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Mechanisms of injuries in World Cup Snowboard Cross: a systematic video analysis of 19 cases

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ABSTRACT

Background Snowboard cross (SBX) became an official Olympic sport in 2006. This discipline includes manoeuvring several obstacles while competing in heats. It is common for the riders to collide, making this sport both exciting and at risk of injuries. Although a recent study from the 2010 Olympic Games has shown that the injury risk was high, little is known about the injury mechanisms.

Objective To qualitatively describe the injury situation and mechanism of injuries in World Cup Snowboard Cross.

Study design Descriptive video analysis.

Methods Nineteen video recordings of SBX injuries reported through the International Ski Federation Injury Surveillance System for four World Cup seasons (2006 to 2010) were obtained. Five experts in the field of sports medicine, snowboard and biomechanics performed analyses of each case to describe the injury mechanism in detail (riding situation and rider behaviour).

Results Injuries occurred at jumping (n=13), bank turning (n=5) or rollers (n=1). The primary cause of the injuries was a technical error at take-off resulting in a too high jump and subsequent flat-landing. The rider was then unable to recover leading to fall at the time of injury. Injuries at bank turn was characterised by a pattern where the rider in a balanced position lost control due to unintentional contact with another rider.

Conclusion Jumping appeared to be the most challenging obstacle in SBX, where a technical error at take-off was the primary cause of the injuries. The second most common inciting event was unintentional board contact between riders at bank turning.

INTRODUCTION

A study from the 2010 Vancouver Olympic Games reported that the injury risk in snowboard cross (SBX) was the highest of all the Olympic events.[1] Recent data from the International Ski Federation (FIS) Injury Surveillance System (ISS) show that during the 5-month FIS snowboard World Cup (WC) season, on average one in every three riders sustained a time-loss injury.[2] In WC competition, the incidence was reported as 2.1 time-loss injuries per 1000 runs from one WC season,[3] whereas data from the FIS ISS from four WC season suggests a rate as high as 8.5 injuries per 1000 runs.[4] Thus, attention needs to be directed at how to prevent SBX injuries.

Understanding the mechanism of injuries is essential for their prevention.[5–7] In SBX, riders are required to manoeuvre past multiple obstacles (jumps, narrow crescent-shaped turns, kickers, gates and rollers) in two individual qualification runs, then in heats of four or six.[8 9] It is not uncommon for riders to collide as they compete for the front position in heats.[10] It is hypothesised that these potential external risk factors, combined with high speed, may contribute to injury. In addition, loss of control from accidental body contact may lead to high-risk situations.[1] However, little is known about the injury mechanisms in SBX.

Torjussen and Bahr[3] reported falling at an obstacle and collisions as the main injury mechanisms based on retrospective interviews of WC SBX riders. Jumping, which is an important feature of the SBX discipline, is thought to be another common cause of injuries for both recreational[11–14] and professional snowboarders.[2 3 15] Zygmuntowicz and Czerwinski[16] suggested that jumping-related injuries among freestyle riders in national snowboard clubs was a result of technical mistakes and rider errors, such as losing control, catching an edge and risk-taking.

Videos of actual injuries contain important injury information. Previous studies in team sport and alpine skiing have provided detailed description of the playing situation, athlete–opponent interaction and joint biomechanics for non-contact anterior cruciate ligament (ACL) and ankle injuries through systematic analyses of video recordings.[17–19] The authors' aim was to describe mechanisms of injuries, in terms of the riding situation and rider behaviour, in WC SBX riders based on systematic analyses of video recordings.[6 20]

METHODS

Injury and video recording

We obtained video recordings of injuries reported through the FIS ISS for four WC seasons (from 2006 to 2010). The FIS ISS was based on retrospective interviews with all athletes, coaches and medical staff from 20 snowboard WC teams.[2 21] Only injuries leading to absence from competition or training for at least 1 day were included in this study. In total, 63 injuries were reported, 51 of these occurred during WC competition, World Snowboard Championships (WSC) and Olympic Winter Games (OWG) (figure 1).

