OPEN ACCESS

Feature-specific terrain park-injury rates and risk factors in snowboarders: a case–control study

Kelly Russell,[1,2,3] Willem H Meeuwisse,[2,4] Alberto Nettel-Aguirre,[1,2] Carolyn A Emery,[2,4] Jillian Wishart,[1] Nicole T R Romanow,[1,2] Brian H Rowe,[5,6] Claude Goulet,[7] Brent E Hagel[1,2]

▸ Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/bjsports-2012-091912).

[1]Department of Paediatrics, University of Calgary, Calgary, Canada
[2]Department of Community Health Sciences, University of Calgary, Calgary, Canada
[3]Department of Pediatrics and Child Health, University of Manitoba, Winnipeg, Canada
[4]Faculty of Kinesiology, Sport Injury Prevention Research Centre, Roger Jackson Centre for Health and Wellness Research, University of Calgary, Calgary, Canada
[5]Department of Emergency Medicine, University of Alberta, Edmonton, Canada
[6]School of Public Health, University of Alberta, Edmonton, Canada
[7]Department of Physical Education, Laval University, Quebec City, Canada

Correspondence to
Dr Kelly Russell, Department of Pediatrics and Child Health, Manitoba Institute for Child Health, 656-715 McDermot Avenue, Winnipeg, MB, Canada R3E 3P4; krussell@mich.ca

Accepted 11 March 2013
Published Online First 1 November 2013

Open Access
Scan to access more free content

To cite: Russell K, Meeuwisse WH, Nettel-Aguirre A, *et al*. *Br J Sports Med* 2014;**48**:23–28.

ABSTRACT

Background Snowboarding is a popular albeit risky sport and terrain park (TP) injuries are more severe than regular slope injuries. TPs contain man-made features that facilitate aerial manoeuvres. The objectives of this study were to determine overall and feature-specific injury rates and the potential risk factors for TP injuries.

Methods Case–control study with exposure estimation, conducted in an Alberta TP during two ski seasons. Cases were snowboarders injured in the TP who presented to ski patrol and/or local emergency departments. Controls were uninjured snowboarders in the same TP. κ Statistics were used to measure the reliability of reported risk factor information. Injury rates were calculated and adjusted logistic regression was used to calculate the feature-specific odds of injury.

Results Overall, 333 cases and 1261 controls were enrolled. Reliability of risk factor information was κ>0.60 for 21/24 variables. The overall injury rate was 0.75/1000 runs. Rates were highest for jumps and half-pipe (both 2.56/1000 runs) and lowest for rails (0.43/1000 runs) and quarter-pipes (0.24/1000 runs). Compared with rails, there were increased odds of injury for half-pipe (OR 9.63; 95% CI 4.80 to 19.32), jumps (OR 4.29; 95% CI 2.72 to 6.76), mushroom (OR 2.30; 95% CI 1.20 to 4.41) and kickers (OR 1.99; 95% CI 1.27 to 3.12).

Conclusions Higher feature-specific injury rates and increased odds of injury were associated with features that promote aerial manoeuvres or a large drop to the ground. Further research is required to determine ways to increase snowboarder safety in the TP.

INTRODUCTION

Snowboarding is a popular sport[1 2] and the risk of injury is higher for snowboarding than for skiing.[3 4] Being a beginner,[5–8] poor weather conditions[9] and not wearing protective equipment[10–12] increase injury risk. Ski areas often include terrain parks (TPs) with man-made features (eg, jumps, rails and half-pipes) for performing tricks and aerial manoeuvres. In November 2007, Resorts of the Canadian Rockies (RCR) removed all man-made jumps from their TPs because they believed jumps increased injury risk.[13] Definitions of common features can be found at: http://www.snowboard-coach.com/freestyle-snowboarding-features.html and in appendix 1.

Between 5% and 27% of skiing and snowboarding injuries occur in TPs[2 14–19] and are more severe than regular slope injuries.[15 16 18] At the 2012 Winter Youth Olympic Games, 35% of all snowboard half-pipe and slope-style competitors were injured.[20] Those injured in TPs tend to be snowboarders, male, 13–24 years old, fall from higher heights[15] or self-perceived experts.[16] There is a dearth of research examining injury rates and intrinsic and extrinsic risk factors for snowboarders in TPs in relation to injury mechanism—a comprehensive approach recommended by sport injury prevention research leaders.[21 22] Therefore, the study objectives were to calculate overall and feature-specific TP injury rates, determine potential risk factors for injury in the TP and assess the reliability of the data collection methods.

METHODS

Definition of cases and controls

This unmatched case-control study was conducted in one Alberta TP during the 2008–2009 and 2009–2010 seasons. There were approximately 290 000 skier–snowboarder visits to the resort annually. Except for the half-pipe and mushroom, the overall TP layout and number of features changed once each season, resulting in four configurations containing all seven feature types. The resort did not assign a difficulty rating to individual features. Helmets were mandatory in the TP.

Cases were snowboarders injured in the TP who presented to either the ski patrol and/or one of two nearby emergency departments (EDs), both Level 1 trauma centres (one adult, one paediatric). Controls were uninjured snowboarders using the same TP. Cases were 'severe' if they presented to an ED, and 'minor' if they presented to ski patrol only or to ski patrol and a non-emergent healthcare provider. Injuries presenting to the ED represent the public health burden and snowboarders injured in the TPs near hospitals may place a strain on EDs.

