Part I
Epidemiology and Injury Assessment

Injury Trends in Recreational Skiers and Boarders in the 16-Year Period 1996–2012

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Abstract Introduction: The Norwegian Ski Lift Association has since 1996 conducted a central registration of the injuries occurring in the major Norwegian ski resorts to survey the injury types. The aim of this study was to report injury trends in the period 1996–2012.

Material and methods: The injuries occurring in 7–16 Norwegian ski resorts were recorded by ski patrols during the 16 winter seasons 1996/1997–2011/2012 and related to a series of demographic factors. The number of skiing/boarder days was calculated from sold lift tickets (day cards), but these were only centrally recorded from the 2000/2001 season.

Results: A total of 55127 injured skiers and boarders were recorded. The injury rate dropped from 1.47 to 1.27 injuries per 1000 skier/boarder days ($P < 0.001$), and the skiing/boarding ability increased ($P < 0.001$) in the period 2000–2012. Most of the injuries occurred on groomed slopes, but an increasing number of injuries occurred in terrain parks, from only 4% in the 2000/2002 seasons to 24% in the last two seasons. More serious injuries (fractures and back injuries) were recorded in terrain parks than those occurring at other locations. Many of the injuries were similarly distributed among skiers and boarders, but alpine skiers suffered more lower extremity injuries, especially knee injuries (24%) compared to snowboarders (7%), whereas the reverse was observed for wrist injuries with 22% for snowboarders and 5% for alpine skiers in the last 2-year period ($P < 0.001$). The prevalence of knee injuries among alpine skiers has been about 25% in the period 1996–2012, but wrist injuries among snowboarders dropped from 29 to 22% ($P < 0.001$). The prevalence of knee injuries was twice as high for females (31%) as for males (15%), whereas the reverse was observed for shoulder injuries with 19% for males and 7% for females in the last 2-year period ($P < 0.001$). These differences have been observed during the whole period. Lower leg fracture for alpine skiers <13 years dropped from 20 to 13% in the period ($P < 0.001$), but has remained unchanged with about

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I.S. Scher et al. (eds.), *Snow Sports Trauma and Safety*,
DOI 10.1007/978-3-319-52755-0_1

4% for teenagers and adult skiers. Helmet use by injured skiers/boarders has increased from 11 to 81% in the period, and the prevalence of head injuries has dropped from 19 to 16% ($P < 0.001$).

Conclusion: The injury rate on Norwegian slopes dropped with 14% in the period 2000–2012. The prevalence of back injuries for injured snowboarders increased by 100% from 1996 to 2012, and this may be related to one-third of the injuries occurred in terrain parks at the end of the period. The prevalence of lower leg fracture in alpine children is declined by 35% in the period. Use of helmet by injured skiers/boarders increased from 11 to 81% and the prevalence of head injuries dropped with 16% during the same period.

Keywords Age • Gender • Helmets • Skiing • Skiing trauma • Skiing/boarding ability • Snowboarding • Telemarking • Tibial fractures

1 Introduction

Skiing has been a popular sport in the Nordic countries for more than a century [1], and snowboarding has gained increasing popularity during the last three decades. But skiing and boarding are not without risk, and it is important to perform epidemiological studies to identify risk factors. Most of the studies have been short-term covering 1–2 seasons [2–5], but several good long-term studies have been published from the USA and France [6–9].

The Norwegian Ski Lift Association has a central registry of the injuries occurring at the major Norwegian ski resorts since the season 1996/1997 [10–12]. The purpose of this study is to report the injury trends of skiing and boarding on Norwegian slopes in the 16-year period 1996/97–2011/12.

2 Material and Methods

The injuries occurring on the slopes of 7–16 major Norwegian ski resorts were recorded by ski patrols during the 16 winter seasons 1996/1997–2011/2012. These slopes accounted for about 50% of the ski lift transport in Norway during the registration period. A skiing/boarding injury was defined as an injury sustained by a skier/boarder who was treated by or consulted the ski patrol after a skiing/boarding accident.

The injuries were related to the type of skiing/boarding, the type and site of accident, age, and gender, skiing/boarding ability, use of protective helmet, physician or hospital treatment, and ambulance transport. Regarding skiing ability, the alpine skiers were classified by their performance of turns: expert (short turns), advanced skiers (parallel turns), intermediate skiers (stem turns), and beginners (plow turns) [13, 14]. The skill of snowboarders, telemarkers, and skiboarders was self-estimated.

The number of skier/boarder days was calculated from sold lift tickets (day cards and season cards). The number of day cards was only recorded from the 2000/2001 season and onwards.

The results are presented as injury rates (number of injured skiers/boarders) per 1000 skier/boarder days, mean days between injuries (MDBI), and prevalences (percentage of injured skiers and boarders in various groups). Differences were evaluated by Chi square and 2 × 2-table tests and considered significant when $P < 0.05$.

3 Results

3.1 Injury-Related Factors

Injury rates—A total of 55127 injured skiers and boarders were recorded. The injury rate declined from 1.47 injuries per 1000 skier/boarder days (680 MDBI) in the 2000/2002 seasons to 1.27 injuries per 1000 skier/boarder days (787 MDBI) ($P < 0.001$) in the 2010/2012 seasons (Fig. 1). Fifty-six percent of the injuries required physician or hospital treatment and 15% ambulance transport.

More than half of the injuries occurred during alpine skiing. Snowboarding peaked with 45% of the injuries in the two seasons 2000/2002, declining to 28% of the injuries during the last two seasons. Telemarking injuries dropped from 9 to 2% and skiboarding injuries from 4 to 2% of all injuries in the period (Fig. 2).

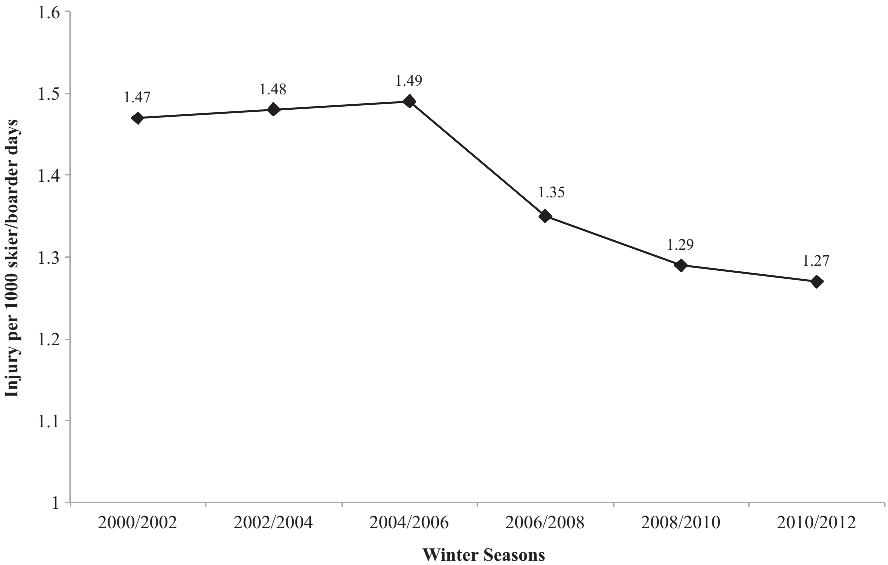

Fig. 1 Injury rates (incidences) for skiers/boarders the seasons 2000/2002–2010/2012. n = number of injured skiers/boarders. The population at risk is based on the number of sold day cards for skiers and boarders

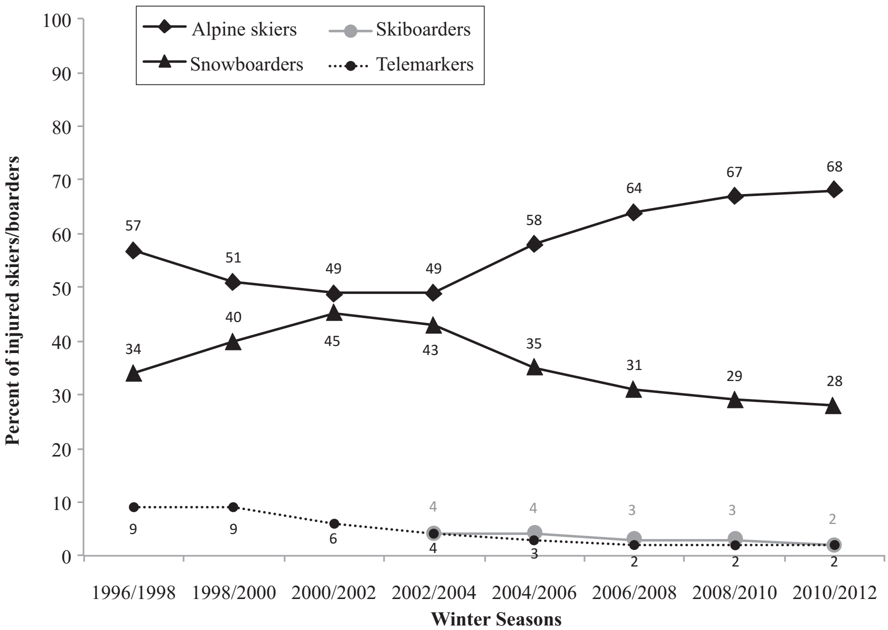

Fig. 2 Prevalences of injured skiers/boarders as percentage of all injured on the slopes the seasons 1996/1997–2010/2012. *n* = number of injured skiers/boarders

Location and type of injury—Many of the injuries were similarly distributed among skiers and boarders, but alpine skiers suffered more lower extremity injuries, especially knee injuries (24%) compared to snowboarders (7%) ($P < 0.001$), whereas the reverse was observed for wrist injuries with 22% for snowboarders and 5% for alpine skiers ($P < 0.001$) in the last 2-year period (Fig. 3). The prevalence of knee injuries among alpine skiers has been about 25% throughout the period, but wrist injuries for snowboarders dropped from 29 to 22% ($P < 0.001$) (Fig. 4). Lower leg fracture was 5.6% for alpine skiers compared to 0.7% for snowboarders ($P < 0.001$) in the 2010/2012 seasons, and this difference has been almost unchanged in the 16-year period. Hand injuries among alpine skiers dropped from 11 to 6% ($P < 0.001$) in the same period (data not shown).

Injury site—Most of the injuries occurred on groomed slopes, but an increasing number of injuries occurred in terrain parks, from only 4% in the 2000/2002 seasons to 24% in the last two seasons when 35% of the snowboarders and 20% of the alpine skiers ($P < 0.001$) suffered their injury in terrain parks (Fig. 5). Injuries in terrain parks were more serious (more fractures, back injuries, and ambulance transports) than those occurring at other locations (Table 1), and the prevalence of back injuries increased from 6 to 12% for snowboarders ($P < 0.001$) and from 5 to 8% for alpine skiers ($P < 0.001$) in the period (Table 2). Injuries suffered off pist and in ski lifts have been stable during the registration period and accounted for about 10%, respectively 5% of all injuries (Fig. 5).

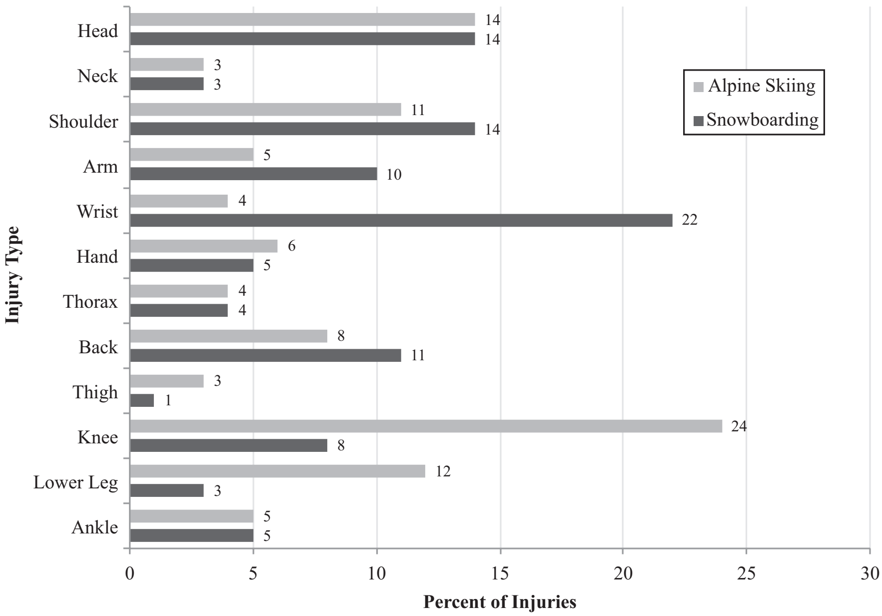

Fig. 3 Type of injuries in alpine skiing and snowboarding the season 2010/2012. *n* = number of injured alpine skiers and snowboarders

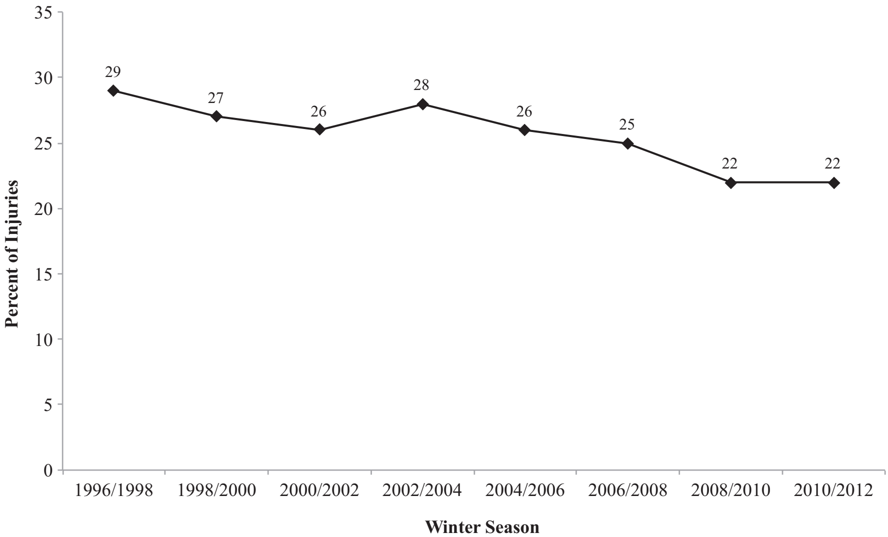

Fig. 4 Prevalence of wrist injuries in snowboarders the seasons 1996/1998–2010/2012. *n* = number of injured snowboarders