In collaboration with the TV producer, Infront (Italy), we obtained recordings of the entire run of 22 injuries from WC competition, all from final runs. Four were excluded. In one case, the rider did not start in the run obtained on video, whereas in the other three no injuries were identified or not visible (due to heavy fog). Additional footage of injuries from the OWG was obtained directly from the International Olympic Committee (IOC). Of

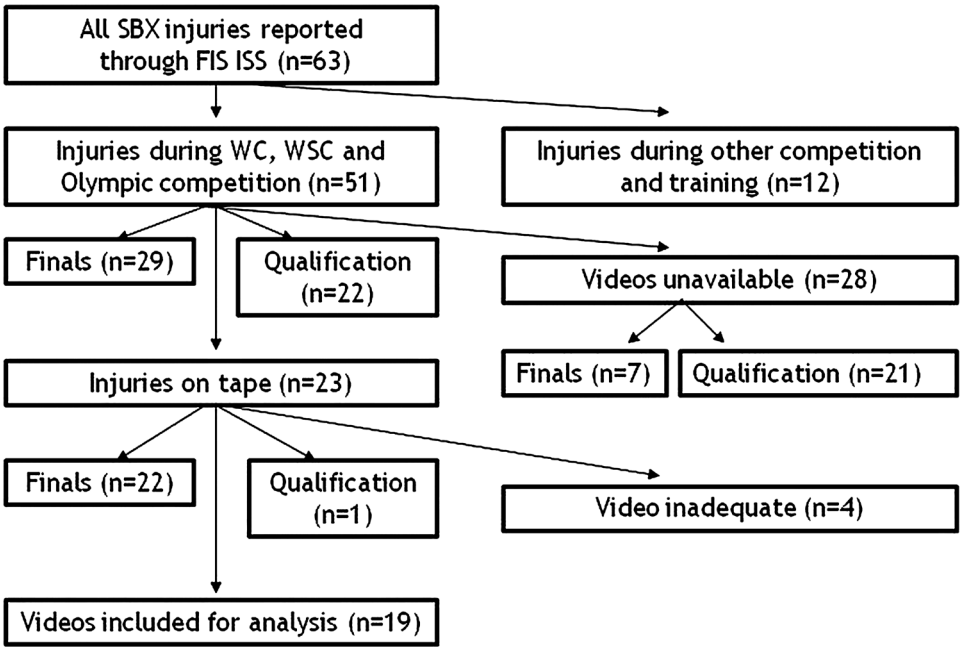

Figure 1 Flow chart showing the process to identify videos of injuries in snowboard cross in World Cup, World Snowboard Championships and Olympic Winter Games based on injury registration through the International Ski Federation Injury Surveillance System (2006-2010).

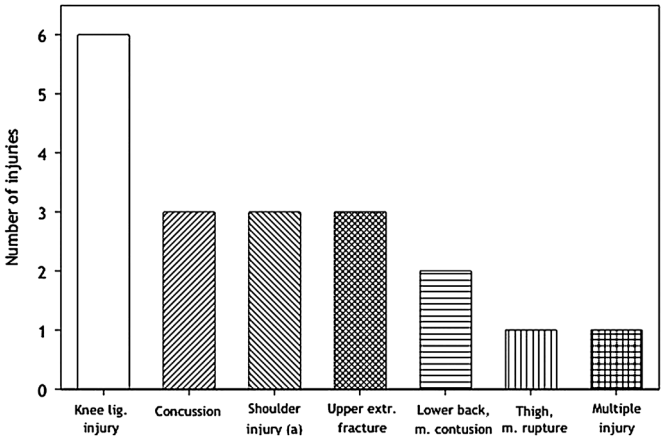

Figure 2 Injury type and location of the injuries included in the video analysis based on injury registration through the International Ski Federation Injury Surveillance System. [(a)]The category shoulder injury includes dislocation, fracture and ligament injury.

the five injuries reported through FIS ISS, the authors captured one injury from a qualification run-on video. In total, we managed to obtain 19 injuries for video analysis, 18 from final runs and one from qualification run. Fourteen of these were captured from one camera angle and six from two camera angles.

Video processing

The 19 videos were mainly received as analogue video files on BetaCam SP (n=18). One version of each video was edited in Final Cut Pro version 6.06 (Apple, Cupertino, California, USA) to include the rider situation from one or two obstacles prior to the injury situation and until the rider came to a full stop. In addition, the starting position was included to allow easy identification of the rider for the analysis. One video was received in digital .avi-format from the IOC TV producer. Analogue files were digitised to PAL-DV 48 kHz. All files were then transcoded to QuickTime (.mov) files in 4:3 formats, which enabled us to analyse the files using QuickTime Player (version 7, Apple, Cupertino, California, USA). In two cases, the authors de-interlaced the videos in order to improve the quality for the analysis by increasing the effective frame rate from 25 to 50 Hz using Adobe Photoshop (CS2 Adobe System Inc, San Jose, California, USA).

