2009) for the third season.

From the official FIS database we identified athletes who had started in at least one World Cup (WC)/World Ski Championship (WSC) event in moguls, dual moguls, halfpipe, aerials and ski cross. We included all athletes from the teams of Germany, Switzerland, Canada, Finland, France, Norway, Italy, Sweden and Austria for all three seasons. For the 2007-08 and 2008-09 winter season we also included complete World Cup teams in the different disciplines from 11 additional nations to increase the study population. Except for the 2006-07 season, when halfpipe was excluded because of cancellations due to lack of snow, we interviewed athletes from all disciplines. We excluded national teams in sub-disciplines if the response rate from that particular nation was less than 80%.[5]

At the final events of the three seasons, we interviewed the athletes from the selected nations who were present in person. If the athlete was not present (due to injury or for other reasons), we interviewed their coaches. Some coaches directed us to their team physician/physical therapist in order to obtain the information required. We also asked the team coaches to control and complete the list of athletes from their nation. Athletes not defined as being on the World Cup team roster by the coaches were excluded (e.g. national athletes starting in races in that country on the national quota).

Research teams consisting of physicians and physical therapists from the Oslo Sports Trauma Research Center performed the interviews in the finishing area in connection with official training or competition, or, in some cases, at the team's hotel. To facilitate athlete recall of participation and time loss due to injury, we used a form outlined as the week-by-week calendar of the freestyle World Cup season as an interview tool.[4]

The Regional Committee for Medical Research Ethics, Region Sør-Norge and the Norwegian Social Science Data Services approved the study.

Injury definition

The injury definition was "all injuries that occurred during training or competition and required attention by medical personnel". This definition, as well as the classification of the type of injury and body part injured, was based on a recent consensus document on injury surveillance in football.[6] Training included activities on snow and basic training not on snow. We classified the severity of injury according to the duration of absence from training and competition as slight (no absence); minimal (1 to 3 days), mild (4 to 7 days), moderate (8 to 28 days) and severe (>28 days).[6] For each injury recorded, the interviewer completed an injury form containing information on the body part injured, the injury type, the severity of the injury, as well as the specific diagnosis. If multiple injuries resulted from the same event, we described all of these on the same form. We also recorded information on where the injury occurred; during World Cup/World Ski Championship competition/official training, other competition/official training, other training activity on snow (i.e. regular training) or basic training not on snow (i.e. running, weightlifting, soccer etc.).[4]

Statistics including injury incidence and exposure

To present the most complete picture of injury risk we have expressed injury incidence as the absolute injury rate (expressed as the total number of injuries per 100 athletes per season) as well as the relative injury rate (corrected for exposure, expressed as the number of injuries per 1000 runs), both with their corresponding 95% confidence intervals (CI). When calculating the absolute injury rate we included all injuries during the season, in competition as well as during training as described in a previous study.[4] To calculate the relative injury rate we included injuries in WC/WSC competitions only – as the number of started runs (exposure) was available from these competitions only. A jump in aerials is also referred to as a run in this study. For each of the skiers we calculated their competition exposure as the exact number of started runs during the 2006-07, 2007-08 and the 2008-09 winter seasons based on information from the FIS database. The database includes information on race completion and positions. If an athlete was disqualified, we included the runs up to and including the disqualified run. For the different disciplines the average of runs per competition varied from one to five in ski cross, one to two in aerials, one to four in halfpipe, one to two in moguls and one to five in dual moguls depending on the racer's final result.

We based our calculations on the Poisson model and used a Z test for comparing injury risk between disciplines and computed the corresponding 95% confidence intervals (CI). We computed relative risks (RR) with their 95% CI to compare injury rate between male and female athletes for severity, distribution with regards to body part injured and the relative risk between the different disciplines for all injuries and knee injuries. A two-tailed p-level of ≤ 0.05 was considered statistically significant.

Results

We interviewed 662 freestyle athletes from the teams selected for the study (426 males and 236 females) during the three winter seasons from 2006 until 2009 (Table 1). Of these, 290 interviews (44%) were done with the athletes and 372 (56%) with coaches/medical personnel. Three athletes were interviewed via telephone/e-mail within 4 weeks of the interviews. Overall, this represents a 98% response rate for athletes on the freestyle World Cup teams in question. During the three World Cup seasons, 93 athletes were interviewed twice and 72 athletes were interviewed each of the three seasons. Only one athlete competed in more than one World Cup discipline and was categorised in the discipline where the best ranking was obtained.