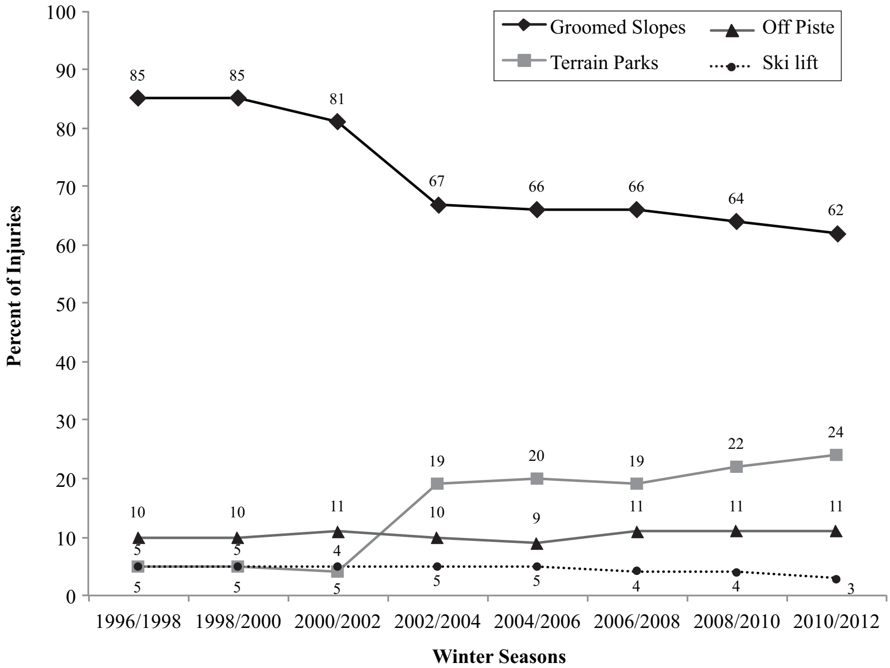

Fig. 5 Site of injury for injured skiers/boarders the seasons 1996/1997–2010/2012. *n* = number of injured skiers/boarders

Table 1 Serious injuries in terrain parks and other slopes the seasons 2010/2012

Injury type	Terrain parks $n = 1803$ (%)	Other slopes $n = 5758$ (%)	Significant differences
Fractures	30	6	$P < 0.001$
Back injuries	18	8	$P < 0.001$
Ambulance transport	30	25	$P < 0.001$

n = number of injuries

Table 2 Back injuries among alpine skiers and snowboarders in the seasons 1996/1998 and 2010/2012

Skiing/ snowboarding seasons	1996/1998 $n = 2221/1319$ (%)	2010/2012 $n = 5792/2354$ (%)	Significant differences
Alpine skiers	5.1	7.8	$P < 0.001$
Snowboarders	5.8	11.5	$P < 0.001$

n = number of injuries among alpine skiers/snowboarders

3.2 Skier-Related Factors

Age—Twenty percent of the injured skiers/boarders were children <13 years, 38% adolescents 13–19 years and 42% adults >19 years. The prevalence of lower leg fracture was related to age and dropped from 20 to 13% for alpine skiers <13 years during the observation period ($P < 0.001$), but remained almost unchanged and about 4% for teenagers and adult skiers (Fig. 6).

Gender—Forty percent of the injured skiers/boarders were females and 60% males. Knee injuries were related to gender, and the prevalence was twice as high for females as for males throughout the period (Fig. 7), whereas the reverse was observed for shoulder injuries (Fig. 8).

Skiing/boarding ability—The skiing/boarding ability increased significantly ($P < 0.001$) during the 12-year period 2000–2012 (Table 3), and the ability for snowboarders increased in the period 1996–2012 ($P < 0.001$). (Table 4). In the 2010/2012 seasons, alpine skiers <13 years suffering lower leg fracture had a significant lower skiing ability than alpine skiers in the same age group suffering other injuries ($P < 0.001$) (Table 5). The ability of the latter increased significantly ($P < 0.001$) from the 1996/1998 to the 2010/2012 seasons (Table 5).

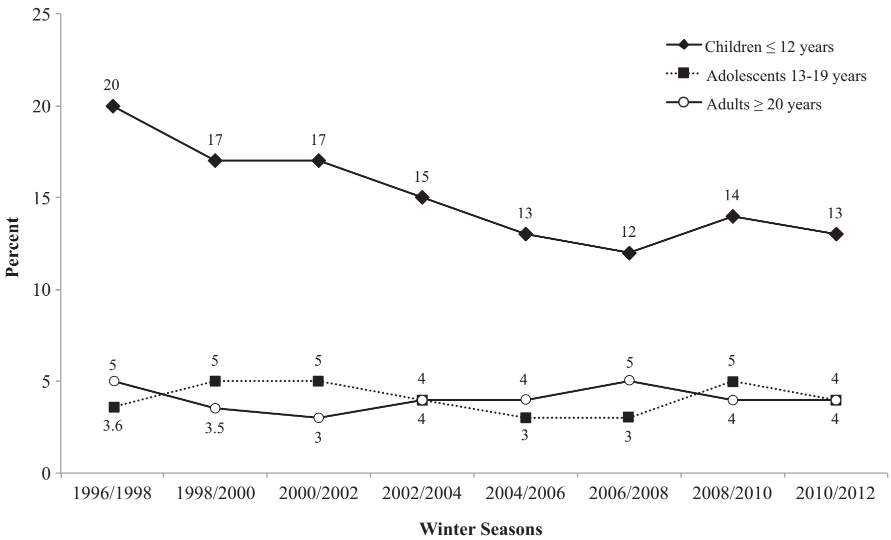

Fig. 6 Prevalence of lower leg fractures in injured alpine skiers during the seasons 1996/1998–2010/2012 recorded for children, adolescents, and adults. n = number of skiers with lower leg fracture

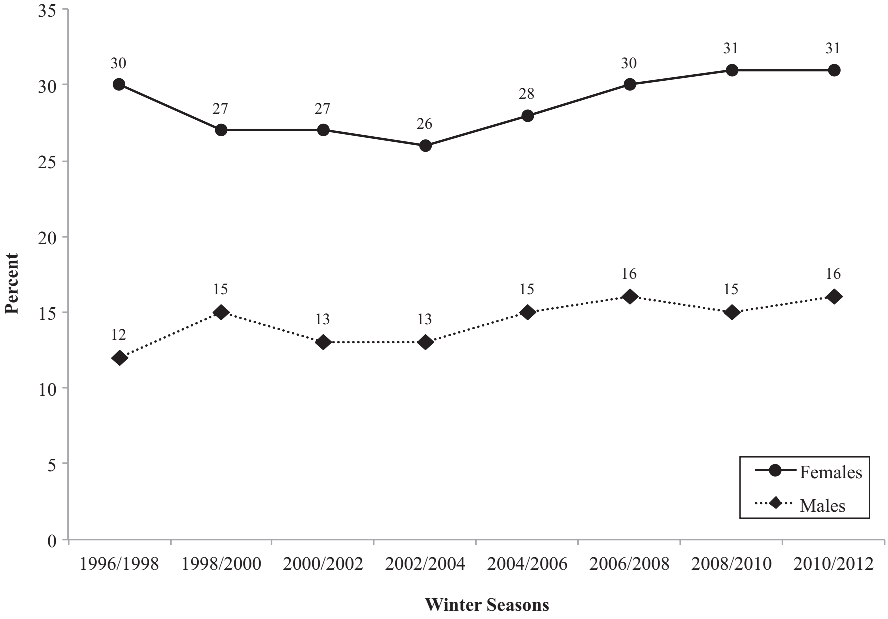

Fig. 7 Prevalence of knee injuries in injured female and male skiers/boarders during the season 1996/1998–2010/2012. *n* = number of skiers/boarders with knee injury

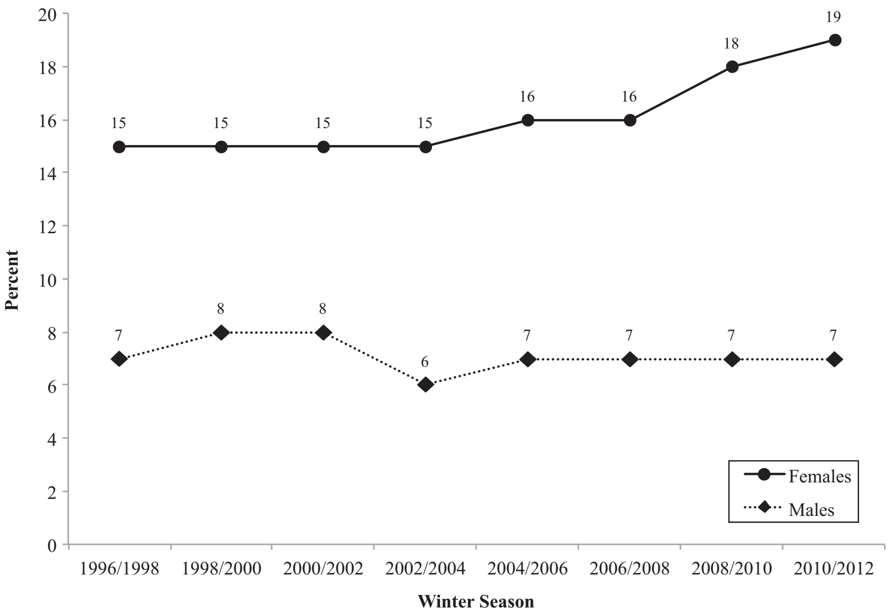

Fig. 8 Prevalence of shoulder injuries in injured female and male skiers/boarders during the seasons 1996/1998–2010/2012. *n* = number of skiers/boarders with shoulder injury

Table 3 Skiing/boarding ability in the seasons 2000/2002 and 2010/2012

Skiing ability	2000/2002 season* $n = 6138$ (%)	2010/2012 season* $n = 7695$ (%)
Expert	14	16
Advanced	28	32
Intermediate	31	31
Beginner	27	20

n = number of injured skiers/boarders
*Significant higher ability for injured skiers/boarders in the 2010/2012 season compared to the 2000/2012 season ($P < 0.001$)

Table 4 Snowboarding ability for injured snowboarders in the seasons 1996/1998 and 2010/2012

Skiing ability	1996/1998 seasons* $n = 1224$ (%)	2010/2012 seasons* $n = 2063$ (%)
Expert	14	16
Advanced	28	35
Intermediate	28	30
Beginner	30	20

n = number of injured alpine skiers and snowboarders
*Significant higher ability for injured snowboarders in the 2010/2012 season compared to the 1996/1998 season ($P < 0.001$)

Table 5 Skiing ability for alpine skiers <13 years with lower leg fracture the seasons 2010/2012 and injured alpine skiers <13 years with other injuries the seasons 2010/2012 and 1996/1998

Skiing ability	2010/2012 seasons: Skiers <13 years with lower leg fracture* $n = 154$ (%)	2010/2012 seasons: Skiers <13 years with other injuries*# $n = 999$ (%)	1996/1998 seasons: Skiers <13 years with other injuries# $n = 336$ (%)
Expert	2	10	2
Advanced	15	27	20
Intermediate	29	35	36
Beginner	54	28	42

n = number of injured alpine skiers
*Significant lower skiing ability in children with lower leg fracture compared to children with other skiing injuries ($P < 0.001$). #Significant higher skiing ability of alpine skiers with other injuries in the 2010/2012 compared to the 1996/1998 seasons

3.3 Equipment-Related Factors

Helmet—The use of helmet by injured skiers/boarders increased from 11 to 81% in the period, and the prevalence of head injuries dropped from 19 to 16% ($P < 0.001$) (Fig. 9). In the 2010/2012 seasons, 15.8% of the skiers/boarders wearing helmet suffered a head injury compared to 16.9% of those without helmet. More skiers/boarders

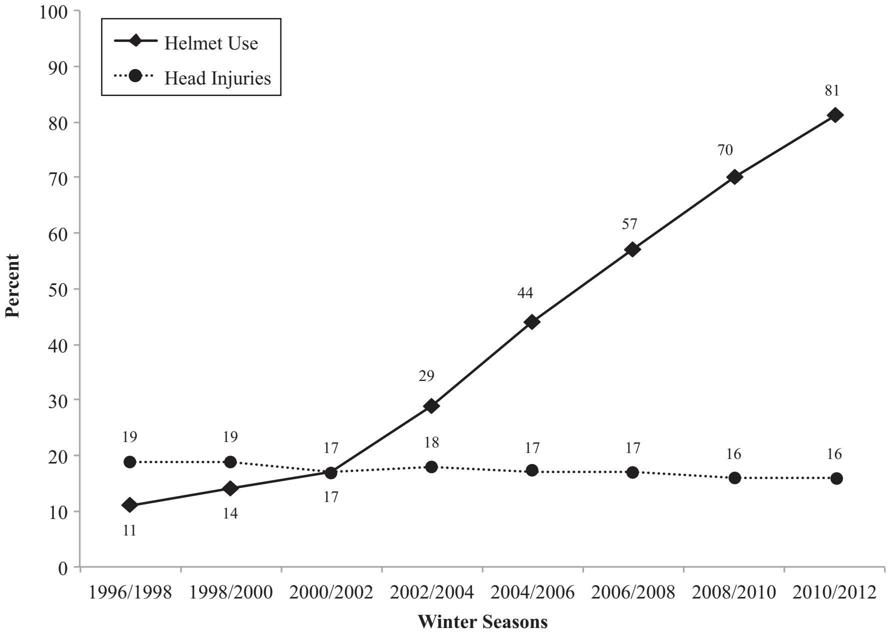

Fig. 9 Use of helmet and prevalence of head injuries in injured skiers/boarders during the seasons 1996/1998–2010/2012. *n* = number of injured skiers/boarders

Table 6 Head injury severity with and without helmet the 2010/2012 seasons

Head injury	With helmet $n = 943$ (%)	With helmet $n = 234$ (%)	Pianificant difference
Direct to hospital	5	13	$P < 0.001$
To physician	54	63	$P = 0.026$

n = number of skiers/boarders with head injury

without helmet needed transport direct to hospital or physician than those with helmet (Table 6). The prevalence of neck injury has been about 3% and similar for skiers/boarders with and without helmet throughout the study.