Video analysis

The authors developed a specific analysis form for SBX based on previous forms for alpine skiing, handball and football.[17–19] The form included open and closed questions regarding (a) the circumstances of injury, (b) the rider situation and (c) rider behaviour (table 1). Five experts in the fields of sports medicine, snowboard and biomechanics formed the analysis team. First, they independently reviewed the injury tapes to estimate the time of the injury, referred to as the index frame. During this phase, the experts were blinded to the opinion of the others, but we provided them injury information on each case (sex, specific diagnosis, injured side and riding style). The videos were then reviewed in a group session to reach a consensus on the index frame. Following the consensus meeting, the experts analysed each video independently to complete the form. Additionally, if experts judged the injury to occur in conjunction with jumping (take-off or landing), they were asked to draw an estimated optimal course-line and the actual course-line taken by the injured rider on topographical sketches of the course/obstacle profile, which the authors prepared in advance for each case using CAD software (Microstation V8i, Bentley Systems, Exton, Pennsylvania, USA).

The final analyses were done in group meetings where the experts carefully reviewed each case based on their completed forms and sketches to reach consensus on the circumstances and mechanisms of injury. Each video was examined as many times as needed to obtain a consensus on all categorical variables. If less than three experts could agree, the variable was reported as 'no consensus'.

Table 1 Variables and categories used in the analysis form to describe the injury situation of each injury case

Variable	Categories
General/environment	
Visibility	Good, reduced, unsure
Snow condition	Icy, hard, soft, unsure
Weather condition	Clear, foggy, snowy, unsure
Type of terrain	Flat, medium, steep, flat to steep, steep to flat/compression, dosed, unsure
Piste condition	Smooth, rough/bumpy, changes frequently, unsure
Preceding the injury (one/two obstacles before the index frame)	
Riding situation	Jumping, bank turning, giant slalom turn, riding on rollers, gliding/straight riding, unsure
If jumping, what type	Single, double, triple jump, spines, step up, step down, table top, unsure
If turning, which phase	Initiation, middle, end, change of turns, change of turn to jump, change of turn to roller, unsure
Loss of control	Yes, no, unsure
Gate contact	Yes, no, unsure
Security net	Yes, no, unsure
Is the rider riding an inappropriate course-line	Yes, no, unsure
If yes, caused by	Timing, opponent, inappropriate strategy, previous obstacle, unsure
Regains control from previous obstacle	Yes, no, unsure
Technique	On edge forward, on edge backward, flat loaded, unsure
Balance	In balance, out of balance
Weight distribution	Equally, mainly on leading leg, mainly on back leg, unsure
If jumping (questions in relation to the sketches)	
Speed in relation to course setting	High, normal, unsure
Speed influence of controlling the jump	Yes, no, unsure
Course-line influence on the injury	Yes, no, unsure
Technical error influence ability to control jump	Yes, no, unsure
Contact	
Any contact	Yes, no, unsure
Type of contact	Intentional, unintentional, unsure
Influence on rider control	Yes, no, already lost control, unsure
Influence on injury	Yes, no, unsure
What is in contact	Board, trunk, arms, head/neck, unsure
Who causes contact	Injured rider, opponent, unsure
Position of the rider who causes contact	In front, behind, beside, unsure, other please describe
Course at contact	Wide, narrow, unsure
Course of influence on contact	Yes, no, unsure
Attention (ie, what is the rider focusing on)	Opponent, the piste, unsure, other please describe
Open question	Please describe the rider situation leading to the injury in your own words

Statistical analysis

As a measure of the accuracy of the index frame estimates, the authors reported the mean absolute deviation (in ms) of the individual estimate from the index frame determined in the consensus meeting.

RESULTS

Injury characteristics

The majority of injuries were to the knee (n=6) and upper extremity (n=6) (figure 2). The most severe injuries occurred when landing from a jump; five of the knee injuries and the two back injuries occurred after landing, and in another case the rider sustained multiple injuries to the thorax, abdomen and shoulder (table 2).

Riding situation and rider behaviour

Thirteen of the 19 injury situations occurred at jumps, five while turning in crescent banks and one while riding on rollers (table 2). In 13 cases, the rider had already lost control before the time of injury (mainly leading to a fall), in three cases due to contact with another rider. In total, 6 of the 19 cases resulted from contact with another rider, whereas in two cases this was not possible to judge. All contacts were unintentional, but influenced rider control and the subsequent injury. Most contacts occurred during bank turning (n=4) followed by jumping (n=2) (table 2).