Table 1. The number of athletes interviewed in the different disciplines for the three seasons in World Cup freestyle skiing

	2006-07		2007-08		2008-09		Sum three seasons		
Discipline	Males	Females	Males	Females	Males	Females	Males	Females	Total
Moguls/dual moguls	47	19	57	27	50	33	154	79	233
Ski cross	48	23	65	29	57	47	170	99	269
Aerials	12	4	31	16	12	13	55	33	88
Halfpipe			24	14	23	11	47	25	72
Total	107	46	177	86	142	104	426	236	662

A total of 291 acute injuries (179 among males and 112 among females) were recorded and 77 injuries (26.5%) did not lead to any time loss from training and/or competition. Of the 211 time-loss injuries, the majority were severe with an absence of >28 days (93, 44%) or moderate (8-28 days absence) (51, 24%). There were 34 mild injuries (4-7 days, 16%) and 33 minimal injuries (1-3 days, 16%). In three cases, we did not have data on injury severity.

The number of injuries and absolute injury rate (injuries per 100 athletes per season) within the different freestyle World Cup disciplines are shown in Table 2. We found a higher total injury rate in the other disciplines compared to moguls/dual moguls (RR ski cross vs. moguls/dual moguls: 1.49, 95% CI 1.13 to 1.98; aerials vs. moguls/dual moguls: 1.60, 95% CI 1.11 to 2.31; halfpipe vs. moguls/dual moguls: 1.62, 95% CI 1.10 to 2.39). There was also a higher injury rate for time-loss injuries in aerials and halfpipe compared to moguls/dual moguls (RR aerials vs. moguls/dual moguls: 1.63, 95% CI 1.07 to 2.48; halfpipe vs. moguls/dual moguls: 1.59, 95% CI 1.01 to 2.50) and a trend for ski cross (RR ski cross vs. moguls/dual moguls: 1.38, 95% CI 0.99 to 1.93). We found no difference in the rate of severe injuries between the different disciplines. There was no sex difference in absolute injury rate in any discipline or severity category (RR females vs. males: 1.13, 95% CI 0.89 to 1.43 for all injuries, RR females vs. males: 1.08, 95% CI 0.81 to 1.43 for time-loss injuries and RR females vs. males: 1.14, 95% CI 0.75 to 1.73 for severe injuries).

Table 2. Number of injuries (N) and absolute injury rate (expressed as the number of injuries per 100 athletes per seasons) with 95% confidence intervals for all recorded injuries (n=291), time-loss injuries (≥1 day absence) and severe injuries (>28 days) for the different disciplines of moguls/dual moguls (MO/DM), ski cross (SX), aerials (AE) and halfpipe (HP).

	All injuries		Time-loss injuries (≥1 day)		Severe injuries (>28 days)	
Discipline	N	Incidence	N	Incidence	N	Incidence
MO/DM	76	32.6 (25.3 to 40.0)	57	24.5 (18.1 to 30.8)	28	12.0 (7.6 to 16.5)
SX	131	48.7 (40.4 to 57.0)	91	33.8 (26.9 to 40.8)	40	14.9 (10.3 to 19.5)
AE	46	52.3 (37.2 to 67.4)	35	39.8 (26.6 to 52.9)	14	15.9 (7.6 to 24.2)
HP	38	52.8 (36.0 to 69.6)	28	38.9 (24.5 to 53.3)	11	15.3 (6.2 to 24.3)
Total	291	44.0 (38.9 to 49.0)	211	31.9 (27.6 to 36.2)	93	14.0 (11.2 to 16.9)

Overall, 135 injuries (46.5%) were located in the lower extremity. The injury distribution is shown separately for males and females in Figure 1. The most commonly injured body part was the knee (n=77, 26.5%), and 38 (49.4%) of these were severe (Table 3). The second most frequently injured body parts were the head/face (n=39, 13.4%), where 5 (12.8%) were severe. There was no difference in the absolute rate of severe knee injuries between males (6.8 injuries per 100 athletes per season) and females (7.9 injuries per 100 athletes per season, RR 1.15 vs. males, 95% CI 0.61 to 2.17). However, we observed a higher risk for head injuries in females compared to males (RR 2.11, 1.12 to 3.95).