Data collection

Case data were collected from ski patrol Accident Report Forms (ARF) and ED medical records. ARFs are completed by the ski patrol for anyone injured and presented to them. ARFs record demographics (age, sex and five-point self-reported ability), injured body region, injury type (fracture, dislocation, sprain/strain, bruise/abrasion/laceration and concussion), environment (temperature, light and snow (groomed/ungroomed)) and contact information. ARFs have previously been used in research[14 18 19 23–25] and were collected from the resort biweekly. Snowboarders who presented to the ED were identified from the Regional Emergency Department Information System. Following verbal consent (parent/guardian if snowboarder was <14 years) and confirmation they were injured at the TP of interest, additional self-reported data were collected by telephone. The previously listed information was captured for snowboarders presenting only to the ED, along with years of snowboarding and TP experience, listening to music, wearing wrist guards, previous snowboarding injury and feature used (jump, kicker, box, rail, quarter-pipe, half-pipe or mushroom) when injured. If the case presented to the ski patrol and could not be contacted or did not consent to the telephone interview, only the ARF data were included.

To collect feature use among controls, trained research assistants (RAs) at the bottom of the hill observed snowboarders' TP runs in 3 h time slots, 3–4 times a week at various times during the day, and recorded feature use on a map. Data were collected each week from 1 January until the resort closed (end of March in Season 1 and mid-April in Season 2) and included all four TP layouts. RAs approached the first snowboarder, obtained consent and asked the same risk factor information as asked to cases. Snowboarders indicated feature use on the map for features not fully visible to the RA. After each interview, the next snowboarder closest to the RA was approached. Temperature (smartphone Weather Network application), light and snow conditions were recorded on an hourly basis.

Injury rate denominator data were collected in the same 3 h slots. Snowboarder runs were counted by an RA at the top of the TP, which was the only run to the right of the chairlift and only serviced by that chairlift. Age-group (<12, 12–17 or >17) and sex were visually assessed. To determine accuracy of observed age-group and sex classifications, RAs independently estimated the age-group and sex of a snowboarder entering the TP and then approached them to confirm. This was repeated in 10 min intervals for 3 h blocks and included 337 snowboarders.

Ethical approval was granted by the University of Calgary Conjoint Health Research Ethics Board.

Analysis

Reliability

Three pairs of RAs independently classified uninjured snowboarders entering the TP by age-group and sex. The Stuart-Maxwell test for overall marginal homogeneity assessed the reliability within the three pairings.[26] To determine accuracy of observed age-group and sex classifications, unweighted κ statistics and 95% CIs were calculated.

At the end of Season 1, cases interviewed within the last month were reinterviewed using the original questions. To measure reliability, unweighted κ with 95% CIs were calculated for variables without ordering and weighted κ (κ_w) with 95% CIs for ordinal variables.[27]

Rates

Injury rates were presented as injuries per 1000 runs; the numerator was the number of injured snowboarders over the two seasons and the denominator was the estimated total runs. The denominator was extrapolated from the observed number of snowboarders entering the TP by multiplying the number of runs per 3 h time slot by the number of time slots the TP was open each season. This resulted in a denominator that was representative of participation at different times of the day during weekends and weekdays. The severe injury rate numerator was snowboarders who presented to the ED. Age-group, sex and age–sex-specific injury rates were calculated.

Feature-specific injury and severe injury rates were calculated. The denominator was the total number of runs taken on that type of feature, extrapolated in the aforementioned manner to reflect exposure opportunity. For example, there were seven opportunities to go over a box during one run but only one opportunity to use a mushroom. The 95% CIs were calculated using the Poisson distribution.[28]

Overall, sex-specific and age-specific rate ratios and 95% CIs were calculated comparing each feature with rails. Rails were the reference feature as they were still permitted in RCR TPs[13] and were hypothesised to have a lower injury rate possibly due to their smaller drop to the ground.

Risk factors

The distributions of potential risk factors between cases and controls, severe cases and controls and severe cases and minor cases were compared using proportions for dichotomous/polytomous risk factors and means with SDs for continuous risk factors. Unadjusted ORs with 95% CIs were calculated.

Logistic regression was used to calculate the association between injury versus no injury and feature use using a backwards elimination.[29] Potential confounders were: age (continuous), sex (male/female), previous injury (yes/no), self-reported ability (beginner-novice/intermediate/advanced/expert), wrist guard use (yes/no), music use (yes/no), temperature (>10C, 0–10C, −10–0C, <−10C), light (sunny/cloud/night) and snow (groomed/ungroomed). These were entered into the model containing feature (jumps, kickers, half-pipe, quarter-pipe, box, mushroom, rails). Whichever confounder produced the smallest change in the feature-specific ORs was removed, provided the change was <15% and repeated until all potential confounders were removed.[30] The 95% CIs were adjusted for the clustering effect of multiple feature use within controls.

To compare severe injuries with no injuries and severe injuries with minor injuries, forward selection was used because of smaller sample size.[31] Potential confounders were added one at a time to the crude model; the confounder that produced the greatest percent change in a feature OR was retained. This was repeated until either the addition of another confounder no longer changed any of the TP feature estimates by >15% or there was one confounder for every 10 cases.[31] The 95% CIs were adjusted for clustering effect of multiple feature use within uninjured controls.