Wrist guard—Only 4% of injured snowboarders used wrist guards.

4 Discussion

The injury rate decreased by 14% during the period 2000–2012. The number of sold day cards was not recorded before 2000, only the number of lift transports. The injury rate is significantly related to skiing ability [8, 9, 15, 16], and the ability on the slopes increased significantly for skiers/boarders during the period (Table 3).

This may partly explain the reduced injury rate at the end of the period. Also Shealy et al. [9] report a reduction of the injury rate in a ski patrol study from 14 American ski resorts in the period 2000–2010, where the injury rate was 2.6 per skier visit in 2000 and 2.5 in 2010. Kim et al. [7] found a decrease in injury rate for alpine skiers, but not for snowboarders in the period 1988–2006 in a study from Vermont, USA. Laporte et al. [8] found an overall decrease in injury rate from 2.7 to 2.43 injuries per 1000 skier/boarder days during the period 2005–2010 in a study from 32 French ski resorts. The injury rate for alpine skiers remained stable in the period, whereas that of snowboarders declined after 2006.

Most of the injuries occurred during alpine skiing, whereas snowboarding peaked with 45% of the injuries on the slopes in the 2000/2002 seasons (Fig. 2). This is not related to differences in risk for alpine skiing and snowboarding, but to the size of the population of skiers and boarders on the slope. The popularity of alpine skiing increased after the carving skis were introduced in the late 1990, with a corresponding sales reduction of snowboards. The popularity of telemark skiing has also gradually decreased during the registration period. Skiboards were introduced in 2002 but did not gain popularity with low sales of the equipment. Also Kim et al. [7] report that snowboarders peaked with 34% of the population on the slopes in 2000/2001 and then dropped to 20% the last years of their study that ended in 2006.

Alpine skiers suffer mainly knee injuries whereas snowboarders suffer mainly wrist injuries. This is in agreement with several other reports [7, 9, 17]. The prevalence of knee injuries in alpine skiers remained almost the same during the period as also reported by Kim et al. [7] and Shealy et al. [9], but the prevalence of wrist injuries in snowboarders decreased (Fig. 4). Beginners were significantly overrepresented among snowboarders with wrist injuries [7, 8, 12]. Snowboarding ability increased significantly during the period with less beginners on the slopes (Table 4), and this may be a possible explanation for the reduced prevalence of wrist injuries at the end of the period. This finding is in accordance with that of Laporte et al. [8] from France whereas both Kim et al. [7] and Shealy et al. [9] found an increase of wrist injuries over time in the USA. The two latter studies do not report if the snowboarding ability changed in the recorded period.

The prevalence of knee injuries was twice as high in females as in males, whereas the reverse was observed for shoulder injuries. These findings were observed throughout the 16-year registration period (Figs. 7 and 8), and have also been reported by others [17–20]. This significant gender difference is observed both in alpine skiing, snowboarding, telemark skiing, and skiboarding, and in each of the four skiing/boarding ability groups: expert, advanced, intermediate, and beginner [12]. It may be due to anatomical sex differences and related to differences in strength and elasticity of ligament and muscles, but so far we have no convincing explanation for these observations.

The prevalence of lower leg fracture in alpine skiers was significantly higher for children than for older skiers (Fig. 6), as reported previously [21, 22]. The risk for lower leg fracture in alpine skiers decreased significantly in the 1970 and 1980, probably due to better boots and release bindings, and better binding setting and adjustment in the ski shops, levelling out to a lower plateau from the 1990 [6]. This has not been observed to the same degree in children where the prevalence of lower leg fracture decreased from 20% in the 1996/1998 seasons reaching a plateau of 12–13% from the 2006/2008 seasons. Alpine skiers <13 years with lower leg fracture have a significant lower skiing ability than skiers <13 years with other injuries, and the skiing ability of the latter increased significantly during the registration period (Table 5). This may partly explain the reduction of lower leg fracture for children in the period, together with better boots and bindings with correct adjustment and setting, and less use of second-hand equipment [23]. Also Greenwald and Laporte [22] have reported beginners to be overrepresented among skiers with lower leg fracture.

Use of a protective helmet increased from 11 to 81% in the period, but the prevalence of head injury only dropped from 19 to 16% (Fig. 9). Helmet offers protection against head injuries [24–26], but the reduction of the head injury prevalence of three percentage points or 16% after an increase of helmet use of 60 percentage points or more than seven times is less than expected and in agreement with the findings of Sulheim et al. [27]. But the injuries suffered by skiers/boarders without helmet were probably more serious as more of them required transport direct to hospital or physician than those suffered by skiers/boarders with helmet (Table 6). Skiers/boarders with helmet suffering head injuries had a higher ability than all injured skiers/boarders with helmet [12]. This may indicate that they ski faster on the slope and may have a sensation seeking behavior [25, 28]. The prevalence of neck injuries has been similar for skiers/boarders with and without helmet throughout the study. Thus, the use of helmet does not increase the risk for neck injuries, as also reported by Cusimano and Kwok [26].

Most of the injuries occurred on groomed slopes, where most of the skiing/boarding population was located. Terrain parks started to appear in the ski resorts around 2000, and since then an increasing share of the injuries occur in terrain parks (Fig. 5). More fractures and back injuries occurred in terrain parks than in other slopes and more injuries from the parks required ambulance transport (Table 1), suggesting the injuries in terrain parks to be more serious. It is difficult to record the injury rate in terrain parks. Laporte et al. [8] reported an increased rate compared to the overall injury rate, whereas Shealy et al. [9] found no evidence for an increased injury rate in terrain parks.

The strength of this study is the high number of injuries recorded in the largest Norwegian ski resorts by the same method during 16 successive ski seasons. The limitation is the lack of a control material of uninjured skiers/boarders from the same period. In the 2001/2002 season, we were able to collect a representative control material enabling us to perform a case-control study with calculation of injury rates and injury risk for different groups of skiers/boarders [5, 16]. Another limitation is that the diagnoses have been made by ski patrols, and some conditions like fractures may have been over diagnosed. The prevalence of the different injuries has, however been quite consistent during the 16-year period. We therefore think that any weakness of diagnostic accuracy by the ski patrols may partly be compensated by the high number of injured skiers/boarders in the material. The ski patrol may also pick up some minor injuries not needing medical attention.

5 Conclusion

The injury rate on Norwegian slopes dropped 14% during the period 2000–2012, possibly due to an increase of the skiing/boarding ability. The prevalence of wrist injuries in snowboarders was also reduced, whereas the boarding ability increased. The prevalence of back injuries in snowboarders increased by 100% from 1996 to 2012, and this may be related to one-third of the injuries occurred in terrain parks at the end of the period. The prevalence of knee injuries was twice as high in females compared to males, whereas the reverse was observed for shoulder injuries throughout the period. The prevalence of lower leg fracture in children dropped by 35% at the end of the period, whereas the skiing ability of children with other injuries increased. The use of helmet increased more than seven times among injured skiers/boarders to 81%, and the prevalence of head injuries dropped with 16% at the end of the 16-year period.

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New Zealand Snow Sports Injury Trends Over Five Winter Seasons 2010–2014

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Abstract Ski patrol national incident data were analysed in New Zealand for alpine skiing and snowboarding injuries from 4 June 2010 to 9 November 2014. Over five winter seasons, there were 5,861,643 visitations and 18,382 incidents. The injury rate per 1000 skier/boarder days was relatively constant (3.2, 3.3, 3.4, 2.7, and 3.1, respectively). Falls accounted for the injury mechanism in 74.3% of all injuries. Four died after catastrophic falls (two skiing, two snowboarding). Overall, more knee injuries occurred skiing in soft snow conditions than hard (55 vs. 45%). Advanced skiers were 2.2 times more likely to sustain a knee injury with non-release of the ski-binding in hard snow surface conditions than when the ski-binding released. Despite increased helmet usage (42–83%), there was a very likely increase in concussion (1.29, 99% CI 1.06–1.57). Hard snow conditions increased wrist injuries for both intermediate and novice snowboarders (30 and 12%, respectively). Wrist protection was most likely to be beneficial in preventing wrist injuries (hazard ratio 0.65, 99% CI O.54–0.79). Good visibility compared to poor visibility led to a twofold increase in injuries. Increased slope congestion, changes in direction to avoid collision with others and speed were possible contributing factors. Collisions accounted for 9.6% of all injuries. Going forward New Zealand injury prevention initiatives need to be multifaceted. Recreational skiers need to ski on torque-tested equipment with release settings that are a match for current physical parameters, style, and the ability to ski in different snow surface conditions. Further research is

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I.S. Scher et al. (eds.), *Snow Sports Trauma and Safety*,
DOI 10.1007/978-3-319-52755-0_2

needed to determine whether wearing a helmet increases reckless behaviour in some age groups. An international standard for snow sports wrist protectors with proven dimensions is also needed before ski areas can make any further investment in wrist protectors.

Keywords Skiing • Snowboarding • Injury • Mechanisms • Trends

1 Introduction

Injury surveillance is a requisite for understanding the injury problem in alpine skiing and snowboarding [1]. Historically, ski areas have monitored incidents in-house and Ski Areas Association New Zealand (SAANZ) has determined collaborative injury prevention endeavour with the support of technical reports. In 2005, all ski areas moved from recording injury incidents on a SAANZ paper-based incident reporting form to a computerised incident reporting system managed on behalf of SAANZ by the New Zealand Mountain Safety Council. Electronic incident data collection made it possible to undertake this first longitudinal skiing and snowboarding injury study. The findings from this study will provide SAANZ with more comprehensive evidence to determine, where injury prevention energy and resources should be focussed.

2 Objectives

Describe the injury rates and trends in snow sports in New Zealand over five winters to inform the development of a national injury prevention strategy.

3 Methods

The Auckland University of Technology ethics committee approved the study—reference 14/146. Ski patrollers, nurses, doctors, and radiographers completed incident reporting forms for all injuries at all commercial ski areas throughout New Zealand. Anonymised data were entered into the electronic database each week of each winter season over 5 years. The NZ Mountain Safety Council maintained the National Incident Database (NID). SAANZ provided ticket sale records and season pass use for each ski area. Demographic data from SAANZ national consumer satisfaction surveys (2007–2009) were supplied in excel. Bare-head and helmet wear counts were undertaken at chairlifts at two major ski areas in 2010 and 2015. Retrospective analyses were performed with the Statistical Analysis System (SAS). Uncertainties in the true values of the outcomes were assessed using magnitude-based inferences. For precision, 99% confidence intervals were computed in SAS. Six approaches were taken in the analyses. Trends in annual incidence rates per 1000 skier/boarder days were determined by summing the injuries at each ski area for each year, then modelling the count in each year with Poisson regression using ticket sales and estimated season pass use. The proportions of skiers, snowboarders, females, and males were determined in excel using SAANZ customer surveys (25,910).

The effect of snow conditions and visibility on predicting injury types was analysed by limiting the data to the six major ski areas that had 82% of the skier/boarder days. As there were always injuries on any day that the ski area was open this strategy avoided the bias that would arise from a given snow or sky condition reducing the injury rate such that no injuries occurred on some days. Hard snow or icy conditions existed when a ski patroller in ski boots could not make an impression in the snowpack. The soft or spring conditions description was used on days when the surface easily permitted leaving a ski-boot impression in the snow. Cloud cover provided effect of visibility data on injury incidence. Clear skies or scattered cloud cover determined good visibility. Poor visibility was determined by overcast conditions with full cloud cover leading to flat light or white out conditions with snow falling, mist, or rain.

Logistical regression was used to analyse the effect of snow condition, visibility, skiing or snowboarding activity, and the ability on the proportions of a given type of injury (e.g. head) and type of incident (e.g. falls, jumps, collisions). Deaths were counted. Injured skiers' self-reported when the ski-binding released during the incident or did not release. Skier accounts of the ski-binding pre-releasing in normal skiing manoeuvres were also included in the three level analysis of the effect of binding release. Probabilistic terms were used to describe the true value of changes in the mechanism (type of incident) over the 5-year period. Where the true value could be substantial in both a positive and negative sense, the result was unclear; otherwise, results were clear and the inference was described as likely trivial, possibly trivial, trivial, likely or a very likely increase or decrease [2].

The effect of helmet use on head injuries (cases) was determined by using other injuries as controls; a method previously applied in an investigation on the relation of head, face, and neck injury in skiers wearing helmets [3, 4]. A hazard ratio was obtained using a Poisson regression model of those that were head injured (using helmets)/(those not using helmets) divided by those that were non-head injured (using helmets)/(those not using helmets). The effect of wrist protection was examined in the same manner.

4 Results

Over five winters 5,861,643 people were active in snow sports at New Zealand ski areas and 18,382 incidents were registered. New Zealand injury trends per 1000 skier/boarder days were 3.2, 3.3, 3.4, 2.7, and 3.1, respectively (2010–2014). There was most likely a trivial decline in injuries over this period (−3%, 99% confidence interval − 9 to 3%). The proportions of people active in each sport were determined from 25,911 SAANZ surveys: 61% skiers, 32.4% snowboarders, and 6.6% both ski and snowboard. No data was collected on the number of people tubing at ski areas.

Knee injuries were the most common injury overall (see Fig. 1). Over two-thirds of knee injuries occurred in skiers when compared with snowboarders and others (tubing/hiking) (76, 21, and 3%, respectively). There was no significant difference in the frequency of back injury between skier and snowboarders; 36% occurred in the cervical/thoracic region; and 64% in the lumbar/sacral region. Wrist injuries were more common in snowboarders (80%). Snowboarders accounted for 52% of the head injuries, skiing 43%, and 5% were attributed to other activities. Shoulder injuries occurred more often in snowboarders (61%). Clavicle injuries were also more prevalent in snowboarders (64%). Conversely, 74% of injuries to the lower leg occurred during skiing.