Table 3. Description of all recorded injuries in freestyle skiing (n=291) with regards to body part injured (rows) and severity category (columns) classified according to the number of days absence from training and competition (no time loss, 1-3 days, 4-7 days, 8-28 days and more than 28 days).

Time loss / Body part injured	No time loss	1-3 days	4-7 days	8-28 days	>28 days	Information missing	Total (%)
Head/face	6	4	10	14	5		39 (13.4)
Neck, cervical spine	2	1					3 (1.0)
Shoulder, clavicle	6	1	3	9	12	1	32 (11.0)
Upper arm					2		2 (0.7)
Elbow	3	2	2	2	1		10 (3.4)
Forearm		1			2		3 (1.0)
Wrist	1	2			4	1	8 (2.7)
Hand, finger, thumb	10	2	1	3	4		20 (6.9)
Chest (sternum,ribs,upper back)	7	4	2		3		16 (5.5)
Abdomen					1		1 (0.3)
Lower back, pelvis, sacrum	7	5	2	3	5		22 (7.6)
Hip, groin	5		3	3	7		18 (6.2)
Thigh	5		1			1	7 (2.4)
Knee	12	6	7	14	38		77 (26.5)
Lower leg, Achilles tendon	10	2		1	5		18 (6.2)
Ankle	2	3	3	2	3		13 (4.5)
Foot, heel, toe	1				1		2 (0.7)
Total (%)	77 (26.5)	33 (11.3)	34 (11.7)	51 (17.5)	93 (32.0)	3 (1.0)	291 (100)

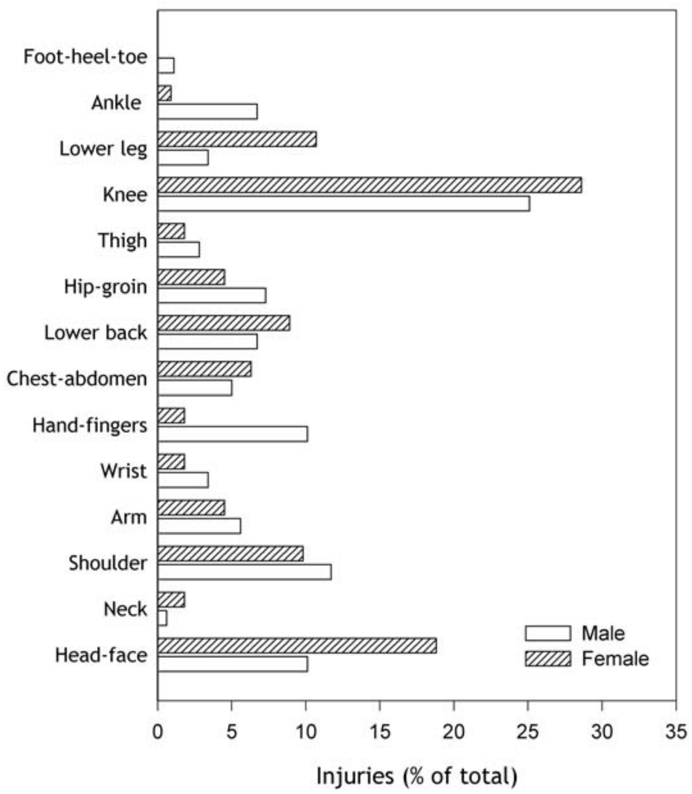

Figure 1: Distribution by body region of all reported injuries (n=291) expressed as the percentage of the total number reported for males (n=179; open bars) and females (n=112; hatched bars).

The most common injury type in freestyle skiing were joint and ligament injuries (42.6%) followed by fractures and bone stress (18.9%). As seen in Table 4, the knee accounted for 69 (55.6%) of all joint and ligament injuries and knee ligament injuries was the most frequent injury type. There were 24 ACL ruptures (63% of all severe knee injuries). We could detect no difference between females and males in the absolute rate of ACL tears (females: 5.1 injuries per 100 athletes per season, males: 2.8; RR 1.81, 95% CI 0.81 to 4.02). Of the 39 head injuries, 32 were concussions, accounting for 97% of all injuries to the nervous system. As many as 19 (59%) of the concussions were moderate or severe.