For the injury versus no injury comparison, a sensitivity analysis using multiple imputation by chained equations with five imputed datasets was conducted[32] to address missing data and test for effect modification by age or sex and feature. Feature, age, sex, ability, previous injury, music, wrist guards, temperature, light and snow were used for imputation. Effect modification was assessed using an omnibus test (p>0.05 indicating no evidence of effect modification), and backwards elimination multiple logistic regression was conducted on the imputed data. Analyses were conducted in Stata/SE V.11.[33]

RESULTS

A total of 333 cases (107 ski patrol, 174 ski patrol and ED, 18 ski patrol and healthcare provider and 34 ED only) and 1261 controls were included. The consent rate was 79% for cases and 94% for controls (figure 1).

Reliability

Based on initial RA observation and follow-up confirmation, the RAs correctly classified age-group in 78% (κ=0.71; 95% CI 0.49 to 0.93) and sex in 100% of uninjured snowboarders (κ=1.00; 95% CI 0.69 to 1.00). There was significant agreement for age and sex classification between the RAs (p>0.05 for each of the three pairs). For interview responses, κ=0.72 (95% CI 0.60 to 0.85) for feature use at the time of injury and

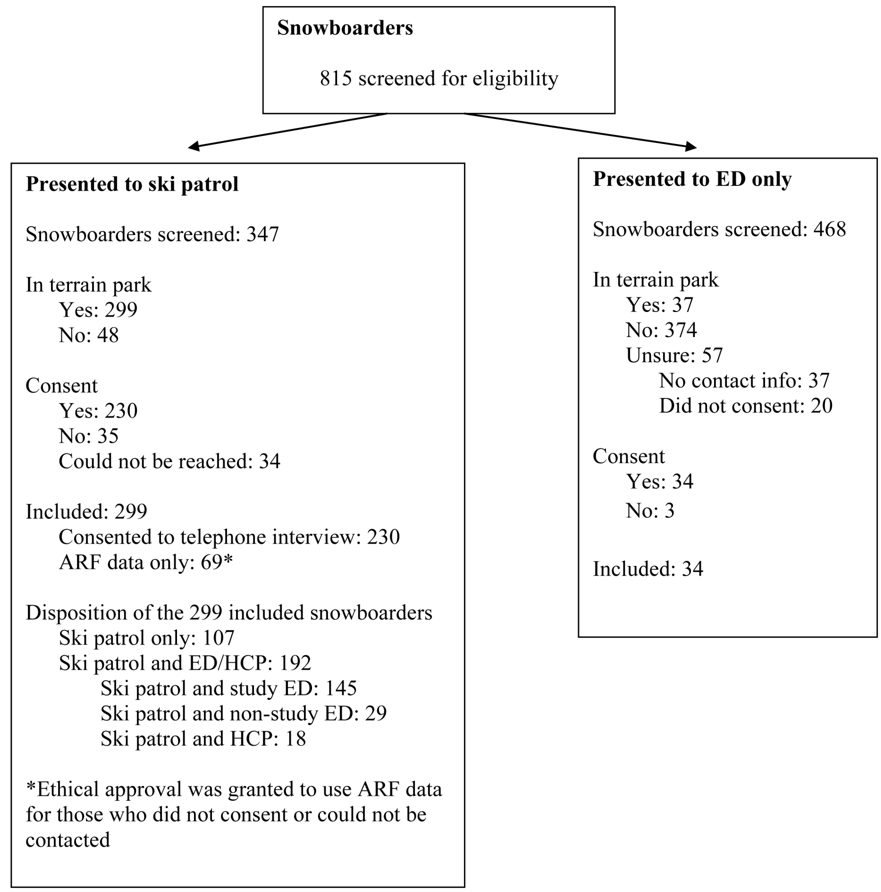

Figure 1 Recruitment of included snowboarders.

this improved when follow-up interviews were conducted within 2 weeks (κ=0.86; 95% CI 0.64 to 1.00). The overall κ were ≥0.60 except for body region of the second and third injuries and diagnosis of the second injury.

Injuries

Overall, 62.5% went to the ED. The most commonly injured body regions were the wrist (20%), and head (14%), while the most common injury type was fracture (36%). Table 1 describes feature use among injured and uninjured TP snowboarders.

Females aged 12–17 and >17 had higher rates of injuries than males, and higher rates of severe injuries at all ages (table 2).

Features that promoted aerial manoeuvres or resulted in a greater drop to the ground typically had higher injury rates than features with a small drop (table 3). Jumps and half-pipe had the highest overall and severe injury rates. Compared with rails, rates of all injuries were significantly higher on the half-pipe, jumps and boxes (table 4).

Baseline characteristics are presented in table 5. The odds of injury were significantly higher when it was −10°C to 0°C compared with 0–10°C, and at night versus sunny weather. Beginners/novices had significantly lower odds of injury than intermediates, as did those with a previous snowboarding injury,

Table 1 Features used by all injured, severely injured snowboarders, and uninjured snowboarders in the terrain park

	All injuries N=333 (%)	Severe injuries N=208 (%)	Features used* N=444689 (%)
Jumps	85 (25.5)	59 (28.4)	33179 (7.5)
Kickers	84 (25.2)	54 (26.0)	136807 (30.8)
Boxes	62 (18.6)	37 (17.8)	95117 (21.4)
Rails	39 (11.7)	21 (10.1)	91634 (20.6)
Half-pipe	19 (5.7)	13 (6.3)	7409 (1.7)
Mushroom	16 (4.8)	7 (3.4)	31134 (7.0)
Quarter-pipes	11 (3.3)	6 (2.9)	45989 (10.3)
Other	0	0	3470 (0.8)
None	13 (3.9)	9 (4.3)	0
Unknown	4 (1.2)	2 (1.0)	0

*Weighted for time of day, weekday versus weekend and exposure opportunity.