SAANZ customer survey data indicated that the percentage of male skiers was 53%, female skiers 47% compared to 61% male and 39% female snowboarders. Female skiers injured the knee more frequently than male skiers (65% vs. 35%). Non-release of the ski-binding resulted in knee injury in skiers more often than release (see Table 1). More knee injuries occurred in soft snow conditions than hard (55% vs. 45%). The rates of knee injuries either in non-release or release were highest in intermediate skiers (45%), followed by novices (30%) then advanced skiers (25%).

In 2010, 42% of skiers and snowboarders wore helmets; this increased to 83% in 2015 (skiers 84% and snowboarders 79%). Concussion very likely increased over the 5 years (1.29, 99% CI 1.06–1.57). By age, 24–32 years olds were less likely to be wearing a helmet when head injured (see Fig. 2). The mean ages for each quartile were 12 years. (SD 3), 20 years. (SD 2), 27 years. (SD 2), and 47 years. (SD 10).

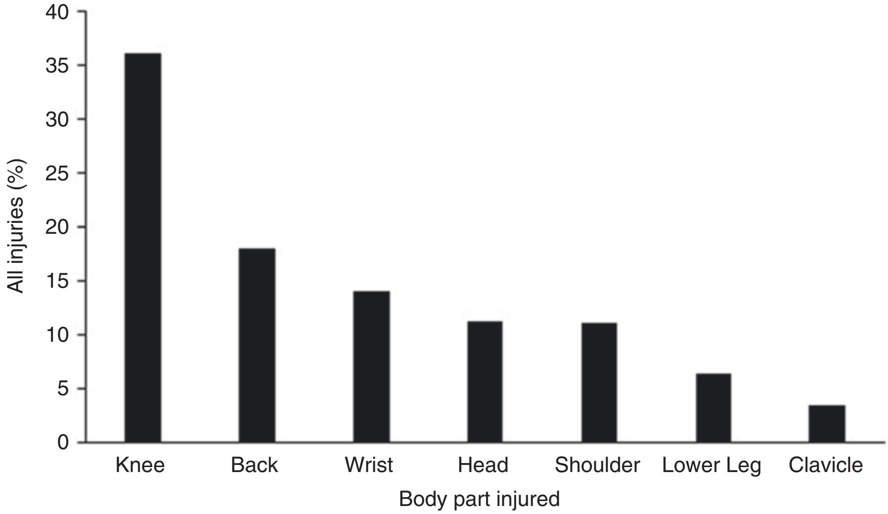

Fig. 1 Body part injured in all snow sports

Table 1 Equipment effects on knee injuries by snow surface condition and skier ability

	Non-release	Release	Difference (non-release/release)	
			Effect; 99% CI	Inference
Advanced Skier				
Soft snow	30.7% (*n* = 430)	21.2% (*n* = 420)	1.5; 1.2–1.7	↑***
Hard snow	27.7% (*n* = 415)	12.9% (*n* = 364)	2.2; 1.7–2.7	↑****
Intermediate Skier				
Soft snow	44.9% (*n* = 847)	29% (*n* = 734)	1.6; 1.4–1.7	↑****
Hard snow	37.2% (*n* = 675)	23.1% (*n* = 606)	1.6; 1.4–1.8	↑****
Novice Skier				
Soft snow	46.8% (*n* = 662)	38.2% (*n* = 448)	1.2; 1.1–1.36	↑**
Hard snow	36.4% (*n* = 495)	33.3% (*n* = 315)	1.1; 0.9–1.3	↑*

Key Asterisks indicate effects clear at the 99% level and likelihood that the true effect is substantial, as follows: *possible, **likely, ***very likely, ****most likely

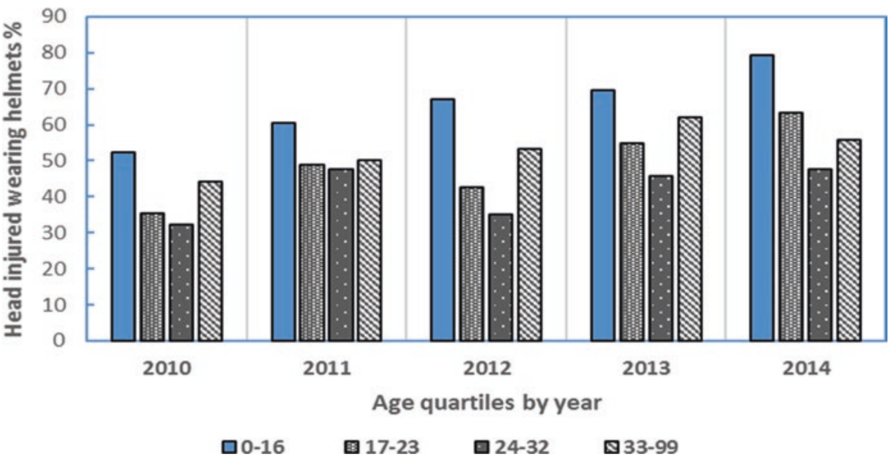

Fig. 2 Head injured wearing a helmet by age group and year

Head injury was higher in advanced and intermediate skiers wearing helmets than novices; 23, 25, and 10%, respectively. For helmet-wearing snowboarders, head injury increased in advanced, intermediate, and novice snowboarders by 41, 29, and 30%, respectively (when compared with those not wearing a helmet). Overall, there was a 26% increased risk of head injury in skiers wearing helmets (hazard ratio 1.26, 99% CI 1.05–1.52) and a 36% increase in head injury in snowboarders wearing helmets (hazard ratio 1.36, 1.05–1.52).

There was a very likely increase in wrist injuries in intermediate snowboarders in hard snow when compared with soft snow conditions (hazard ratio 1.3, 99% CI 1.17–1.45). Novice snowboarders had a possible increase in the likelihood of wrist injury in hard snow conditions (hazard ratio 1.12, 99% CI 1.02–1.21). Regardless of whether snowboarders were in a terrain park or in open mountain terrain, wrist protection was most likely beneficial in preventing wrist injuries (hazard ratio 0.65, 99% CI O.54–0.79).

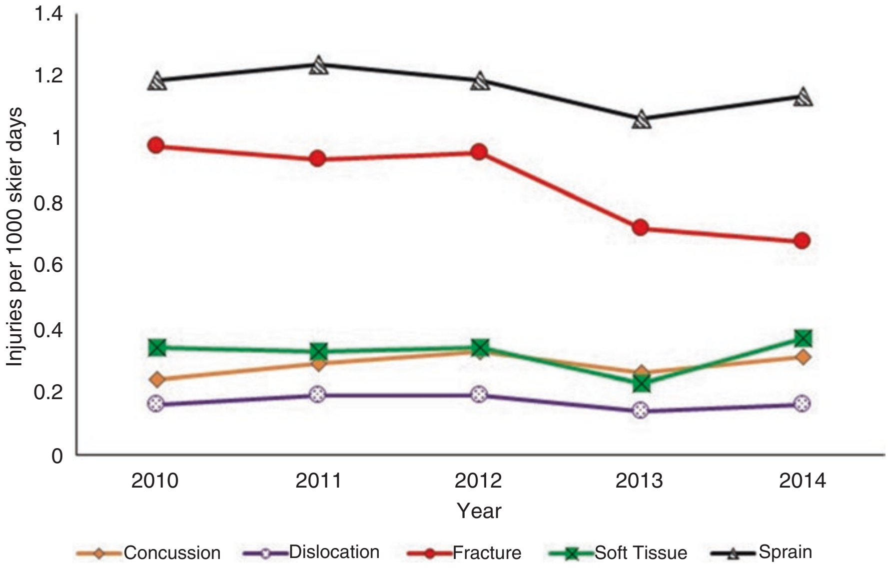

Fig. 3 Types of injury in skiing and snowboarding

The combined skiing and snowboarding results for types of injury are detailed in Fig. 3. Fractures declined by 0.3 per 1000 skier/boarder days. There was no decline in the incidence of concussion, dislocation, soft tissue injuries, or sprains.

Falls accounted for 74.3% of incident types with no difference between skiers and snowboarders; collisions 9.6%—snowboarders were more commonly injured in collisions than skiers 34 vs. 58% (8% tubing or other activity). In 2010, two skiers and one snowboarder died, two of three were not wearing helmets. In 2013, another snowboarder died attempting to retrieve a snowboard. All four deaths involved catastrophic sliding falls in hard snow resulting in severe injuries that included the head.

The proportion of injuries attributed to jumps were 7.3%; man-made terrain features 5.3%; lift accidents 2%; and sliding whilst tubing or other incident types accounted for the remaining 1.5%. When considering mechanisms of injury using counts of injury types in each year there was a likely decrease in jump-related injuries (0.83, 99% CI 0.69–0.99), likely trivial decrease in falls (0.94, 99% CI 0.88–1.00) and the inference for collisions was unclear (1.00, 99% CI 0.83–1.22).

In terms of sky cover, there was 2.5 times more likelihood of injury in good visibility conditions (hazard ratio 2.5, 99% CI 1.97–3.19). In good visibility, advanced skiers most likely increased injuries to the lower leg when the snow was soft vs. hard (hazard ratio 2.06, CI 99% 1.55–2.7) and a likely increased probability of knee injury in soft snow vs. hard (hazard ratio 1.28, 99% CI 1.11–1.48). In poor visibility, the probability that advanced skiers injured the lower leg in soft snow vs. hard snow was a likely increase (hazard ratio 1.63, CI 99% 0.94–2.71). Soft snow conditions led to a very likely increase that advanced skiers sustained knee injuries (hazard ratio 1.59, 99% CI 1.16–2.11). Intermediate skiers in good visibility had a very likely increase in lower leg injury (hazard ratio 1.34, CI 99% 1.12–1.60); however, in poor visibility and soft snow the results were unclear (hazard ratio 1.02, CI 99% 0.73–1.40). For the knee, there was a very likely increase of injury in intermediate skiers when the visibility was good and the snow was soft (hazard ratio 1.27, CI 99% 1.16–1.39). In poor visibility, intermediate skiers had a most likely increase of injury (hazard ratio 1.63, 99% CI 1.38–1.89). Novice skiers had similar findings to intermediate skiers when the visibility was poor.

5 Discussion

New Zealand injury trends per 1000 skier/boarder days were higher than the 2.5 per 1000 skier/boarder days in the US National Ski Areas Association (NSAA) 10-year interval study (3.2, 3.3, 3.4, 2.7, and 3.1, respectively) [5]. An overall target of less than 2.5 injuries per 1000 skier/boarder days in New Zealand (SAANZ national incident data) is clearly desirable. There was no known reason for the decline of injuries in the 2013 season; this decline was not sustained. The influence of the snow-pack on injury incidence will need to be considered and accounted for in future statistical analysis so that the effectiveness of injury prevention interventions can be separated from natural events. More skiers than snowboarders were active on the slopes. The SAANZ customer satisfaction survey data (2007–2009) indicated that there were slightly more male skiers than females and that snowboarding was dominated by males. The lack of 2010–2014 demographic data is a potential limitation; however, major changes in the make-up of the snow sports population are unlikely.

Nearly one-third of NZ adult skier injuries involved the knee, with female skiers at greater risk of knee injury than males. These findings align with earlier studies [5–8]. Since the introduction of the carving ski in 1993, female skiers have dominated knee injury trends. For females, the risk of knee sprain was two to three times higher in females, and there was an even greater risk of anterior cruciate ligament rupture. Ski-binding release settings that were too tight were associated with knee and lower leg injury in all skiers [9, 10]. One solution found to reduce knee and lower leg injuries was regular equipment torque testing and set-up checks [11]. To determine that ski-binding-boot systems are not too tight and that the ski equipment is working effectively, the snow sports industry in New Zealand need to invest in torque-testing equipment [12–16]. The analogy of an annual motor vehicle warrant of fitness could be used to encourage skiers to have ski equipment regularly torque tested and tuned.

Presently, there are no recommendations from standard organisations to account for snow surface conditions when setting up the ski-binding-boot system. Given the increased probability of injury to the lower leg and knee in soft snow, adjusted lower settings that promulgate release when skiing in soft snow surface conditions seem logical. The release results in this study add further weight to the need for vigilance during ski-binding set-up. Changes in weight, growth, and skiing style need to be factored into pre-season release setting calculations. Advanced skiers may no longer have the fitness level or the desire to ski at speed aggressively on steep pitch in all snow conditions and as such these changes in skiing style warrant lower ski-binding release settings. Further public education on safe ski-binding set-up is needed. Researchers working with ski equipment manufacturers also need to continue the quest for solutions that will protect the knee whatever the direction of the injurious force [17, 18].

Skiers and snowboarders had similar rates of back injury, with nearly two-thirds of these involving the lumbar/sacral region. An earlier New Zealand study in the Southern Lakes region (1991–2002) found a higher proportion of skiers had burst/compression fractures when compared with snowboarders. The most frequently fractured vertebrae were found at the thoracic-lumbar junction at the posterior base of the rib cage [19, 20]. The change in the injury pattern to the lumbar/sacral region is possibly due to the advent of twin tip skis and snowboards leading to more aerial manoeuvres. The Swiss found that the majority of severe spinal injuries ($n = 63$) admitted to a tertiary trauma centre were related to skiing, with over half of all spinal injuries sustaining injury at two or more levels [21]. Injury prevention interventions to decrease back injuries will need to consider the changes that have occurred in the way people ski and snowboard.

Helmets have been proven to dampen forces and protect the head from injury when skiing or snowboarding with no increased risk of neck injury [4, 22–26]. Helmets are designed to limit linear acceleration to no more than 300 g following a 2.0 m drop onto a steel surface (translating to 27.7 km/h). Helmets have been proven to reduce head abrasions, lacerations, and mild concussion [4]. The increase in concussion rates raises concern that those wearing helmets are overestimating the protective capacity of the helmet and are taking greater risks with speed and/or jump-height than those not wearing a helmet. More research is needed on risk-taking behaviours [27, 28].