Jumping-related injuries

Of the 13 jumping-related injuries, nine were caused by an individual technical error (losing control, catching the edge or timing of jump), two by contact with another rider, one by an inappropriate course-line at take-off and one by too high speed at take-off. Of the nine technical errors, five occurred at take-off, three at landing, whereas the experts were uncertain in one case (table 2).

The most common technical error at take-off was a too-high-jump trajectory, which resulted in a flat-landing. As a result, the rider was unable to recover when landing (compression), leading to a fall and injury (cases #1–5). A similar mechanism

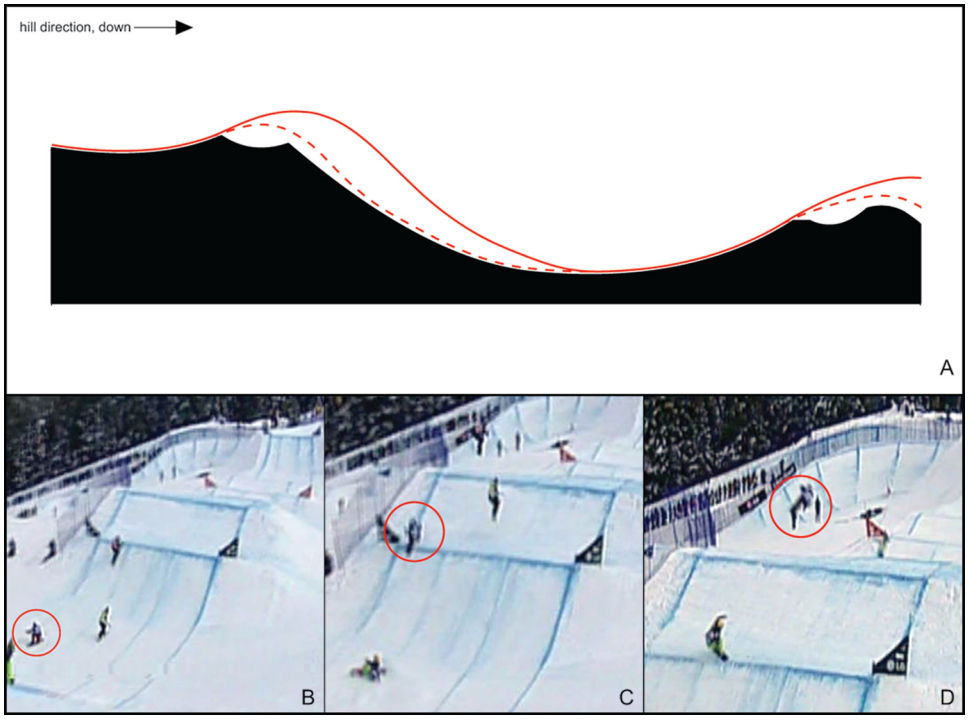

Figure 3 Injury 4: technical error at take-off. (A) Sectional view of the jump showing the trajectory the injured rider (continuous line is injured rider, broken line is assumed optimal line based on trajectory of other riders). (B) The injured rider lands flat and leaning backwards after a technical error from previous jump, is unable to recover. (C) Leading to unbalanced position at take-off on following jump (injury site). (D) As a result, unable to control jump, uncontrolled flight.