Table 2 Overall, sex-specific and age-specific injury rates (per 1000 runs and 95% CI)

	N	All injuries rate (95% CI)	N	Severe injuries rate (95% CI)
Overall	333	0.8 (0.7 to 0.8)	208	0.5 (0.4 to 0.5)
Males	291	0.7 (0.6 to 0.8)	180	0.4 (0.4 to 0.5)
Females	42	1.1 (0.8 to 1.4)	28	0.7 (0.5 to 1.0)
Age <12	26	0.5 (0.4 to 0.8)	16	0.3 (0.2 to 0.5)
Males	25	0.5 (0.4 to 0.8)	15	0.3 (0.2 to 0.5)
Females	1	0.4 (0.0 to 2.2)	1	0.4 (0.0 to 2.2)
Age 12–17	186	0.8 (0.7 to 0.9)	120	0.5 (0.4 to 0.6)
Males	161	0.8 (0.6 to 0.9)	103	0.5 (0.4 to 0.6)
Females	25	1.0 (0.7 to 1.5)	17	0.7 (0.4 to 1.1)
Age >17	121	0.9 (0.7 to 1.0)	72	0.5 (0.4 to 0.7)
Males	105	0.8 (0.7 to 1.0)	62	0.5 (0.4 to 0.6)
Females	16	1.5 (0.8 to 2.4)	10	0.9 (0.4 to 1.7)

Table 3 All and severe injury rates (per 1000 feature exposures and 95% CI)

Feature	All injuries* rate (95% CI)	Severe injuries* rate (95% CI)
Aerial manoeuvre or substantial drop to the ground		
Half-pipe	2.6 (1.5 to 4.0)	1.8 (0.9 to 3.0)
Jumps	2.6 (2.1 to 3.2)	1.8 (1.4 to 2.3)
Kickers	0.6 (0.5 to 0.8)	0.4 (0.3 to 0.5)
Mushroom	0.5 (0.3 to 0.8)	0.2 (0.1 to 0.5)
Small drop to the ground		
Boxes	0.7 (0.5 to 0.8)	0.4 (0.3 to 0.5)
Rails	0.4 (0.3 to 0.6)	0.2 (0.1 to 0.4)
Quarter-pipes	0.2 (0.1 to 0.4)	0.1 (0.1 to 0.3)

*Injury rates were adjusted for weekday versus weekend, time of day and exposure opportunity (ie, incorporates days when the terrain park or certain features were closed).

music use, or when it was above 10°C versus 0–10°C. When comparing severely injured with uninjured snowboarders, the same patterns were observed except that music or temperatures above 10°C were not significant. There were no significant differences between severe versus minor injuries.

The crude associations between injury and feature use showed significantly greater odds of injury for jumps and half-pipe, compared with rails and significantly lower odds of injury for quarter-pipes (table 6). For severe injury versus no injury, the crude odds of severe injury were significantly greater on jumps, half-pipe and kickers compared with rails.

There were significant increases in the adjusted odds of injury for half-pipe (OR 9.63; 95% CI 4.80 to 19.32), jumps (OR 4.29; 95% CI 2.72 to 6.76), mushroom (OR 2.30; 95% CI 1.20 to 4.41) and kickers (OR 1.99; 95% CI 1.27 to 3.12) versus rails. The adjusted odds of severe injury versus no injury were significantly higher for half-pipe, jumps and kickers compared with rails. After accounting for clustering, the 95% CI width increased marginally but significance did not change.

Using the imputed dataset, there was no evidence of effect modification of feature by age or sex (p=0.41) versus rails, significantly increased adjusted odds of injury on half-pipe (OR 5.88; 95% CI 3.25 to 10.63) and jumps (OR 4.78; 95% CI 3.22 to 7.11) and significantly decreased odds of injury on quarter-pipes (OR 0.49; 95% CI 0.25 to 0.97).

DISCUSSION

To our knowledge this is the first study to examine feature-specific injury rates and potential risk factors for TP snowboarding injuries. Data collection methods were found to be accurate and reliable for age and sex information. There was 'substantial' to 'perfect' agreement for most risk factors for injured snowboarders, including feature use.[27] Self-reported risk factors were confirmed with reliable sources where possible. The overall injury rate of TP snowboarders was estimated at 0.75/1000 runs. Feature-specific injury rates were higher for features that supported aerial manoeuvres or a large drop to the ground. Aerial features facilitate more air time and we hypothesise that snowboarders may have more opportunity to lose their sense of body position/orientation and land with more force and this increases the likelihood of injury.

Research suggests that TP injuries are more severe than those on regular slopes.[15 16 18] One study reported an overall TP injury rate of 0.62/1000 ski and snowboard days, including both skiers and snowboarders, but only ski patrol injuries.[15] If each skier and snowboarder took only one TP run during their day, this rate is lower than our observed rate. It is unknown if the TPs were similar in size or number of features. A literature review[34] reported that ski patrol-reported injuries among snowboarders varied from 2.1[35] to 7.0/[36]1000 outings; however, a TP-specific injury rate or the precise injury definition was not provided.

Half-pipes and jumps significantly predicted injury. Torjussen and Bahr[37] found professional snowboarders competing in half-pipe and big air competitions had a significantly higher injury risk compared with giant-slalom, where the snowboarder does not leave the ground.