Death was attributed in-part or in-full to traumatic brain injury in the four tragedies at New Zealand ski areas. After the 2011 inquests for three of these deaths the Coroner recommended that ski areas actively promote the use of helmets when skiing or snowboarding (mandatory use was not included in the court summations). Helmet wear has been promoted in the SAANZ snow sports injury prevention strategy and the new snow safety code [29]. Further work is warranted on trends in head injury severity using Glasgow coma scale scoring (these head injury observations are entered in the patient report section of the SAANZ incident reporting form but not entered in the NID). To continue to improve the design of snow sports helmets further understanding of the torsional and coup–contrecoup forces that brain tissues are exposed to are also needed [30].

Other countries have found similarly high rates of wrist fractures in snowboarding as were reported in this study. Some researchers detailed up to a tenfold increase when compared snowboarding to skiing, with most wrist fractures occurring within the first 7 days of learning to snowboard [31–34]. We found that there was a very likely increase in wrist injuries in snowboarders that were intermediate and a possible increase in novices in hard snow conditions. More education on safe techniques for riding in hard snow conditions is needed for intermediate and novice snowboarders. Development of a national snowboarder education programme has been promoted in the strategy to counter fall mechanisms that result in wrist fractures [31]. Wrist protection was clearly found to be beneficial in preventing wrist injuries. Presently, there is no international standard for snow sports wrist protectors. In New Zealand, some of the wrist protectors are potentially too short, finishing proximal to the wrist joint. Short wrist guards have the potential to transfer the force to forearm and cause breaks [35]. Further investment and promotion of wrist protection will occur in New Zealand when the international standard for snow sports wrist protectors has been agreed on [34].

Snow surface condition and visibility information informs ski area decisions on whether to open all runs. When runs are open regular updates on snow surface conditions matched to the ability are needed so that trail choices are a better match for the skier or snowboarder, particularly the novice and intermediate. When mountain weather conditions are changeable good vision is needed for hazard identification. The visual deficiencies created by foggy goggles, inappropriate lens colour, or no optical correction may account for injury on poor visibility days. Decreased visual acuity has been found to delay reaction-times and the ability to take evasive action [36–38]. Regular eye testing and wearing prescription eyewear whilst skiing or snowboarding has been included in the strategy. GPS mapping that pinpoints where incidents are occurring aligned with snow surface conditions and visibility information could also provide opportunities to mitigate injury. An increased provision of equipment-related information to at-risk groups such as check your set-up, sharpen edges for hard snow conditions, and choose the correct wax to help glide and reduce friction would also be of value [39].

6 Conclusion

Injury trends in snow sports in New Zealand indicate that there was no significant decline over five winters. Future injury prevention priorities need to be based on injury surveillance. Going forward, strategies will be needed to counter, “the higher or faster you go, the harder you fall” phenomena. The high proportion of advanced skiers and intermediate skiers with knee injuries that occurred with non-release in both hard snow and soft snow conditions raises concern that ski-binding release settings were too high. To help mitigate equipment-related injury risk skier education on correct set-up is needed alongside industry adoption of international equipment torque testing and practice standards. Knee injuries that occur skiing also beseech an equipment design solution. Using helmets unfortunately was not a panacea for decreasing the number of head injuries but likely reduced the gravity. Further research is needed on head injury to understand why those that are wearing helmets are suffering more head injuries than those that are not protected by a helmet. Risk compensation was one possible explanation. The ability to avoid hazards in poor visibility could potentially be enhanced by improving technique, regular eye testing, and for those that need it, wearing prescription eyewear on the snow. Wrist protectors were clearly of benefit in reducing wrist fractures in snowboarders. The release of the international snow sports wrist protector standard is eagerly awaited so that wrist protectors with the proven correct dimensions can be promoted. The four deaths that occurred were a sobering reminder that injury prevention efforts cannot diminish. No deaths would be a more than reasonable goal; however, due to human fallibility and the unpredictable challenges faced in mountain terrain this may never reach zero. The development of snowboard brakes could reduce risk of injury during retrieval of a runaway snowboard. Furthermore, when ski area staff open terrain for the public, full account needs to be taken of hard snow surface conditions that increase the risk of sliding falls.

7 Limitations

The SAANZ national customer satisfaction survey programme was discontinued in 2010. SAANZ reports for 2010–2014 estimated that these demographics were unchanged; however, there was no data provided to support this assumption. Changes in the make-up of the active snow sports population may have occurred over the years of this study. These surveys may also have had interviewer bias, with one group being interviewed more than another group. There was also no data on the number of people that declined to be interviewed. To effectively target at-risk groups, demographic data (skier, snowboarder, female, or male) needs to be routinely collected at ski areas on each day of operation and included in future analysis of National Incident Data.

Head injury and bare-head count data were only provided by two major ski areas. Counts are needed at all ski areas to more accurately determine the effect of increased helmet use.

Acknowledgements Heads of safety services, ski patrollers, and mountain clinic staff are gratefully acknowledged for their roles in collecting data. The executive of Ski Areas Association New Zealand and the New Zealand Mountain Safety Council are also acknowledged for providing central co-ordination and encouragement over the years of this study.

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Skiing and Snowboarding in Switzerland: Trends in Injury and Fatality Rates Over Time

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Abstract Introduction: Skiing and snowboarding are two of the most popular sports in Switzerland, but their popularity means that the absolute number of injuries remains high. To plan and evaluate effective injury prevention, detailed insights into the injuries that occur are needed. Objective: The aim of this study was to characterize the current status (average winter season 2008–2012) and trends in injury rate (between 2005 and 2012) and fatality rate (between 2000 and 2014) among skiers and snowboarders in Switzerland. Materials/Methods: Injury data from different sources were collected and analyzed. Extrapolation and estimates were made based on a special household survey and insurance data. All fatal injuries were recorded in a separate database. Moreover, an annual survey on Swiss slopes was conducted that delivered different information about skiers and snowboarders in these areas. Skier days were collected by the Swiss Cableways. Results: The rate of sustaining an injury while skiing or snowboarding on Swiss slopes was 2.8 per 1000 skier days on average from 2008 to 2010. The fatality rate was 0.7 deaths per one million skier days in the same period of time. The injury rate remained relatively stable between 2005 and 2012, and the fatality rate has not changed since 2000. Discussion: Compared with other countries, the rates of injury or even fatality while skiing or snowboarding falls in the mid-range for Switzerland; however, further prevention efforts targeting behavior and conditions are needed to minimize and even reduce injuries.

Keywords Skiing • Snowboarding • Injury rate • Epidemiology

1 Introduction

Skiing and snowboarding are two of the most popular sports in Switzerland. Each year, some 2.5 million Swiss residents take to the slopes at least occasionally on skis and another 370,000 on snowboards [1]. Moreover, ski tourism in Switzerland attracts many visitors from other countries. Around a quarter of skiers and

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I.S. Scher et al. (eds.), *Snow Sports Trauma and Safety*,
DOI 10.1007/978-3-319-52755-0_3

snowboarders on Swiss slopes are from outside of Switzerland [1]. In 2013, 35% of Swiss adults (15–74 years) and 53% of Swiss children (10–14 years) skied [2, 3] and the proportion of active skiers in the Swiss population rose between 2007 and 2013 by 9 (adults, 15–74 years) and 12 (children, 10–14 years) percentage points. The proportion of active snowboarders however, has remained more stable between 2007 and 2013 (adult change: 0 percentage points, children: + 1 percentage point) and in 2013, 5% of Swiss adults and 13% of Swiss children were snowboarding at least occasionally. No change has been observed between 2007 and 2013 for the days per year or time per day skiers and snowboarders spend on the slopes. Nevertheless, skier days, which are a good measure of the skiers and snowboarders using a resort, have declined slightly in Swiss ski resorts in recent years [4, 5] (Fig. 1). One skier day is generated when one person visits a ski area for the purpose of skiing, snowboarding, or other downhill activity, regardless of the visit duration. The popularity of snow sports in Switzerland means that absolute numbers of injuries remains high. From a 5-year average for 2008–2012, estimated 51,000 skiers and 15,000 snowboarders who reside in Switzerland sustained injuries serious enough to require medical attention [6] (Table 1). However, to identify the full extent of injuries on Swiss slopes, the injuries of visitors from other countries must be taken into account as well. Moreover, injury rate needs to be calculated to track

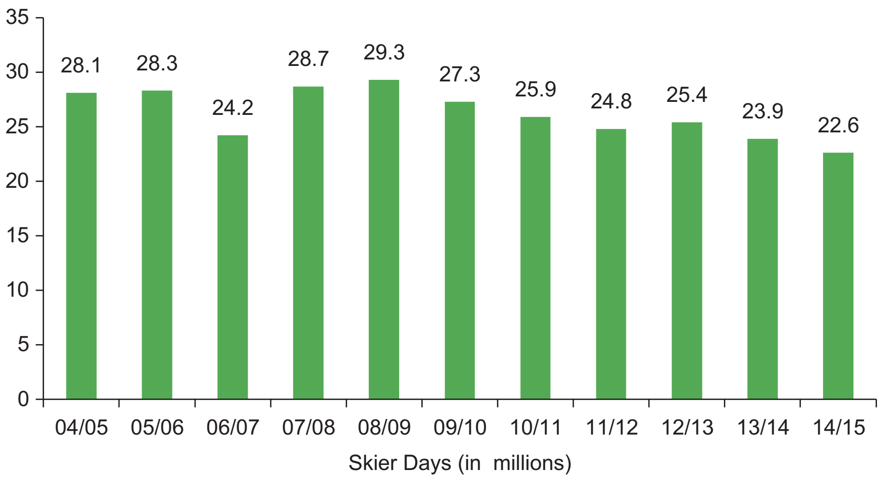

Fig. 1 Trend for skier days in Swiss ski resorts registered by Swiss aerial cableways (SBS), winter season 2004/05–2014/15

Table 1 Absolute numbers of injured skiers and snowboarders (all Swiss residents) on slopes in Switzerland and other countries per year in 2005–2012 and Ø 2008–2012

Sport	2005	2006	2007	2008	2009	2010	2011	2012	Ø 2008–2012
Skiing	48,030	49,650	45,090	52,550	52,960	50,460	47,490	50,600	50,812
Snowboarding	15,160	14,980	15,060	15,060	15,550	13,920	14,450	14,070	14,610
Total	63,190	64,630	60,150	67,610	68,510	64,380	61,940	64,670	65,422

trends and compare it with the injury rate associated with other sports and other countries. Detailed insights into the injuries that occur are the basis for planning and evaluating effective injury prevention.

2 Objective

The aim of this study was to portray the current status (average winter season 2008–2012) and trends in injury rate (between 2005 and 2012) and fatality rate (between 2000 and 2014) among snow skiers and snowboarders in Switzerland.

3 Materials and Methods

Snow sport injuries have been recorded in Switzerland in a variety of injury databases, in some cases for as long as 30 years. However, no data covering all population groups or the whole of Switzerland are available for the sports sector, and estimates must be used. The estimated absolute number of injuries sustained by Swiss residents while skiing and snowboarding on slopes in and outside of Switzerland has served as a basis for the present calculations [6] (Table 1). Primarily, the data for the estimation were acquired in a special survey of 15,000 Swiss households using computer-assisted telephone interviews [7]. This calculation is not part of the current study and can be accessed in the corresponding report [7].

To calculate the full extent of injuries in Swiss ski resorts, several assumptions based on different data bases were required. Data from the Central Office for Statistics under the Federal Law for Accident Insurance enable determination of the proportion of injuries that Swiss residents sustain on slopes outside of Switzerland [6]. This information contains data on injuries sustained by around four million employed people (approximately 50% of the Swiss population). However, data are missing for some population groups such as children, students, senior citizens, those who are not employed, or visitors from other countries. Therefore, the database described in the following was also consulted. To evaluate personal protective equipment used in winter sports (helmet, wrist protector, back protector), a sample survey is conducted every year on different runs in 21 snow sport resorts, and demographic information like age, gender, type of sport, and country of residence is collected as well [8]. Since winter 2002/03, more than 5000 skiers and snowboarders have been randomly selected and surveyed annually. This survey allows estimation of the proportion of skiers and snowboarders as well as Swiss residents and visitors from other countries on Swiss slopes. Moreover, a full survey of all fatal sports accidents has been recorded in a separate database since 2000 [9, 10]. These data include all fatalities that have occurred during sporting activities (excluding road traffic accidents) if the victims died as a result of the injury either at the site or within 30 days of the accident. Due to the variety of variables tracked, these data give insight into skiing and snowboarding fatalities and allow for their detailed analysis.

The absolute number of injuries differs from year to year depending on different factors, e.g., snow conditions, weather, holidays, or economics. Therefore, a 5-year average of the newest data available (2008–2012) was used to show the current injury situation in Swiss ski resorts. To communicate the injury rate with winter sport and to compare it in an international context, two units of measurement were used: number of injured skiers or snowboarders per 1000 skier days (or skier visits) and mean days between injuries (MDBI), or the average of skier days between two injury events. The higher the MDBI value, the lower the rate of injury. The different steps in the calculation are shown with the 5-year average. The results are presented in absolute injury numbers and injury rates, and 95% confidence intervals (CI) are also presented.

4 Results

In a 5-year average for 2008–2012, a projected 51,000 skiers and 15,000 snowboarders who reside in Switzerland annually sustain injuries serious enough to require medical attention [6] (Table 1). During these 5 years, 14% (95% CI 0.13–0.14) of skiers and 8% (95% CI 0.08–0.09) of snowboarders represented in the statistics sustained an injury on slopes outside of Switzerland. Consequently, on Swiss slopes, an average of 44,000 skiers and 14,000 snowboarders residing in Switzerland sustain injuries (Table 2). Visitors from other countries also suffer injuries while skiing and snowboarding in Switzerland, and the frequency for these foreign guests on Swiss slopes barely differs from those for Swiss residents [11]. The representative annual survey on Swiss slopes shows that 27% (95% CI 0.21–0.32) of skiers and 20% (95% CI 0.16–0.25) of snowboarders are visitors from foreign countries. Overall, taking the 5-year average for 2008–2012, annually 60,000 skiers and 17,000 snowboarders on Swiss slopes are injured seriously enough to require medical attention.