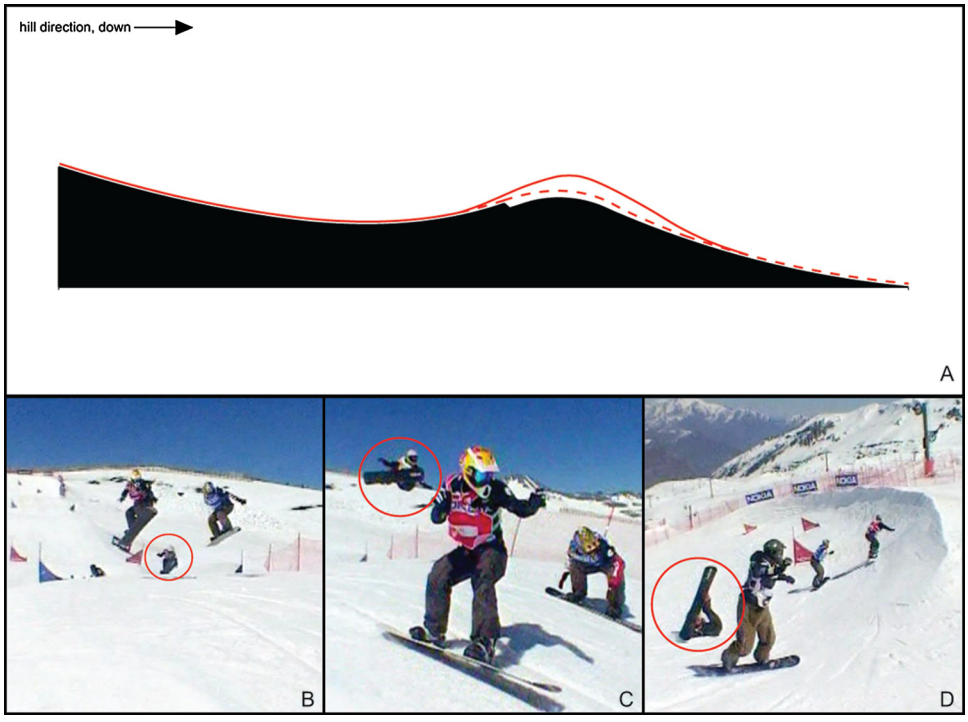

Figure 4 Injury 2: technical error at take-off. (A) Sectional view of the jump showing the trajectory taken by the injured rider (continuous line is injured rider, broken line is assumed optimal line). (B) The rider (circled) loses control at take-off. (C) Leading to uncontrolled flight with a high-speed trajectory. (D) The injured rider lands flat, outside the piste with a head fall (concussion).

was also assumed in two other cases. In the first case, the rider chose an inappropriate course-line into the jump, which resulted in long air-time and a flat-landing outside the piste (case #10). In the second case, the rider gained too high speed from an outer position out of a bank turn leading to a high-jump trajectory with long air-time. The landing in this case was not possible to fully visualise on video, but was assumed to be flat (case#11) (figures 3,4).

Table 2 Results from video analysis of the riding situation preceding the injury in SBX

				Riding situation					Contact				
										Influence on			
Case #	Specific diagnosis	Sex*	Accuracy (ms)†	Out of balance	Course-line	Speed	Technical error	Location of error	Contact	Injured rider	Rider control	Injury	Position**
Jumping													
1	Concussion	M	±30	Lost balance	Inappropriate	Normal	Yes	Take-off	No contact				
2	Concussion	F	±160	Lost balance	Appropriate	Normal	Yes	Take-off	No contact				
3	Fracture UE††/radius	M	±70	Backwards	Inappropriate	Normal	Yes	Take-off	Unsure				
4	Contusion low back	F	±110	Lost balance	Appropriate	Normal	Yes	Take-off	No contact				
5	Multiple trauma	M	±230‡	Lost balance	Inappropriate	Normal	Yes	Take-off	No contact				
6	Quadriceps rupture‡‡	F	±490¶	Lost balance	Appropriate	Normal	Yes	Landing	No contact				
7	Knee injury/ligament	M	±490§	Forwards	Appropriate	Normal	Yes	Landing	No contact				
8	Muscle injury low back/pelvis	M	±200‡	Lost balance	Appropriate	Normal	Yes	Landing	No contact				
9	Knee injury/ACL	M	±130	Backwards	Appropriate	Normal	Yes	Unsure	No contact				
10	Knee injury/ACL	M	±160	Lost balance	Inappropriate	Normal	Unsure	Take-off	No contact				
11	Knee injury/ACL	M	±125	Lost balance	Appropriate	High	Unsure	Take-off	No contact				
12	Knee injury/twisted	F	±30	Lost balance	Appropriate	Normal	No		Board/board Arms/arms	Active	Yes	Yes	Behind
13	Shoulder injury/ligament	M	±80	Lost balance	Appropriate	Normal	No		Board/board	Passive	Yes	Yes	In front
Bank turn													
14	Shoulder injury/AC§§	M	±110	In balance	Appropriate				Board/board	Both	Yes	Yes	Unsure
15	Fracture UE††/forearm	M	±40	In balance	Appropriate				Board/board	Passive	Yes	Yes	In front/beside
16	Concussion	F	±310‡	Lost balance	Inappropriate				Board/board	Active	Yes	Yes	In front
17	Knee injury/MCL¶¶	F	±50	In balance	Appropriate				Board/board Trunk/trunk Arms/arms	Passive	Yes	Yes	In front
18	Shoulder injury/ligament	M	±50	Forward	Inappropriate				Unsure				
Rollers													
				Index frame					Alternative index frame				
19	Fracture UE††/thumb	M	±340¶	Forward	Appropriate				Board/hand	Active	Already lost control	Yes	In front

*Sex, male (M), female (F).
†Accuracy, mean of the absolute deviations of the initial, individual estimates from the index frame determined in the consensus meeting
‡One outlier relative to consensus.
§Two outliers.
¶Consensus based on three experts.
**Position, position of the rider who caused the contact.
††UE, upper extremity.
‡‡Injury sustained in qualification run (individual run).
§§AC, acromioclavicular joint injury.
¶¶MCL, medial collateral ligament.
ACL, anterior cruciate ligament; SBX, snowboard cross.