Overall 34% of snowboarders listened to music through a personal music player. The unadjusted result indicated that listening to music reduced the odds of injury. In a laboratory setting, sport students listening to music while wearing a helmet with built-in speakers had similar mean reaction time to peripheral stimulus as those who were wearing a helmet but not listening to music.[38] Similar to non-TP research, snowboarding in suboptimal environmental (bad weather/visibility) conditions affected the odds of injury.[9] In contrast to previous research,[5–8] we found beginners had significantly reduced odds of injury; perhaps beginners realise they are in an environment beyond their skill level and choose easier features or do not use features as intended (eg, not leaving the ground when going over a jump).

Future research should identify and evaluate ways to reduce injuries without sacrificing participation, motor learning or skill development. Injury prevention should focus on risk mitigation.

Table 4 Feature-specific injury rate ratios and 95% CI

	All injuries			Severe injuries		
	Cases (n=277)*	Controls (rails) (n=39)	RR (95% CI)	Cases (n=176)†	Controls (rails) (n=21)	RR (95% CI)
Half-pipe	19	39	**6.03 (3.29 to 10.68)**	13	21	**7.66 (3.52 to 16.02)**
Jumps	85	39	**6.02 (4.07 to 9.03)**	59	21	**7.76 (4.65 to 13.45)**
Kickers	84	39	1.44 (0.98 to 2.17)	54	21	**1.72 (1.02 to 3.00)**
Mushroom	16	39	1.21 (0.63 to 2.21)	7	21	0.98 (0.35 to 2.40)
Boxes	62	39	**1.53 (1.01 to 2.35)**	37	21	1.70 (0.97 to 3.05)
Quarter-pipes	11	39	0.56 (0.26 to 1.12)	6	21	0.57 (0.19 to 1.46)

N, number; RR, rate ratio.
*Four snowboarders could not recall feature used at time of injury and 13 snowboarders were not using a feature at the time of injury but were in the boundaries of the terrain park (TP) for a total of 333 TP injuries.
†Two snowboarders could not recall feature used at time of injury and nine snowboarders were not using a feature at the time of injury but were in the boundaries of the TP for a total of 208 severe TP injuries. Bold refers to statistically significant results.

Table 5 Summary of the characteristics of all injured and uninjured snowboarders (crude OR and 95% CI)

	All injuries n=333 (%)	Severe injuries n=208 (%)	Minor injuries n=125 (%)	No injuries n=1261 (%)	All injuries† crude OR (95% CI)	Severe injuries† crude OR (95% CI)	Severe injuries‡ crude OR (95% CI)
Age mean (SD), years*	17.06 (0.29)	17.03 (0.37)	17.10 (0.49)	17.54 (0.15)	0.98 (0.96 to 1.01)	0.98 (0.95 to 1.01)	1.00 (0.96 to 1.04)
Missing	0	0	0	14 (1.1)			
Sex							
Female	42 (12.6)	28 (13.5)	14 (11.2)	119 (9.4)	1.36 (0.91to 2.00)	1.46 (0.91 to 2.30)	1.23 (0.60 to 2.65)
Missing	0	0	0	23 (1.8)			
Ability							
Beginner/novice	20 (6.0)	11 (5.3)	9 (7.2)	121 (9.6)	**0.43 (0.24 to 0.73)**	**0.40 (0.18 to 0.79)**	0.83 (0.29 to 2.45)
Intermediate	126 (37.8)	75 (36.1)	51 (40.8)	329 (26.1)	1.00	1.00	1.00
Advanced	126 (37.8)	82 (39.4)	44 (35.2)	299 (23.7)	1.10 (0.81 to 1.49)	1.20 (0.83 to 1.73)	1.27 (0.74 to 2.18)
Expert	49 (14.7)	32 (15.4)	17 (13.6)	84 (6.7)	1.52 (0.99 to 2.33)	1.67 (1.00 to 2.76)	1.28 (0.61 to 2.73)
Missing	12 (3.6)	8 (3.9)	4 (3.2)	428 (33.9)			
Snowboarding experience mean (SD), year*	5.70 (0.25)	5.80 (0.29)	5.48 (0.47)	5.98 (0.11)	0.98 (0.94 to 1.02)	0.99 (0.94 to 1.03)	1.02 (0.95 to 1.10)
Missing	88 (26.4)	40 (19.2)	48 (38.4)	48 (3.8)			
TP experience mean (SD), year*	3.92 (0.22)	4.08 (0.28)	3.57 (0.37)	4.15 (0.09)	0.98 (0.93 to 1.02)	0.99 (0.94 to 1.05)	1.05 (0.96 to 1.14)
Missing	91 (27.3)	43 (20.7)	48 (38.4)	72 (5.7)			
Listening to music							
Yes	69 (20.7)	51 (24.5)	18 (14.4)	425 (33.7)	**0.65 (0.47 to 0.88)**	0.74 (0.52 to 1.06)	1.58 (0.83 to 3.08)
Missing	57 (17.1)	24 (11.5)	33 (26.4)	11 (0.9)			
Wrist guards							
Yes	16 (4.8)	13 (6.3)	3 (2.4)	64 (5.1)	1.13 (0.60 to 2.01)	1.39 (0.69 to 2.61)	2.23 (0.59 to 12.48)
Missing	55 (16.5)	22 (10.6)	33 (26.4)	15 (1.2)			
Previous snowboard injury							
Yes	119 (35.7)	82 (39.4)	37 (29.6)	692 (54.9)	**0.61 (0.47 to 0.81)**	**0.64 (0.46 to 0.88)**	1.13 (0.66, 1.95)
Missing	60 (18.0)	24 (11.5)	36 (28.8)	20 (1.6)			
Temperature (°C)							
Above 10	23 (6.9)	17 (8.2)	6 (4.8)	189 (15.0)	**0.57 (0.34 to 0.93)**	0.72 (0.39 to 1.27)	2.00 (0.70 to 6.54)
0–10	145 (43.5)	85 (40.9)	60 (48.0)	685 (54.3)	1.00	1.00	1.00
−10–0	140 (42.0)	87 (41.8)	53 (42.4)	274 (21.7)	**2.45 (1.85 to 3.24)**	**2.59 (1.84 to 3.66)**	1.16 (0.70 to 1.92)
Below −10	25 (7.5)	19 (9.1)	6 (4.8)	113 (9.0)	1.06 (0.63, 1.71)	1.37 (0.76 to 2.38)	2.24 (0.79 to 7.22)
Missing	0	0	0	0			
Light							
Sunny	186 (55.9)	117 (56.3)	69 (55.2)	795 (63.1)	1.00	1.00	1.00
Cloudy	69 (20.7)	44 (21.2)	25 (20.0)	292 (23.2)	1.01 (0.73 to 1.38)	1.02 (0.69 to 1.50)	1.04 (0.56 to 1.93)
Night	73 (21.9)	44 (21.2)	29 (23.2)	174 (13.8)	**1.79 (1.29 to 2.49)**	**1.72 (1.14 to 2.55)**	0.89 (0.50 to 1.63)
Missing	5 (1.5)	3 (1.4)	2 (1.6)	0			
Snow							
Not groomed	24 (7.2)	13 (6.3)	11 (8.8)	122 (9.7)	0.74 (0.45 to 1.17)	0.63 (0.32 to 1.15)	0.69 (0.27 to 1.76)
Missing	7 (2.1)	4 (1.9)	3 (2.4)	7 (0.6)			