In the same period, the Swiss aerial cableways registered an average of 27.2 million skier days [4, 5] (Fig. 1). Thus, the rate of injury for 2008–2012 on Swiss slopes was on average 2.8 injuries per 1000 skier days (95% CI 2.79–2.83) or 355 (95% CI 353–358) MDBI. Assuming that the distribution of skiers and snowboarders on Swiss slopes can be translated to the distribution of skier days for these two sports, 80% (95% CI 0.77–0.82) of skier days are generated by skiers and 20% (95% CI

Table 2 Absolute number of injured skiers and snowboarders on slopes in Switzerland according to sport and country of resident, Ø 2008–2012

	Skiing		Snowboarding		Total	
Country of resident	Number	Share, %	Number	Share, %	Number	Share, %
Swiss residents	44,000	73	14,000	80	58,000	75
Foreign visitors	16,000	27	3000	20	19,000	25
Total	60,000	100	17,000	100	77,000	100

0.18–0.23) by snowboarders [12]. Therefore, people skiing in Switzerland sustained 2.8 injuries per 1000 skier days (95% CI 2.74–2.78) or 363 MDBI (95% CI 360–366), whereas snowboarders experienced 3.0 injuries per 1000 skier days (95% CI 2.99–3.08) or 330 (95% CI 325–335) MDBI. Assuming that the proportion of foreign visitors on Swiss slopes remained the same between 2005 and 2012, the risk stayed almost unchanged over these 8 years (Fig. 2).

According to the statistics for fatal sports accidents, for 2008–2012, every year 19 people on average died while skiing or snowboarding. Of these, 8 out of 14 fatal ski accidents as well as four out of five fatal snowboarding accidents occurred outside of the marked and protected slopes while freeriding. With regard to skier days, in this 5-year period (2008–2012), the fatality rate was 0.7 deaths per one million skier days (95% CI 0.38–1.01) (0.7 for skiers (95% CI 0.31–0.98) and 0.9 for snowboarders (95% CI 0.11–1.69)). The absolute risk of sustaining a fatal snow sport injury remained about the same between 2000 and 2014 (Fig. 3).

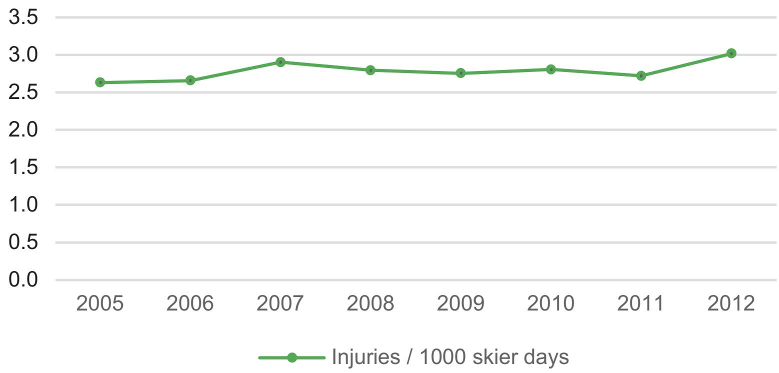

Fig. 2 Trend for non-fatal injury rate while skiing and snowboarding in Switzerland (95% confidence interval, standard deviation ±0.02–0.04), 2005–2012

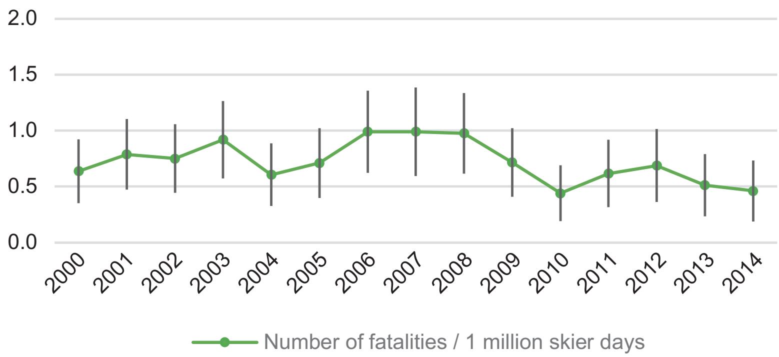

Fig. 3 Trend for fatal injury rate while skiing and snowboarding in Switzerland (95% confidence interval), 2000–2014

In relation to the 60,000 skiers and 17,000 snowboarders injured annually, the case fatality on Swiss slopes was 2.3 fatalities per 10,000 injuries for skiers (95% CI 1.12–3.57) and 3.0 deaths per 10,000 injuries for snowboarders (95% CI 0.37–5.59) (2.5 fatalities per 10,000 skiing and snowboarding injuries (95% CI 1.37–3.60)).

5 Discussion

Snow sports are constantly evolving. Over the years, new equipment has been introduced and transport facilities and slope preparation and maintenance continuously modernized. It is, however, not always clear what effect the different factors have had on the risk and severity of various injuries. According to the Swiss aerial cableways, the rate of skier visits shows a declining trend [4, 5], but Swiss residents do not seem to have skied or snowboarded less in recent years [2, 3]. Hence, the declining trend seems to be due to the diminishing number of foreign visitors, not least because of the high cost of the Swiss currency. Moreover, Swiss residents might also ski and snowboard more often in other countries because of the lower costs.

The injury rate on Swiss slopes ranks in the mid-range compared with the incidence per skier days of skiing and snowboarding injuries published by other countries in recent years (Table 3). Studies comparing skiing and snowboarding

Table 3 Comparison of injury rate on slopes in different countries

Country	Winter season or year	Injury/1000 skier days	Database
Switzerland	2008–2012	2.8	Extrapolation of injuries according to different sources
Austria, Ruedl et al. [17]	2012/13	0.6	Injuries collected in questionnaires by rescue personnel on ski slopes and physicians in the hospital or their practices
Norway, Ekeland and Rødven (2015) [18]	2012/13	1.3	Ski patrol-reported injuries
Greece, Zacharopoulos et al. [19]	2005/06	6.1	Case–control study at two major ski resorts; medical station-reported injuries
Greece, Zacharopoulos et al [20]	2007–2013	4.1	Case–control study at two major ski resorts; medical station-reported injuries
France, Médecins de Montagne [13]	2012/13	2.6	Injuries recorded by 47 medical doctors based in ski resorts
France, Médecins de Montagne [14]	2014/15	2.5	Injuries recorded by 47 medical doctors based in ski resorts
United States, Shealy et al. [15]	2010	Ski: 2.5, Snowboard: 6.1	Injuries recorded directly or through insurance companies in all ski areas in the United States
United States, Johnson et al. [21]	2010	Ski: 1.9	Injuries presenting to an injury clinic at one medium-sized ski area
United States, Kim et al. [16]	2005/06	Snowboard: ~3	Injuries presenting to an injury clinic at one medium-sized ski area

injuries all find a higher injury risk for snowboarders compared to skiers [13–16]. The lowest rate has been reported in two studies from Austria (0.6 injuries/1000 skier days) [17] and Norway (1.3 injuries/1000 skier days) [18], both made in winter 2012/13. The highest published injury rate was observed in Greece in winter 2005/06 (6.1 injuries per 1000 skier days) [19]. However, the injury rate during the period 2007–2013 was still 4.1 injuries per 1000 skier days [20]. In France, the injury rate has been reported to be almost the same as in Switzerland, with snow sport participants sustaining 2.6 injuries per 1000 skier days in winter 2012/13 (ski: 2.5, snowboard: 2.9) [13]. Newer data from France, however, show an even lower rate of 2.5 injuries per 1000 skier days (winter 2014/15) [14]. In the United States in winter 2010, the injury rate for skiers was also lower than in Switzerland (2.5 injuries/1000 visits), but the rate for snowboarders sustaining an injury on slopes in the United States was 6.1 injuries per 1000 visits, much higher than in Switzerland [15]. In comparison, another US study using injury reports from one medium-sized northern ski area found an overall injury rate of only 1.9 injuries per 1000 skier visits (excluding snowboarders) for 2010 [21]. In addition, snowboard injuries at the same ski area analyzed in another study showed a much lower incidence than that calculated for the United States overall [16]. In that study, in one 5-year period (2001/02–2005/06), the risk for sustaining a snowboard injury was lower than 300 MDBI, which corresponds to around three injuries per 1000 skier days.

Data collection and analysis methods vary among countries. Some calculations are based on ski patrol reports [18], others on information gained from physicians in hospitals or doctors based in ski resorts [13, 14, 16, 19–21], and other on combinations of different methods of data collection [15, 17]. Therefore, it is difficult to compare the injury incidence among the various countries. One review article addressing snowboarding injuries has illustrated the wide range of injury rate due to different databases and years; the authors found injury rates ranging from 0.8 to 8.0 per 1000 snowboarder days [22].

In Switzerland, no clear change can be identified in the development of overall rate (Figs. 2 and 3). Injuries have remained relatively stable between 2005 and 2012. A similar observation can be made for Norway between 1996 and 2012, where the injury rate varied between 1.2 and 1.5 injuries per 1000 skier days [18, 23]. In France, the rate for sustaining an injury has remained the same over a long period of time (1992–2014), and the skiing injury rate has increased and decreased only little over more than 20 years [14, 24]. However, a slightly growing rate of injury was observed for snowboarders between 1992 and 2005 (from 2.6 to 2.7 injuries per 1000 skier days), followed by a subsequent reversal trend with the lowest rate of 2.4 injuries/1000 skier days in 2010. Studies from the United States demonstrate an increase in injury rate for snowboarders since the turn of the millennium, whereas the risk of sustaining an injury while skiing decreased over the years [16]. Another US study calculated a decrease of 55% in injury rate while skiing, down to 1.9 injuries per 1000 skier visits since the 1970s [25]. In Austria, a decline in overall snow sports injury rate was observed for skiers and snowboarders: the risk of sustaining an injury dropped from 1.4 in 1997/98 to 1.3 injuries per 1000 skier days in 2002/03 [26]. Moreover, another Austrian study showed a further decline to 0.6 injuries/1000 skier days up to 2012/13 [17]. It seems that in many regions, the overall risk of sustaining a snow sport injury has remained the same or even dropped through the years. It can be assumed that snow sports have been made safer, especially from the 1970s to the 1990s, when the injury risk was halved [27]. Relating to the data of various other countries, it can be speculated that the risk of skiing injury decreased while the risk of a snowboarding injury slightly increased.

According to calculations from the Observatory Sport and Physical Activity Switzerland, the Swiss population experienced some 35 medically treated injuries per 100,000 h of skiing activity and 77 injuries per 100,000 h of snowboarding activity [28]. To compare, the highest estimated rate in that study was 193 injuries per 100,000 h of playing soccer, and the lowest was 3 per 100,000 h of practicing fitness, aerobic, or gymnastics. Hence, across all types of sport, the injury rate in snow sports ranks in the mid-range. Although the exposure-related injury rate is quite low in comparison to other types of sport, the popularity of snow sports in Switzerland means that the absolute number of injuries remains high.

In Switzerland, the rate of sustaining a fatal snow sport injury has changed little since the turn of millennium (Fig. 2). In those 15 years, only a few studies have been published showing the fatality rate while skiing or snowboarding on slopes. In the United States, different studies by the same research group have relied on several databases [29–31]. In 2006, these authors published their newest study, which took into account different sources and therefore gives the best overall view [31]. On average, of the 14 winter seasons included in their study (1991/92–2004/05), the overall death rate was 0.7 death per million skier visits and thus similar to the rate on Swiss slopes. In contrast to the data generated in Switzerland, the incidence rate of fatalities in skiing (0.8 deaths per million skier visits) remains greater than for snowboarding (0.5 deaths per million skier visits). In accordance with the Swiss data, no evidence suggests that the fatality rates for snowboarding or skiing have changed significantly over the years. However, no data from this database are available for the United States since 2004/05. According to US data collected by the National Ski Areas Association (NSAA), the fatality rate in the winter 2014/15 was 0.7 per million skier visits [32]. In a 5-year average, 0.7 deaths occurred per one million skier visits, which is comparable with the data from Switzerland. Moreover, no increase or decrease in the NSAA data emerged in the study period.

In Austria, the reported average is 0.4 skier and snowboarder fatalities per million skier days, resulting from trauma (i.e., fall, collision, impact, avalanche on the slopes) [33]. In contrast to the studies from Switzerland and the United States, the Austrian study excluded fatalities happening off-piste. In Switzerland, almost two thirds of skiing and snowboarding fatalities have occurred outside marked and secured slopes. Moreover, the Austrian study showed that another 0.4 deaths per million skier days resulted from non-trauma-related (primarily cardiac arrest) incidents. Non-traumatic events are not included in the Swiss database of fatal sports accidents. Even if the rates are not directly comparable because different databases were used, however, the rates of fatal ski and snowboard accidents among the different countries are similar.

6 Study Limitations

Snow sport injuries have been recorded in Switzerland in a variety of injury databases. However, no data covering all population groups or the whole of Switzerland are available for the sports sector, so estimates must be used. Moreover, some data (e.g., proportion of visitors from other countries) are not available for every year individually forcing the assumption that the proportion remains the same over different winter seasons. This study was not designed to address data quality, per se, however, quality assurance measures to uncover inconsistencies and other anomalies in the data were consistently applied. Although the data quality was checked in many areas, bias cannot be ruled out. Future research is planned to evaluate the data validity more precisely.

7 Conclusion

The rate of sustaining an injury while skiing or snowboarding on Swiss slopes was 2.8 per 1000 skier days on average from 2008 to 2010. The fatality rate in the same period was 0.7 deaths per one million skier days. Injury rates have remained relatively stable between 2005 and 2012, and fatality rate has not shifted since the turn of the millennium. Compared with other countries, in Switzerland, the rates of injury and fatality ranks in the mid-range. Even if the exposure-related injury rate is quite low in comparison to other types of sports, the popularity of snow sports in Switzerland means that the absolute number of injuries remains high. Further prevention efforts targeting behavior (e.g., the wearing of personal protective equipment) and conditions (e.g., the safer construction of snow parks) are needed to minimize or even reduce these numbers [34].