In three landing situations, the rider appeared to be in control at take-off and in the air, but lost control and/or caught an edge when landing, leading to a fall and injury (cases #6–8, figure 5).
The final two jumping-related cases were caused by one rider losing control and/or caught an edge when landing and consequently caught the board of another rider. The other rider then lost balance, leading to a fall and injury (cases#12–13).

Bank turn injuries

The second most common injury situation was turning in crescent banks (n=5). In all but one case a rider in a balanced position lost control due to contact with another rider (table 2, cases #14–17). Contact was caused by another rider in two cases, by the injured rider in one and both in one situation. In all situations, the rider causing the contact was in front. In three of the four contact situations, the rider who caused contact changed the position during the turn from inner to outer position riding into the course-line of the other rider, and caused contact by catching the board of the other rider. The injured rider then lost control leading to a fall at the time of injury (figures 6, 7). In one of these three cases, the rider hooked a gate with the board in an unbalanced position after contact with another rider (case#16).

The remaining two cases represent mechanisms different from the cases above. During the completion phase of the turn, another rider lost control and fell in front of the injured rider, thereby caused contact (case#17). In the final case no contact occurred. In a change of turn to roller, the rider was forced to take an inappropriate course-line by the other rider. The rider came out of balance forward, which led to a fall at time of injury (case#18).

Roller injuries

In one case the rider lost balance forward on a roller as a consequence of a technical error from the previous roller. In an

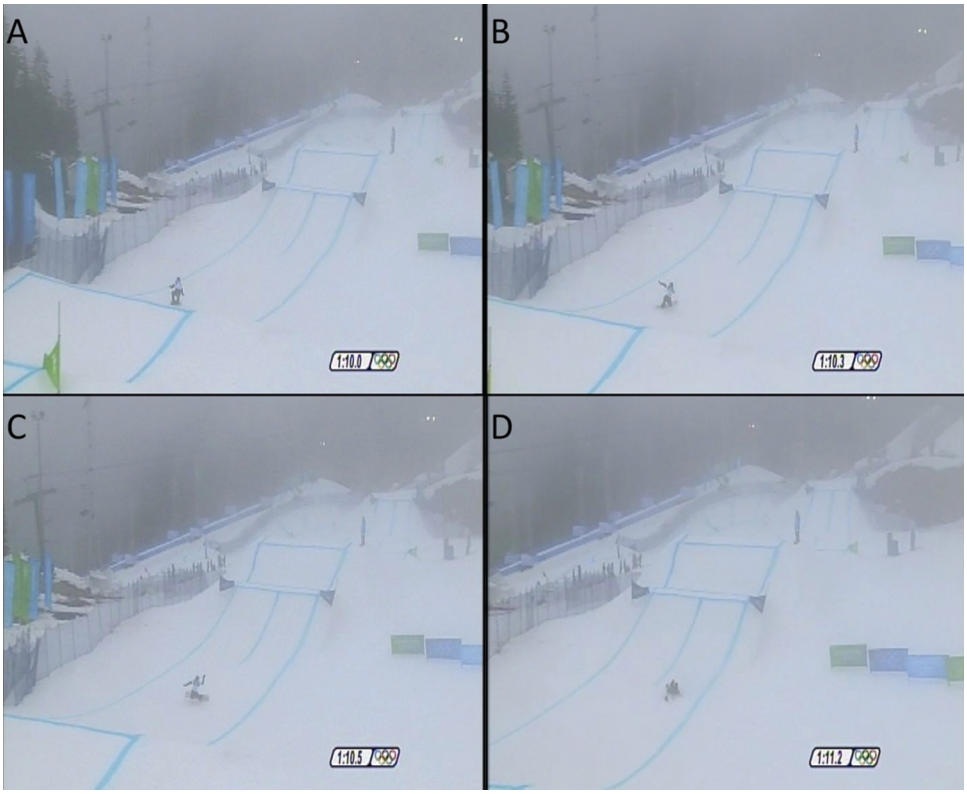

Figure 5 Injury 7: technical error at landing. (A) The rider lands out of balance backwards. (B) The rider tries to recover with a heel turn, (C) catches the edge and (D) falls backwards.