Table 4. Description of all recorded injuries (n=291) with respect to body part injured (rows) and injury type (columns)

Injury type Body part injured	Fractures and bone stress	Joint and ligament	Muscle and tendon	Contusions	Lacerations and skin lesions	Nervous system incl concussions	Other	Information not available	Total
Head/face	3				2	32	2		39 (13.4)
Neck, cervical		2	1						3 (1.0)
Shoulder, clavicle	6	15	8	3					32 (11.0)
Upper arm	1		1						2 (0.7)
Elbow	2	6		2					10 (3.4)
Forearm	3								3 (1.0)
Wrist	5	2						1	8 (2.7)
Hand, finger, thumb	12	7			1				20 (6.9)
Chest (sternum, ribs, upper back)	4	4	4	4					16 (5.5)
Abdomen							1		1 (0.3)
Lower back, pelvis, sacrum	5	5	5	6		1			22 (7.6)
Hip, groin	1	2	6	9					18 (6.2)
Thigh			6	1					7 (2.4)
Knee	4	69	4						77 (26.5)
Lower leg, Achilles tendon	7		3	7				1	18 (6.2)
Ankle	1	12							13 (4.5)
Foot, heel, toe	1			1					2 (0.7)
Total	55 (18.9)	124 (42.6)	38 (13.1)	33 (11.3)	3 (1.0)	33 (11.3)	3 (1.0)	2 (0.7)	291 (100)

Table 5 Number of all injuries (n=106) and exposure (the total number of runs, n=8734) in the different disciplines during World Cup/World Ski Championship competitions. Injury incidence is shown with 95% confidence intervals for all injuries in the different disciplines among male and female skiers as well as for knee injuries only (n=31), as well as the relative risk for males versus females.

	Injuries; n (Knee injuries)		**Exposure (runs)**		**Incidence (injuries per 1000 runs)**			**Relative risk**	**Knee injury incidence (injuries per 1000 runs)**			**Relative risk**
Discipline	Male	Female	Male	Female	Male	Female	Total	Males vs. females	Male	Female	Total	Males vs. females
Ski Cross	34 (11)	27 (8)	2054	1240	16.6 (11.0 to 22.1)	21.8 (13.6 to 30.0)	18.5 (13.9 to 23.2)	0.76 (0.46 to 1.26)	5.4 (2.2 to 8.5)	6.5 (2.0 to 10.9)	5.8 (3.2 to 8.4)	0.83 (0.33 to 2.06)
Moguls/Dual moguls	17 (7)	5 (2)	1477	906	11.5 (6.0 to 17.0)	5.5 (0.7 to 10.4)	9.2 (5.4 to 13.1)	2.09 (0.77 to 5.65)	4.7 (1.2 to 8.3)	2.2 * (0 to 5.3)	3.8 (1.3 to 6.2)	2.15 (0.45 to 10.3)
Halfpipe	8 (1)	2 (0)	258	161	31.0 (9.5 to 52.5)	12.4 * (0 to 29.6)	23.9 (9.1 to 38.7)	2.50 (0.53 to 11.8)	3.9 * (0 to 11.5)	0 *	2.4 * (0 to 7.1)	-
Aerials	7 (1)	6 (1)	405	273	17.3 (4.5 to 30.1)	22.0 (4.4 to 39.6)	19.2 (8.8 to 29.6)	0.79 (0.26 to 2.34)	2.5 * (0 to 7.3)	3.7 * (0 to 10.8)	2.9 * (0 to 7.0)	0.67 (0.04 to 10.8)
Total	66 (20)	40 (11)	4194	2580	15.7 (11.9 to 19.5)	15.5 (10.7 to 20.3)	15.6 (12.7 to 18.6)	1.02 (0.69 to 1.50)	4.8 (2.7 to 6.9)	4.3 (1.7 to 6.8)	4.6 (3.0 to 6.2)	1.12 (0.54 to 2.33)