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The Utility of Two National Injury Databases to Evaluate Snow-Sports Injuries in New Zealand

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Abstract To accurately inform injury-prevention initiatives an in-depth evaluation of the utility of injury-incidence databases is essential. As part of development of a 5-year national injury-prevention strategy for snow sports in New Zealand, injury rates were compared in two databases: the Accident Compensation Commission (ACC) claims database of all snow-sports injuries treated by physiotherapists or doctors and the national incident database (NID) of injuries treated at all commercial ski areas. The ACC database focuses on treatment costs, whereas the NID database provides details of skier/boarder ability, terrain, surface condition, visibility, and equipment factors, all important information for developing injury-prevention interventions. The total injury rate in the ACC database was 8.8 injuries per 1000 skier/boarder days in the 2010 and 2011 winter seasons. The NID revealed that only one-third of these injuries were assessed and treated at mountain clinics. Sprains accounted for the greatest difference in injury rates between the ACC and the NID (5.3 and 1.3, respectively). Rates of all other main types of injury where higher in the ACC. This "bypass" effect likely represents a delay in seeking treatment that may be explained by increased swelling or pain after leaving the ski area. The bypass effect presumably applies to injury rates in all studies based solely on mountain-clinic incident data and needs to be taken into account when assessing injury trends and aetiology in alpine skiing and snowboarding.

Keywords Skiing • Snowboarding • Injury • Causation • Mechanisms • Prevention

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I.S. Scher et al. (eds.), *Snow Sports Trauma and Safety*,
DOI 10.1007/978-3-319-52755-0_4

1 Introduction

The development of the New Zealand snow sports injury-prevention strategy [1] provided the impetus to increase understanding of skiing and snowboarding injuries and apply discoveries made. Traditionally, the magnitude of the injury problem in alpine skiing and snowboarding was solely determined for Ski Areas Association New Zealand (SAANZ) using the national incident database (NID) database. NID analysis provided only one part of the picture, injured people that were assessed and treated at all commercial ski areas. To determine the true magnitude of the injury problem, the proportion and type of injuries that bypass mountain clinics then seek treatment off-the-hill needed to be determined. The Accident Compensation Commission (ACC) database provided all personal injury claims for snow sports; comparison of both the NID and ACC would provide a complete picture.

2 Aims

The primary aim of this study was to quantify the magnitude and nature of the injury problem in alpine skiing and snowboarding in New Zealand. The secondary aims were to determine the utility of two snow-sports injury databases and inform the development of a national injury-prevention strategy.

3 Methods

The NID incident reporting form was revised by the primary researcher and a SAANZ working group in the summer of 2010 prior to commencing NID data collection. Data collected at all ski areas was modified and expanded to include: resident or non-resident; free text space for description of the incident; fall, jump/landed, or slide; type of lift (chair-lift, Tbar, platter, ropetow, carpet lift, fixed grip tow); equipment ownership (self-owned, borrowed, rented on-hill, rented off-hill); equipment maintenance (binding calibration this season, >1 season, or never) and ski-binding release settings; skier height and weight; ski-binding release, no release, or premature release; and, terrain-park detail (box, jump, or rail). Activity, collision factors, visibility, snow conditions, protective equipment, and the injury code data points were retained unchanged. Ethics approval was gained from the Auckland University of Technology ethics committee (#14146) and the ACC ethics committee (#258). Descriptive epidemiological analyses and comparisons were made of ACC personal injury claimant data from the legislated government no-fault insurance scheme and the NID for incidents treated at all commercial ski areas 1 June to 31 October in 2010 and 2011. SAANZ provided population numbers for each season using ticket sales and season pass records. The ACC diagnosis, read code, and read code description data were used to group ACC data into the condition categories used in the NID. Analysis of the comprehensive cost details in the ACC data was not undertaken.

Medical condition categories in the NID were not included. Both data sets were evaluated for completeness by undertaking checks of blank fields and missing codes.

Proportions of injuries and injury risk were analysed using Poisson or logistic regression. Analysis was performed with the Statistical Analysis System (SAS). Injury rates per 1000 skier days were determined using SAANZ population data. A factor of 0.82 was applied to ACC injury counts to remove injuries that occurred outside commercial ski areas and thereby, allow comparison with NID counts. The *p* value for the difference of the rates was derived by assuming the normal approximation for the sampling distribution of the two proportions and by assuming (conservatively) the independence of the two proportions. The ratio of the proportions was assumed to have a log-normal sampling distribution, and the confidence limits for the ratio were derived from the *p* value using a spreadsheet [2]. The magnitude-based inference to assess the uncertainty in the outcomes was also calculated in this spreadsheet. Proportion ratios of 0.90 and the inverse 1.11 were assumed to be the smallest clinically important ratios.

4 Results

The ACC database provided body part injured and diagnoses on 24,793 incident claims. The data required considerable checking, filtering, and manipulation to resolve inconsistencies in recording the nature and location of injuries. Missing data were found for <2% of ACC cases; these blanks did not impact determination of a diagnosis. ACC incorrectly attributed <0.01% of snow-sports injuries to water-skiing, jet-skiing, or wakeboarding. Free text written by the injured skier or snowboarder (claimant) describing the mechanism of injury were not thematically analysed as apart from "fall" there was no consistency in terms.

The NID provided comprehensive descriptive data on 7851 incidents. Ski-binding release, non-release, and ski equipment servicing data were collected only in skiing knee and lower-leg injuries. Missing data were found for <1% of NID cases; these blanks did not effect determination of a diagnosis. There were no differences in NID incident reporting practices at small ski areas staffed solely by ski patrollers when compared to large ski areas staffed by doctors, nurses, radiographers, and ski patrollers. Coding of injury severity was not consistent in the NID. For example, fractures that occurred in the same part of the body were either coded status three moderate or status four minor. Status codes were also problematic in three cases where minor injuries were incorrectly recorded at one ski area as deceased. A ski area manager corroborated the coding error. Mortality data from the Coronial Services of New Zealand confirmed the dates, times, and causes of three ski area fatalities (two skiers, one snowboarder). Two of three of these fatalities were recorded as status one critical, and the third fatality was not recorded.

The overall injury rate for the combined winter seasons 2010 and 2011 was 8.8 per 1000 skier/boarder days (ACC) and 3.2 per 1000 skier/boarder days (NID). Sprains accounted for the biggest difference in injury rate between the ACC and the

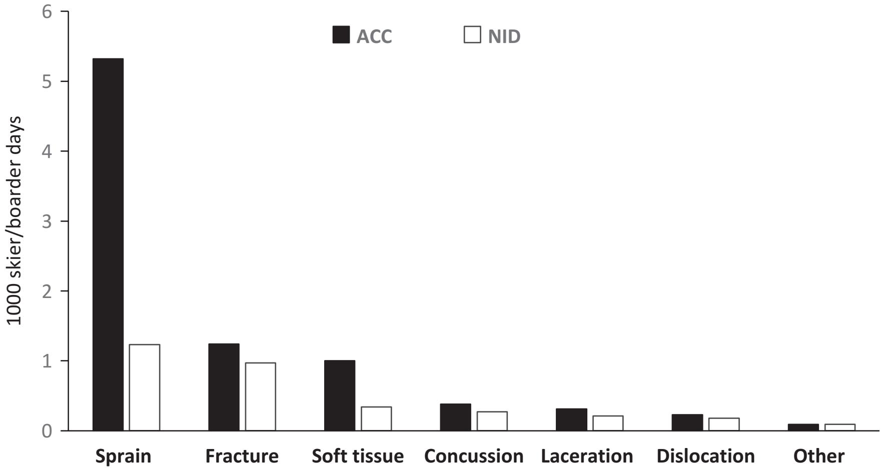

Fig. 1 ACC and NID comparison of injury type per 1000 skier/boarder days

NID (5.3 and 1.3, respectively). Figure 1 provides a graphic of the differences in all injury categories.

In comparing the injury counts per 1000 skier/boarder days for the ACC and NID shown in Fig. 1, sprains were 5.3 vs. 1.2 (ratio 4.3, 99% confidence interval, confidence interval 4.2–4.5); fractures 1.2 vs. 1.0 (ratio 1.28, 1.19–1.36); soft tissue 1.0 vs. 0.34 (ratio 2.9, 2.7–3.2); concussion 0.38 vs. 0.27 (ratio 1.4, 1.3–1.6); lacerations 0.31 vs. 0.21 (ratio 1.5, 1.3–1.7); dislocation 0.23 vs. 0.18 (ratio 1.3, 1.1–1.5); and other injuries (burns, nerve injuries, foreign bodies, dental) 0.09 vs. 0.09 (ratio 1.0, 0.8–1.3). Internal injuries were extremely rare: 8 ACC cases and 15 NID cases, respectively.

The approximate proportion of the population active in each snow sport were: 61% skiers, 32% snowboarders, 7% both ski and snowboard. Skiers suffered more sprains than snowboarders (ACC 68% vs. 54%; NID 48% vs. 28%), less fractures (ACC 10% vs. 21%; NID 21% vs. 38%), and similar proportions of concussion (ACC 4% vs. 5%; NID 8% vs. 9%). The proportions of other injury categories were similar for skiers and snowboarder. Similar agreement between the ACC and the NID were found for body part injured. For example, sprains commonly involved the knee in skiers vs. snowboarders (ACC 33% vs. 15%, NID 54% vs. 21%), whereas snowboarders had more wrist fractures than skiers (ACC 54% vs. 24%, NID 57% vs. 22%). Sustaining a fracture of the lower leg remained the domain of skiers rather than snowboarders (ACC 16% vs. 3%, NID 16% vs. 2%).

5 Discussion

The purpose of this study was to quantify the magnitude and nature of the injury problem in alpine skiing and snowboarding in New Zealand, determine the utility of two snow-sports injury databases, and inform the development of the national injury-prevention strategy [1]. An understanding of the coding, classifications, and terminology used in each database is the first requirement for undertaking a study that compares data [3]. ACC used a single diagnosis code for an individual claimant; multiple injuries were not captured in the code. The compact hierarchy of medical codes were developed by Dr. James Read in 1983 to cater for computer systems that had limited memory. Discordance relating to diagnosis may occur when assigning the Read code, and the code may also be applied incorrectly [4–7]. In New Zealand, there has been no systematic education for health professionals on how to use Read codes, this lack of education has added to concerns that diagnostic coding errors may occur [6]. However, missing diagnoses in the ACC database of <2% would not be an issue for assessment of trends in injury incidence.

The NID used simplified diagnostic codes for up to three injuries for one individual, with a four part number and letter system for status, body part injured, side and condition. These nomenclatures added an element of sophistication and provided description of individual skiers or snowboarders who had multiple injuries. The small percentage of NID coding errors was seemingly typographical. Use of status 1 (critical problem with an immediate threat to life) as opposed to status 0 (dead) may have been due to patients being under resuscitation at the time of handover to the helicopter emergency medical service. Missing diagnoses in the NID database of <1%, as for the ACC, would not be an issue for assessment of trends in injury incidence.

Statistical methods have been designed to support comparison of injury incidence in studies of snow sports [8–11]. When comparing studies consideration needs to be given to the fact that some jurisdictions only include injuries that have been assessed and diagnosed by medical practitioners and other areas may only analyse ski patrol data. Depending on what data is entered into the incident database the number of injuries and patterns of injury may increase or decrease. Medical practitioner incident data may have less minor injuries than ski patrol data. For example, a skier suffering a minor laceration from a ski-edge may only require first aid, not require suturing, and therefore, will not see a doctor. In New Zealand, regardless of the staff skill mix lacerations were recorded as soft tissue injuries in the NID. This reporting culture may lead to an increased proportion of soft tissue injuries when compared with other studies. Importantly, there was no difference in accuracy of data entry when comparing small New Zealand ski areas staffed solely by ski patrollers and large ski areas staffed by a mixed medical team. These finding correlate with Canadian analysis of ski patrol information quality [12].

Norway has a central registry representing 53% of skier/boarder days; 1.3 injuries per 1000 skier/boarder days occurred in the 2008/2009 and 2009/2010 seasons [13]. In a study of 10 French ski areas in 2007 and 2010, Laporte et al. [14] found that incident rates fell from 2.8 to 2.4 per 1000 skier/boarder days. Shealy et al. [15] found that the weighted US skiing incident rates in national ski areas association data declined from 3.1 in 1980 to 2.5 per 1000 visits in 2010. The NID incident rates for skiers and snowboarders treated at ski areas in New Zealand were higher than France, Norway, and the USA.

The substantially higher injury rate in the ACC compared with the NID represents a “bypass effect”. This effect is most likely due to evolving symptoms leading to first presentations occurring off-the-hill and the no-fault accident compensation system that covers personal claims. For example, symptoms of concussion may not develop immediately following an incident on the snow. Injured international skiers and snowboarders are unlikely to return home for first treatment as ACC covers treatment costs, and New Zealand is an international flight away from other countries. Ski areas located in large continents are likely to see bypass as injured skiers and snowboarders return to their state or country of origin, making it difficult to capture this group of injured.

The ACC system has been heralded as a world-leading solution when comparing medical systems that have burgeoning costs, but it has also been criticised for its potential for false claims by individuals who did not sustain an acute injury in the activity that was registered in the claim [16, 17]. It seems unlikely that there would be a substantial misattribution of injuries to snow sports. However, the ACC system may promote claims for minor injuries where the individual in a user pays environment possibly would not seek treatment. Injured individuals can make a personal injury claim with a medical practitioner, physiotherapist, or other ACC accredited health provider. The choice of treatment modality may in-part explain higher injury rates in the ACC data. For example with universal insurance cover, a skier or snowboarder with back strain can present directly to a physiotherapist or chiropractor for assessment and treatment at no cost or a low cost surcharge and ACC will cover the remaining treatment costs. In other health systems, the back sprain incidence may be lower as skiers and snowboarders opt for self-management rather than registering as injured.