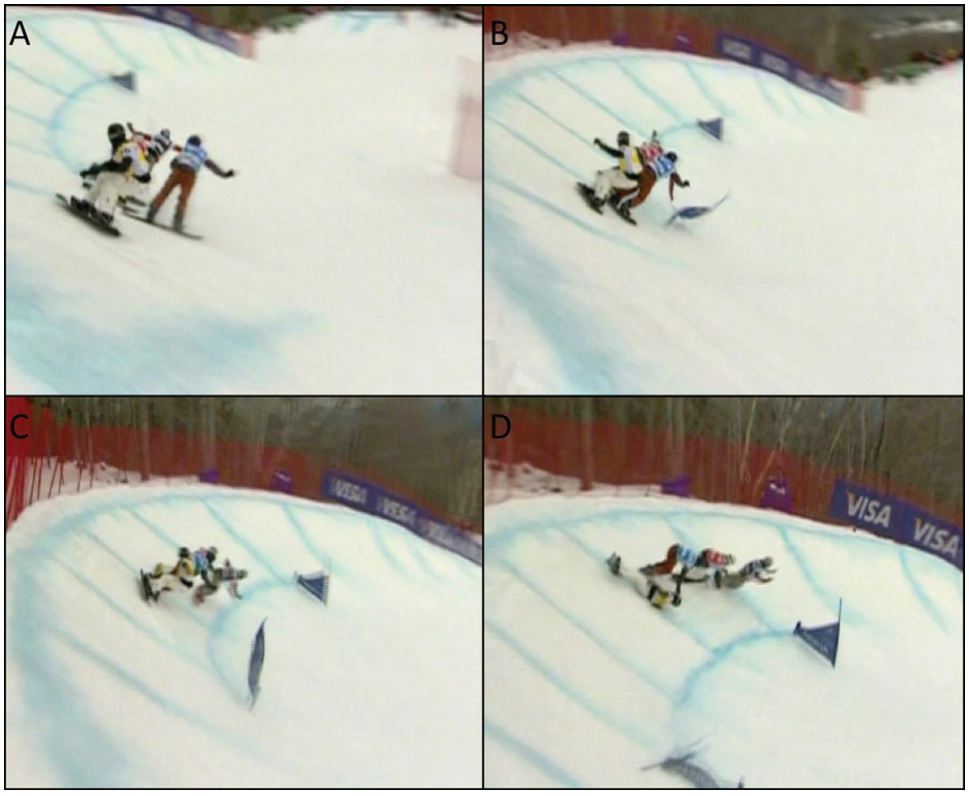

Figure 6 Injury 16: bank turn injury, contact. (A) The other rider (blue jersey) in an inner position at initial phase of bank turn. (B) The other rider changes position from inner to outer position, riding into the course-line of the injured rider (yellow jersey) and (C) causing contact by catching the board of the injured rider. (D) As a result the injured rider loses balance and falls onto the shoulder (index frame).