*Odds of injury increases for every increase in year.
†Compared with no injuries.
‡Compared with minor injuries.
N, numbers; N/A, not applicable.

Table 6 Association between injury and feature type after controlling for confounders (OR and 95% CI)

	All injuries vs no injuries*		Severe injuries vs no injuries*		Severe injuries vs minor injuries†	
	Crude OR (95% CI)	Adjusted OR (95% CI)	Crude OR (95% CI)	Adjusted OR (95% CI)	Crude OR (95% CI)	Adjusted OR (95% CI)
Half-pipe	**6.08 (3.39 to 10.89)**	**9.63 (4.80 to 19.32)**	**7.73 (3.76 to 15.86)**	**13.28 (5.84 to 30.19)**	1.86 (0.59 to 5.89)	2.25 (0.47 to 10.78)
Jumps	**4.11 (2.79 to 6.08)**	**4.29 (2.72 to 6.76)**	**5.30 (3.20 to 8.80)**	**5.97 (3.38 to 10.55)**	1.95 (0.89 to 4.25)	1.85 (0.62 to 5.49)
Kickers	1.42 (0.96 to 2.08)	**1.99 (1.27 to 3.12)**	**1.69 (1.02 to 2.82)**	**2.32 (1.31 to 4.12)**	1.54 (0.71 to 3.34)	1.40 (0.48 to 4.04)
Mushroom	1.07 (0.59 to 1.93)	**2.30 (1.20 to 4.41)**	0.87 (0.37 to 2.06)	1.88 (0.76 to 4.63)	0.67 (0.21 to 2.15)	0.45 (0.11 to 1.94)
Boxes	1.32 (0.88 to 1.98)	1.37 (0.85 to 2.20)	1.46 (0.85 to 2.51)	1.53 (0.83 to 2.81)	1.27 (0.57 to 2.85)	0.89 (0.30 to 2.69)
Quarter-pipes	**0.48 (0.24 to 0.94)**	0.51 (0.23 to 1.13)	0.48 (0.19 to 1.20)	0.57 (0.21 to 1.55)	1.03 (0.27 to 3.94)	1.61 (0.25 to 10.45)

*Adjusted for previous injury, ability and temperature. Age, sex, listening to music, wearing wrist guards and light and snow conditions did not change any of the feature-specific estimates more than 15%.
†Adjusted for music and light. Age, sex, ability, wrist guard use and temperature and snow conditions did not change any of the feature-specific estimates more than 15%.

Possible strategies include marking landings, smaller TPs for progression to larger features, marking feature difficulty, controlling speed and slope for take-offs and landings, enforcing TP etiquette rules or reducing the height of aerial features. Further research is needed to develop guidelines regarding optimal TP design. The efficacy of these strategies should be investigated.

Limitations

Snowboarders who climbed up to reattempt features were counted as one run, which would underestimate the number of TP runs. Injured snowboarders who did not present to the ski patrol or either of the two nearest EDs were missed. This selection bias resulted in rate underestimation and observed associations between feature and injury would be overestimated if missed snowboarders were injured on rails. However, only 47 (14%) of the included snowboarders said they saw the ski patrol and a non-participating healthcare provider, indicating that most sought treatment at a participating ED.