* Less than 5 cases and need to be interpreted with cautions

Of the 291 injuries, 106 (36.4%) occurred during WC/WSC competitions, 74 (25.4%) during official training for these competitions, while 59 (20.3%) injuries resulted from regular training on snow. Four injuries (1.4%) occurred during basic training (not on snow) and the rest (48, 16.5%) during other competitions. Based on the FIS database we estimated the total exposure during WC/WSC competitions for the athletes interviewed to 6774 runs (Table 5) and the relative injury rate could be estimated for the 106 injuries which occurred during these events. Of these, 72 lead to time loss from training/competition, corresponding to a relative rate of 10.6 (95% CI 8.2 to 13.1) time-loss injuries per 1000 runs. The relative injury rate across the different disciplines for all injuries (n=106) as well as knee injuries (n=31) is shown for males and females in Table 5. Compared to moguls/dual moguls, the other disciplines had a higher injury rate (RR ski cross vs. moguls/dual moguls: 2.00, 95% CI 1.23 to 3.27; RR aerials vs. moguls/dual moguls: 2.08, 95% CI 1.05 to 4.12; RR halfpipe vs. moguls/dual moguls: 2.59, 95% CI 1.22 to 5.46). There was no significant difference in the relative rate of injury or knee injury between males and females in any of the disciplines, but it should be noted that in some disciplines there were less than 5 cases and the results therefore must be interpreted with caution.

Discussion

This is the first cohort study to examine the overall injury risk and detailed injury pattern among World Cup freestyle skiers during the competitive season. The main finding was that the injury rate was high, especially for severe injuries and knee injuries. We observed no difference in the absolute or relative injury rate between male and female skiers.

However, there are some limitations that must be borne in mind when interpreting the results. We have reported all injuries occurring during three consecutive World Cup seasons based on retrospective interviews with athletes, and, in more than half of the cases, with their coaches. Recall bias is a challenge with retrospective interviews. However, a methodological study found this to be the best method available to record injuries among World Cup skiers and snowboarders.[4] A freestyle skiing team is a close-knit community where each coach is responsible for a small number of athletes, travelling and living together during the entire World Cup season. In contrast, the team doctor and physiotherapist rarely travel with the team. It is therefore not surprising that the capture rate was much higher when interviewing the athlete or coach, as injuries occurring while on tour are not always seen by team medical staff. The same methodological study also found a good to very good agreement for body part injured and injury type between retrospective athlete interviews and prospective injury recording by medical team personnel.[4] Nevertheless, when using interviews with non-medical persons, it may be a challenge to obtain the correct specific diagnosis. Another limitation is that the injuries recorded in this study were from the World Cup season only; we do not know what occurs during training the rest of the year. Also, when looking at the injury incidence for the different disciplines, the number of knee injuries was limited in some of the disciplines and the results therefore must be interpreted with caution.

Injury incidence

We have estimated the injury rate in two different ways; as the absolute rate (the injury risk per season) and the relative rate (the injury risk per run). However, the relative injury rate could only be estimated for injuries in WC/WSC competitions, where we could extract a complete record from the FIS database of the exact number of runs for each of the athletes interviewed. We found that the absolute injury rate for mogul/dual mogul skiers was lower compared to the other disciplines for all injuries. There was, however, no significant difference in the absolute injury rate between the different disciplines for the most severe injuries. For injuries during WC/WSC competitions, we also found that mogul/dual moguls had the lowest injury rate compared to the other disciplines. The freestyle disciplines are diverse. Ski cross features the longest course and occasional body contact between the four to six skiers, who face a number of challenging freestyle elements. In halfpipe and aerials the course is shorter, but with difficult manoeuvres and spectacular jumps. When comparing the relative injury rate between these disciplines these differences need to be noted. Nevertheless, the number of injuries per 1000 runs is the exposure estimate most frequently used for elite skiers and snowboarders.[7-9] There is only previous study available from freestyle skiing, reporting on injuries in United States Ski Association freestyle competitions from 1976 to 1980.[3] This reported the number of injuries per 1000 skier days for practice and competitions, the most common measure used for recreational skiing. Considering the many changes that have taken place since the 70s, which includes the addition of ski cross and halfpipe as new disciplines (and the removal of ballet), a direct comparison is difficult. Nevertheless, their finding of a lower injury rate in mogul events compared to aerial events is confirmed in our study. No study has described the injury rate for ski cross and halfpipe previously. However, if we compare to World Cup alpine skiing, the injury rate in ski cross, halfpipe and aerials (ranging from 18.5 to 23.9 injuries per 1000 runs in the current study) seems to be at least as high as that reported from downhill skiing (the highest among the alpine skiing disciplines with 17.2 injuries per 1000 runs).[10] One similarity with alpine skiing is that the majority of the reported freestyle injuries were severe, leading to a time loss from training and competition of >28 days. This is in contrast to most other sports, where severe injuries are the least frequent. Considering the challenging manoeuvres executed in each of the freestyle disciplines, the high frequency of severe injuries may not come as a surprise. However, the data show that research is needed to understand the injury mechanisms and develop appropriate preventive measures.