High proportions of knee sprains in skiing were found in recent epidemiological studies [13, 14, 18–20]. The large numbers of knee sprains bypassing mountain clinics in New Zealand highlight that the problem is greater than previously considered. Delays in seeking assessment and treatment for sprains can be explained by swelling evolving over time, increasing limitation of movement, and difficulty with managing pain. Grades of medial collateral ligament injury provide a possible explanation for bypassing mountain clinics [21]. Grade I knee injuries may be painful in the days after skiing but have no laxity and would probably not limit a skier getting off-the-hill without assistance. Grade II knee injuries involve separation of the collagen fibres of the medial collateral ligament, have partial laxity, and may involve the joint capsule, anterior and/or posterior cruciate ligament. Depending on the degree of disability and laxity, grade II medial collateral knee ligament injury may not present at mountain clinics or seek assistance from ski patrollers for extrication by toboggan. However, it is likely that grade II injured individuals would have difficulty getting on and off a chair-lift. Grade III medial collateral knee ligament injuries are a severe injury that would limit capacity to continue skiing. The complete rupture that occurs in a grade III injury, lax joint, and increased chance of haemathrosis would mean that this group of injured skiers would likely present to ski patrol on-the-hill. Skiers with grade I or grade II injuries possibly take a wait and see approach to see what level of disability exists in the days following skiing. There was no difference in the definition of a sprain in the NID and ACC coding that could lead to an alternative explanation for the high proportion of knee sprains in the ACC data.

Both databases indicated that fractures of the lower leg were more common in skiers than snowboarders. The sharp decline in lower-limb fractures seen after the invention of the dual-direction ski-binding in the 1970s and 1980s has not been sustained [22–24]. Poor ski-binding maintenance, incorrect release settings, ill-fitting ski boots, changes to skiing style, and skiers unprepared for the trajectory of the carving ski are possible explanations for the continued issue of fractures of the lower leg.

The ACC and the NID reported higher proportions of wrist fractures in snowboarders when compared to skiers; this is consistent with findings in other studies [25, 26]. The mechanics of falling on an out-stretched hand and frequency of falling when snowboarding (particularly for novices) explains the difference in injury proportions [27]. Interventions to reduce the incidence of wrist fractures in snowboarders could include instruction on staying upright, instruction on how to fall, and increased use of wrist protectors [28].

The proportions represented by concussion in skiers and snowboarders were similar. Further research is needed to describe the nature of head injuries in skiers and snowboarders in New Zealand. In the interim, analysis of head injuries elsewhere has provided sufficient evidence for promoting the wearing of helmets [29–31].

6 Conclusion

Researchers informing the development of injury-prevention interventions should not rely solely on one injury database. Bypass injury rates are needed to determine the true magnitude of the injury problem in skiing and snowboarding. Insurance databases are a relatively blunt tool for determining behavioural, equipment, or environmental risk factors. Mountain-based epidemiological studies provide the detail required to inform injury-prevention initiatives. Increased understanding is needed on the demographic of skiers and snowboarders who delay seeking treatment, as early intervention may reduce severity and enhance recovery.

Acknowledgements The authors are grateful to SAANZ and ACC for supplying data. SAANZ are also acknowledged for their unequivocal encouragement during the development of the New Zealand Snow Sports Injury Prevention Strategy (2015–2020).

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A Sport Concussion Assessment Tool (SCAT2) for Use in Snowsports: Can the Balance Component of the Tool Be Improved?

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Abstract Background: Currently, there are no recommended assessment protocols for monitoring possible effects of head injury in snowsports athletes who are in competition and training. Objective: This project evaluated the Sport Concussion Assessment Tool 2 (SCAT2) for concussion assessment in a snowsport athlete group. In addition, the project determined the effectiveness of enhancing the SCAT2 protocol by using accelerometer smartphone technology in the balance assessment component of the test battery, with a view to an enhanced protocol for assessment of changes in human motor performance post-concussion injury. Methods: The research team recruited 22 athletes from the New South Wales Institute of Sport and the Olympic Winter Institute Australia snowsport athlete squads who were undertaking baseline sport science testing during the Australian 2012 and 2013 winter seasons. Results: Overall correlation between the SCAT 2 over two separate occasions was moderate/strong (Pearson's $r = 0.58$, $p = 0.006$). Examination of the subcategories within the SCAT2 indicated that the overall correlation was being mediated by the strong correlation of the subset "Symptom Score." The subset "Balance Score" did not correlate across test occasions ($r = 0.42$, $p = 0.054$). There were no other significant correlations across the two occasions of testing. Those who had reported a major head impact history, signified by damage to their helmet during the impact, were significantly older (21.5, SD 4.6 years) than the group not reporting a major head impact (17.5, SD 2.6 years). Two of the instrumented balance test measures, one in the double-leg stance and one in the single-leg stance protocol, showed a significant difference between the "major helmet impact" and "no helmet impact" groups warranting further investigation in a larger sample.

Keywords Skiing • Snowboarding • Concussion • Concussion assessment

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I.S. Scher et al. (eds.), *Snow Sports Trauma and Safety*,
DOI 10.1007/978-3-319-52755-0_5

1 Introduction

Snowsports are popular winter sports in Australia and have a strong appeal to young and beginner participants. As in any sport, there is a risk of injury, including head injury. Internationally, it has been suggested that traumatic brain injury (TBI) is the leading cause of death in snowsports [1, 2]. Results from an Australian study of patients presenting to the Canberra Hospital with a snowsport-related head injury found that the incidence of head injuries was 1.8 per 1,000,000 skier days ($n = 25$) with snowboarders having three times the incidence of head injuries of skiers [3]. As with the broader population, snowsport athletes are also at risk of concussion and head injury though at a higher incidence and severity [4, 5]. Thus, there is a need for an effective mechanism to assess any cumulative effects of repeated head impacts or injuries on cognitive and motor performance.

Helmets are proposed to protect against snowsport head injuries [6–10]. An Australian study in Victoria indicated that usage has increased, with children more likely to wear helmets than adults (67% cf. 16% in 2008), however usage was declining [11]. While it has been demonstrated that helmets may reduce the severity of minor injuries in snowsports [11], there continues to be debate about their effectiveness in all circumstances, hence discussion continues about their usefulness. This is consistent with the "Consensus Statement On Concussion In Sport" (CSCS), which states that there is "no good clinical evidence that currently available protective equipment will prevent concussion" [12, 13] though in snowsports helmets may reduce other head and facial injuries. Further, increased helmet usage has not resulted in the expected benefit of less reported head injuries [4]. Yet they are required by FIS for all events [14] but manufactured at similar test standards as recreational helmets where it has been suggested that helmets may not be effective in an impact with a solid object at speeds greater than 23 km/h [2].

The CSCS defines concussion as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" [12, 13]. Research has been conducted on footballers and ice hockey players related to repeated "mild-impact" and the risk of post-concussion syndrome [15], and there have been efforts to achieve some consensus about how to prevent and manage sport-related concussions [12, 13]. Yet, to date there is no research that reports and monitors the incidence of concussion injury in either athlete or recreational snowsport participants.

The CSCS suggests that "a detailed concussion history is of value" including baseline data gathering prior to a sporting season. A structured concussion history should include specific questions as to previous symptoms of a concussion: not just the perceived number of past concussions. It is also worth noting that dependence upon the recall of concussive injuries by team members or coaches has been demonstrated to be "unreliable" [16]. To this end, the Sport Concussion Assessment Tool 2 (SCAT2) was developed as the recommended tool for assessment of concussion in sport. The SCAT2 is a tool for assessing symptoms and signs reported by the concussed athlete. The SCAT2 score does not independently determine the diagnosis of concussion, nor the athlete's return-to-play status. The SCAT2 protocol is designed for use to determine a pre-injury baseline and to assess readiness for return-to-play in sports such as the football codes and motor sports. The SCAT2 scoring system incorporates scores for the fields, (1) Symptoms and (2) Cognitive and Physical Evaluation, that includes cognitive assessment, physical signs, balance and coordination, the Glasgow coma scale, and the Maddocks Score.

This project focused on the reliability of the SCAT2 as a baseline test across seasons and on the standing balance assessment component of the SCAT2 test, as the protocol uses a relatively coarse balance assessment approach. The static component of the test uses a hands-on-hips, single-leg stance for 20 s test, with the test scored as the number of times the participant makes movements with the hands away from hips, touches down with one leg, etc. to recover balance, taken as a measure of change in postural sway. With the advances in smart phone technology [17], including the addition of accelerometer systems, the capacity to discover much finer grades of change in sway posture may enhance the sensitivity of the test to detect changes in sway that are indicative of low-level cumulative change in neurologic function. This additional and refined information may then lead to the design of more sensitive SCAT tools.

2 Objectives

As there are currently no recommended assessment protocols for monitoring possible effects of head injury in snowsport athletes who are involved in both competition and training, this project had three objectives:

1. To evaluate the SCAT2 for concussion assessment in a snowsport athlete group
2. To determine the effectiveness of enhancing the SCAT2 protocol using accelerometer smartphone technology in the static "balance assessment" component of the SCAT test
3. To inform the design of an enhanced protocol for assessment of changes in motor performance post-concussion injury: towards an improved SCAT

3 Materials/Methods

Athletes involved in snowsport programs with the New South Wales Institute of Sport and the Olympic Winter Institute of Australia who were competing regionally through to World Cup events were invited to participate in this project. Those who had a significant health issue or those who may have been pregnant did not participate in this study. 22 athletes, 12 male, and 10 female, across a range of snowsport activities (moguls, snowboard cross, and skier cross), volunteered to participate in this project. All were familiarized with the protocol prior to commencing.

Upon consenting to participate, athletes completed the SCAT2 questionnaire sections. A structured concussion history was taken, which included specific questions as to previous symptoms of a concussion, and a question about the number of severe impacts to the head region. A severe impact was indicated where they reported damage to their helmet as a result of an impact, which is one objective measure where medical diagnosis is not available. The clinical history collected included information about all previous head, face, or cervical spine injuries, as these may also have clinical relevance. As part of the clinical history, details regarding protective equipment employed at the time of injury were also gathered, both for recent and old injuries.

Parallel with the SCAT2 protocol, balance was further assessed via:

1. Accelerometer Data Pro smartphone app, a smartphone application that allows recording of acceleration data via a tri-axial accelerometer on an iPhone 3
2. And the "gold standard," Kistler static force platform, which is commonly used in biomechanics applications for assessment of body sway and accelerations

All measures were undertaken concurrently for all balance tests. The smartphone was worn on the waist in a conforming belt and the participant stood on the force plate (Fig. 1). The suitability of the smartphone accelerometer technology for this application has been demonstrated previously [18]. Accelerometer data was analyzed by determining differences in the standard deviation of the vector sum of

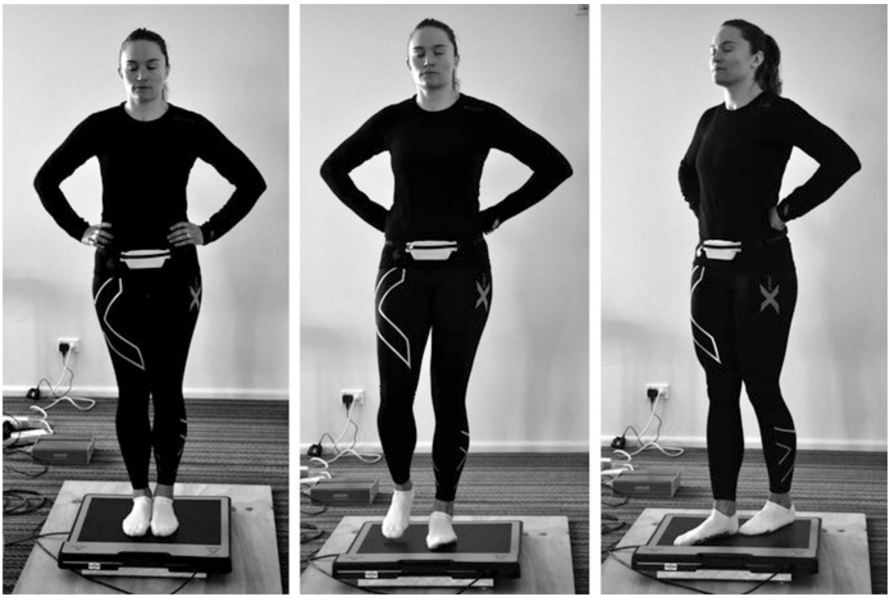

Fig. 1 Positioning of iPhone 3 on the participants' waist belt and balance positions undertaken in the balance component of the SCAT2, double-leg standing, single-leg standing, and tandem-stance

accelerations and force platform data via differences in center of pressure area between each balance activity.

Data collection occurred according to the following schedule:

Time 1: Preseason, 2012, (SCAT2A) baseline evaluations and obtaining athlete histories in line with recommendations of the “Consensus Statement on Concussion in Sport,” evaluations involving:

- Administering the SCAT questionnaire component
- Concurrently assessing the static balance component of the SCAT via the Accelerometer Data Pro on a smart phone device and the Kistler static force platform

Time 2: Beginning of following winter season (2013) again as described in T1 above (SCAT2B).

Mean center of pressure and peak frequency measures for the force platform and accelerometer data were determined in each of the *x*, *y*, and *z* planes for each of the standard balance posture tests comprising the balance assessment protocol in the SCAT2 (Fig. 1). Correlations were determined between the overall SCAT2 data scores, and all subsets of the SCAT2 data as well as the mean center of pressure and peak frequency measures for the accelerometer and force platform data.

To determine any difference between those who reported an episode of a major head impact and those who did not, the data was separated into two categories; “those who reported a major head impact history” ($n = 8$) and those “without a major head impact history” ($n = 14$). Independent samples t-tests were undertaken on these data to assess any between-group differences.

4 Results

T-tests were undertaken on the data both within-group, comparing participant trials across the data collection period, from pre-test to post-test, and between-group across the snowsport versus control participant groups, in order to determine any differences between the groups using the SCAT2 protocol. Additional test data obtained, where any participant received a head impact during the trial period, was also assessed in the manner described above to determine any impact on sensitivity obtained by including the force or accelerations data in the protocol. 22 participants were assessed over two occasions (Table 1).

Overall correlation between the SCAT2 over the two separate occasions (2012 season SCAT2A and 2013 season SCAT2B) was moderate/strong, with a Pearson’s r of 0.58, $p < 0.01$. Examination of the subcategories within the SCAT2 indicated that the overall tool correlation was being mediated by the strong correlation of the subset “Symptom Score,” with the Symptom Score A correlating with Symptom Score B Pearson’s $r = 0.7$, $p < 0.01$. The subset “Balance Score” did not correlate significantly across the two test occasions Pearson’s $r = 0.42$, $p = 0.054$). There were no other significant correlations across the two occasions of testing.