There was potential misclassification by feature if the injured snowboarder could not recall the feature; however, this occurred only four times. Controls may not have correctly reported their feature use when the RA could not see the entire TP and it was not possible to determine the reliability of controls' feature use. This could have an unpredictable effect on the ORs if it operated differently by feature type. Only age-group and sex of the uninjured controls could be assessed for accuracy and our observations were found to be valid. There was potential for misclassification of severe injury because factors other than severity could predict presentation to the ED, such as parental fear or anxiety influenced by a recent celebrity skiing death.[39] It was unknown if non-consenting injured snowboarders presented to a non-study ED and were incorrectly classified as a minor injury. Fortunately, few who saw the ski patrol went to a non-study ED (8%).

It is possible that some important confounders were overlooked, such as first attempt at a new feature, manoeuvre performed, speed, fatigue, height or weight. There may be behavioural confounders, such as peer pressure to attempt difficult features or manoeuvres. However, some of these potential confounders were likely accounted for by other variables such as ability, age and sex. Although this study was conducted at only one resort, the TP layout changed four times during the two seasons and this enhances the generalisability of the results.

CONCLUSION

Feature-specific injury rates ranged from 2.56 injuries/1000 runs (jumps and half-pipe) to 0.24 injuries/1000 runs (quarter-pipe). Half-pipe, jumps and kickers were significant risk factors for any injury and severe injury. Recommendations have been made for prevention strategy development to reduce TP injury risk. These strategies will require rigorous evaluation.

What are the new findings?

- In this study, the overall injury rate for snowboarding terrain park (TP) injuries is 0.75 injuries/1000 runs.
- The injury rates are highest for jumps (2.56/1000 runs) and half-pipe (2.56/1000 runs) and lowest for rails (0.43/1000 runs) and quarter-pipes (0.24/1000 runs).
- Compared with rails, the odds of injury is significantly higher on the half-pipe (OR 9.63; 95% CI 4.80 to 19.32) and jumps (OR 4.29; 95% CI 2.72 to 6.76).

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

- Terrain parks (TPs) are popular and the majority of snowboarders injured in the TP present to the emergency department.
- With the identification of potential risk factors for TP injuries among snowboarders, injury prevention programmes can be tailored to those at greatest risk of injury.
- Should these programmes be effective, clinicians can expect to treat fewer snowboarders injured in the TP.

Acknowledgements The authors thank the research assistants for their role in data collection and the Ski Patrol.

Contributors All authors contributed to the conception and design, or analysis and interpretation of data; drafting the article or revising it critically for important intellectual content and gave final approval of the version to be published. KR conceived and designed the study, co-ordinated the study, collected data, conducted the analysis, drafted the manuscript and provided methodological expertise. JW collected data, conducted the analysis, and drafted the manuscript, and critically revised and approved the submitted manuscript. NR participated in data collection, and critically revised and approved the submitted manuscript. WM, AN-A, CE, BR, CG and BH conceived and designed the study, provided methodological expertise, and critically revised and approved the submitted manuscript. BH is the guarantor of this study.

Funding This work was supported by the Canadian Institutes of Health Research Strategic Team in Applied Injury Research—Child and Youth (TIR-104028).

Competing interests KR was supported by a Doctoral Studentship from AHFMR. BEH holds the Alberta Children's Hospital Foundation (ACHF) Professorship in Child Health and Wellness, funded through the support of an anonymous donor and the Canadian National Railway Company, as well as the Alberta Heritage Foundation for Medical Research (AHFMR) Population Health Investigator (PHI) and CIHR New Investigator Awards. CAE is supported by an AHFMR PHI award, a New Investigator Award from CIHR and a Professorship in Pediatric Rehabilitation from the Department of Paediatrics (ACHF), Faculty of Medicine. BHR is supported as a 21st Century Canada Research Chair in Evidence-Based Emergency Medicine by the CIHR by the Government of Canada (Ottawa, ON). JW received summer studentship support from the University of Calgary Program for Undergraduate Research Experience, O'Brien Centre Bachelor of Health Sciences programme, and Alberta Children's Hospital Research Institute for Child and Maternal Health, CIHR Training Program in Genetics, Child Development and Health. BEH had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. The funders were not involved in the design and conduct of the study; collection, management, analysis and interpretation of the data; and preparation, review or approval of the manuscript.

Ethics approval University of Calgary Conjoint Health Research Ethics Board.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1 Emery CA, Meeuwisse WH, McAllister JR. Survey of sport participation and sport injury in Calgary and area high schools. *Clin J Sport Med* 2006;16:20–6.
2 Canadian Ski Council. *Canadian skier and snowboarder—facts and stats*. Collingwood, ON: Canadian Ski Council, 2010.
3 Kim S, Endres NK, Johnson RJ, *et al*. Snowboarding injuries: trends over time and comparison with alpine skiing injuries. *Am J Sports Med* 2012;40:770–6.
4 Sulheim S, Holme I, Rødven A, *et al*. Risk factors for injuries in alpine skiing, telemark skiing and snowboarding—case-control study. *Br J Sports Med* 2011;45:1303–9.
5 Ronning R, Ronning I, Gerner T, *et al*. The efficacy of wrist protectors in preventing snowboarding injuries. *Am J Sports Med* 2001;29:581–5.
6 Shealy JE, Ettlinger CF. Gender-related injury patterns in skiing. In: Mote CD Jr., *et al*., eds. *Skiing trauma and safety: tenth volume*. Philadelphia: American Society for Testing and Materials, 1996:45–57. 1996 1996.