Knee injuries

Previous studies have shown that the knee is the most commonly injured body part among World Cup alpine skiers, as well as adult recreational skiers,[10-14] and the same pattern was seen in elite freestyle skiers in the late 1970s.[3] Our results confirm that the knee is the most commonly injured body part in freestyle skiing, accounting for one-fourth of all injuries. The ACL was involved in at least 38% of these; however, this probably represents a minimum estimate, as not all athletes/coaches could give a precise diagnosis. Nevertheless, our findings are supported by Heir and co-workers,[15] who showed that 47% of the 95 participants in the FIS Freestyle World Championship in 2001 had experienced at least one major knee injury with an absence of at least 20 days. One-fourth of the skiers in the same study reported to have suffered at least one previous ACL injury.

Whether the injury mechanisms in World Cup freestyle skiing are the same as those described to cause ACL injuries in recreational alpine skiing [16-21] is unknown. The numbers (and thus the statistical power) become small when we divide the knee injuries into the different disciplines, but it seems that the risk for knee injuries is high across all disciplines. Whether injuries result from landing after a jump, resembling the boot-induced anterior drawer mechanism with deep knee flexion described to be common among high-level alpine skiers,[16] or occur when the skier is off balance in the mogul course or are due to collisions/crashes in ski cross needs to be investigated. According to the FIS freestyle competition rules,[2] bindings must be of a recognized release system meeting international standards for all the disciplines. Heir and co-workers[15] found that freestyle World Cup skiers tighten their bindings to values well above the recommended standards. Although studies from recreational skiing have shown that well-adjusted release bindings have reduced the risk of lower leg injuries,[22-24] they have not prevented knee sprains.[24]

Head injuries

Although helmet use is compulsory in all freestyle disciplines in the FIS World Cup and we would expect that athletes at this level use helmets also for training and in other competitions, we found head injuries to be frequent. Most of these were concussions and as many as 53% were moderate to severe. A reduction in the risk of head injuries of between 29 and 60% have been reported with the use of helmets.[25,26] Mecham and co-workers[27] looked at head impacts to freestyle aerial skiers and found that slapback events were common. These occur when the skier over-rotates in the air, resulting in a rotation backwards after the ski tails contact the snow and then the back and head impact the landing surface. Through more detailed information on the energy transfer it may be possible to develop helmets specifically for freestyle skiing.

Sex differences

In recreational alpine skiing, some studies have shown the total injury rate to be unrelated to sex,[11,23] while some specific injury types seem to be more common among either men or women. A recent study from World Cup alpine skiing has shown that the overall injury risk and the injury incidence in World Cup/World Ski Championship competitions were twice as high in males compared to females.[10] In contrast, the present data on freestyle skiing shows no sex difference in the absolute or relative injury risk. Several studies have reported a twofold greater rate of knee injuries among female recreational skiers,[14,28-30] while the rate of shoulder, spine and head injuries has been shown to be higher rate in male skiers.[14,28,31-33] However, no sex differences were found in the rate of knee injuries among World Cup alpine skiers.[10] Heir and co-workers [15] found, among 95 freestyle competitors at the FIS World Championship (2001), that the prevalence of previous, major knee injuries was significantly higher in women than men, but there was no significant difference in the prevalence of former ACL injuries or any other specific knee injuries between male and female skiers. Although we observed a higher risk for head injuries in females, we could not detect any sex difference in the absolute or relative knee injury rate or between the different disciplines. This corroborates the findings from World Cup alpine skiing, but is in contrast to team sports like team handball and soccer,[10,34-36] where women have a 4- to 6-fold higher rate of non-contact ACL injuries. As noted for alpine skiing, perhaps the technical demands and forces involved in freestyle skiing overrule any vulnerability factors related to sex.

WHAT IS ALREADY KNOWN ON THIS TOPIC

- There is no recent data from large cohort studies on the injury risk and pattern among elite freestyle skiers.

WHAT THIS STUDY ADDS

- The injury rate among World Cup freestyle skiers during the competitive season is high, particularly for severe injuries
- Knee injuries are common, followed by head injuries
- There is no difference in the overall injury risk or risk for knee injuries between male and female skiers

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Competing Interest: None declared.

Patient consent: Orally obtained before each interview.

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