7 Boldrino C, Furian G. Risk factors in skiing and snowboarding in Austria. In: Johnson RJ, eds. *Skiing trauma and safety: twelth volume, ASTM STP 1345*. West Conshohocken, PA: American Society for Testing and Materials, 1999:166–74.
8 Langran M, Selvaraj S. Increased injury risk among first-day skiers, snowboarders, and skiboarders. *Am J Sports Med* 2004;32:96–103.
9 Hasler RM, Berov S, Benneker L, *et al*. Are there risk factors for snowboard injuries? A case-control multicentre study of 559 snowboarders. *Br J Sports Med* 2010;44:816–21.
10 Russell K, Christie J, Hagel BE. The effect of helmets on the risk of head and neck injuries among skiers and snowboarders: a meta-analysis. *Can Med Assoc J* 2010;182:333–40.
11 Russell K, Hagel B, Francescutti LH. The effect of wrist guards on wrist and arm injuries among snowboarders: a systematic review. *Clin J Sport Med* 2007;17:145–50.
12 Ishimaru D, Ogawa H, Wakahara K, *et al*. Hip pads reduce the overall risk of injuries in recreational snowboarders. *Br J Sports Med* 2012;46:1055–8.
13 Fernie. RCR Focuses on Terrain Park Safety by Removing Jumps [August 21, 2008].
14 Bridges EJ, Rouah F, Johnston KM. Snowblading injuries in Eastern Canada. *Br J Sports Med* 2003;37:511–15.
15 Brooks MA, Evans MD, Rivara FP. Evaluation of skiing and snowboarding injuries sustained in terrain parks versus traditional slopes. *Inj Prev* 2010;16:119–22.
16 Moffat C, McIntosh S, Bringhurst J, *et al*. Terrain park injuries. *Western J Emerg Med* 2009;10:257–62.
17 Greve MW, Young DJ, Goss AL, *et al*. Skiing and snowboarding head injuries in 2 areas of the United States. *Wilderness Environ Med* 2009;20:234–8.
18 Goulet C, Hagel B, Hamel D, *et al*. Risk factors associated with serious ski patrol-reported injuries sustained by skiers and snowboarders in snow-parks and on other slopes. *Can J Public Health* 2007;98:402–6.
19 Ruedl G, Kopp M, Sommersacher R, *et al*. Factors associated with injuries occurred on slope intersections and in snow parks compared to on-slope injuries. *Accid Anal Prev* 2013;50:1221–5.
20 Ruedl G, Schobersberger W, Pocecco E, *et al*. Sport injuries and illnesses during the first Winter Youth Olympic Games 2012 in Innsbruck, Austria. *Br J Sports Med* 2012;46:1030–7.
21 Bahr R, Krosshaug T. Understanding injury mechanisms: a key component of preventing injuries in sport. *Br J Sports Med* 2005;39:324–9.
22 Meeuwisse WH, Hagel BE, Emery CE, *et al*. A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clin J Sports Med* 2007;17:215–19.
23 Hagel BE, Russell K, Goulet C, *et al*. Helmet use and risk of neck injury in skiers and snowboarders. *Am J Epi* 2010;171:1134–43.
24 Tarazi F, Dvorak MF, Wing PC. Spinal injuries in skiers and snowboarders. *Am J Sports Med* 1999;27:177–80.
25 Mueller BA, Cummings P, Rivara FP, *et al*. Injuries of the head, face, and neck in relation to ski helmet use. *Epidemiol* 2008;19:270–6.
26 Stuart AA. A test for homogeneity of the marginal distributions in a two-wy classification. *Biometrika* 1955;42:412–16.
27 Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977;33:159–74.
28 Ulm K. A simple method to calculate the confidence interval of a standard mortality ration (SMR). *Am J Epi* 1990;131:373–5.
29 Rothman KJ, Greenland S, Lash TL, eds. *Modern epidemiology*. Philadelphia, PA: Lippincott Williams & Wilkins, 2008:116.
30 Mickey RM, Greenland S. The impact of confounder selection criteria on effect estimation. *Am J Epidemiol* 1989;129:125–37.
31 Harrell FEJ, Lee KL, Mark DB. Multivariable prognostic models: issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors. *Stat Med* 1996;15:361–87.
32 Royston P. Multiple imputation of missing values: further update of ice, with an emphasis on categorical variables. *Stata Journal* 2009;9:466–77.
33 Stata. 11 ed. College Station, TX: StataCorp LP, 2009.
34 Russell K, Hagel BE, Goulet C. Snowboarding. In: Caine DJ, Harmer PA, Schiff MA, eds. *Epidemiology of injury in olympic sports. The encyclopedia of sports medicine. 16*. Chicester, West Sussex: Blackwell Publishing Ltd, 2010:447–72.
35 Lipskie TL, Birkett N, Pickett W, *et al*. Risk for snowboarding and skiing injury. *Am J Epidemiol* 2001;153:S72.
36 Shealy JE, Ettlinger CF. Third end of decade analysis of snow sports injuries in the USA. *Knee Surg Sports Traumatol Arthrosc* 2004;12:171.
37 Torjussen J, Bahr R. Injuries among elite snowboarders (FIS Snowboard World Cup). *Br J Sports Med* 2006;40:230–4.
38 Ruedl G, Pocecco E, Wolf M, *et al*. Does listening to music with an audio ski helmet impair reaction time to peripheral stimuli? *Int J Sports Med* 2012;33:1016–19.
39 Keays G, Pless IB. Impact of a celebrity death on children's injury related emergency room visits. *Can J Public Health* 2010;101:115–18.