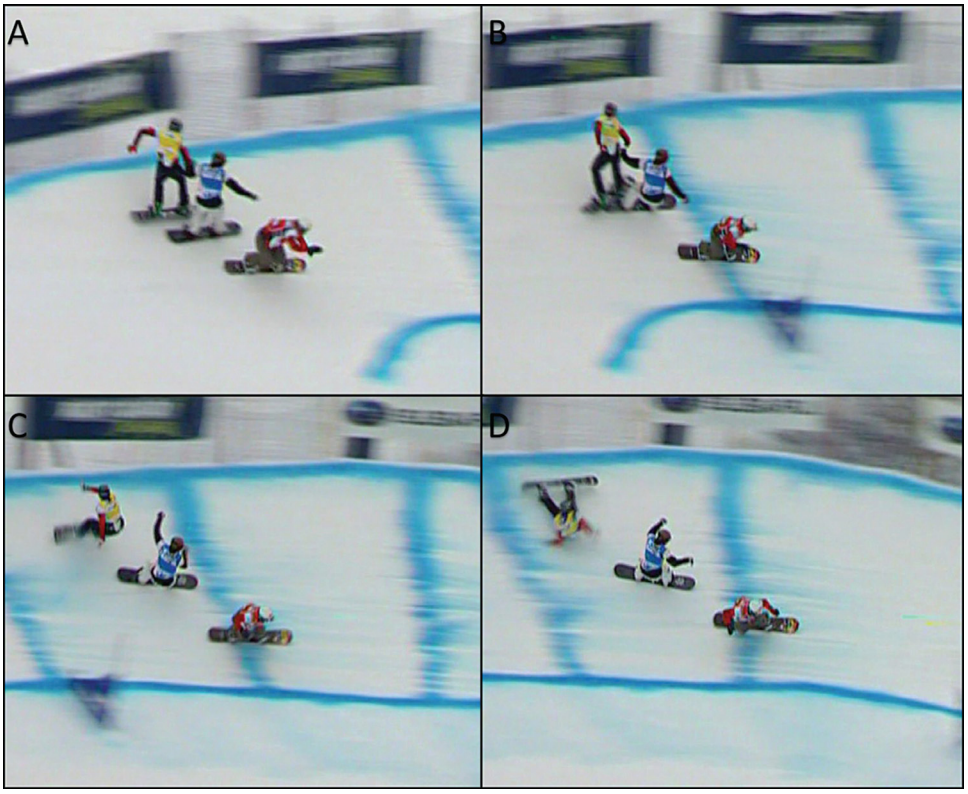

Figure 7 Injury 15: bank turn injury, contact. (A) The rider in the red jersey has the inner position in the initial phase of a bank turn. (B) The red rider forces the blue rider to change position from inner to outer, riding into the course-line of the injured rider (yellow jersey). (C) Causes contact by catching the board to the injured rider. (D) As a result, the injured rider loses balance and falls onto his outstretched hand and sustains a fracture of the forearm.

attempt at regaining balance, the rider leaned on his hand resulting in injury (case#19).

DISCUSSION

This is the first study to examine the injury mechanisms in WC SBX based on systematic video analyses. The principal finding was that most of the injuries resulted from an individual technical error at take-off when jumping. The second most common inciting event was unintentional board contact between riders at bank turning.

Riding situation

All injuries in this study occurred when jumping, bank turning and at rollers. Jumping accounted for over half of the injury cases. Previous studies on recreational snowboarders have also shown that jumping is associated with high injury rate.[11–14 22–24] However, in contrast to jumps in snowboard parks, in SBX competition the jumps are designed to facilitate speed and less airtime,[8] with a jump trajectory following the course profile as closely as possible.[25] Interestingly, we found in the majority of the cases that the injury was caused by an individual technical error (wrong timing, incorrect damping at take-off, losing control or catching the edge). This is supported by previous findings on freestyle snowboarders in national snowboard clubs.[16] Furthermore, we identified that half of the technical errors were at take-off, resulting in a too-high-jump trajectory and a flat-landing beyond the intended landing zone. The rider was then unable to recover during the landing phase, which led to a fall at the time of injury. This mechanism corresponds very well with one rider's perspectives on how jump injuries occur (Stian Sivertzen, Norwegian Team SBX rider, personal communication, May 2011). Although it appeared that the technical errors happened without interference from other riders, he commented that riders often feel stressed by the other riders as they try to maintain their position in the heat, thus forcing errors.

For injuries occurring at bank turns (n=5), four happened as a result of an unintentional board contact between riders. We observed a pattern were the rider who caused the contact changed from inner to outer position during the turn, riding into the course-line of the other rider. The injured rider lost control due to board contact, which led to a fall. An explanation for these injuries may be the design of the turns. Although the turns were rated as wide in the majority of the cases, the experts pointed out that the actual riding space was narrow, considering that the turns are highly dosed. Combined with high speed, these factors may make the turn technically challenging and provoke contact. Another explanation may be that the riders are not fully aware of the position of the others as they seek the shortest course-line to execute the turn, or they may be riding back to back.[25]

Rider behaviour

We observed that in 13 of the 19 cases the rider was out of balance well before the time of injury. In all of these cases, the rider lost control from a technical error either at take-off, landing or at rollers. In the remaining six cases, the rider lost balance at the time of injury as a result of accidental board contact. In all cases, the contact had a direct influence on the injury and mainly occurred as a board contact between two riders, only. In addition to the four contact situations identified at bank turns, the authors found two when landing after a jump. In these, the contact situation was distinctly different from the situations described at bank turns. The rider who caused the contact, positioned in front

of the other rider, lost control when landing from an individual technical error. In an attempt at regaining balance, the rider then accidentally caught the board of the injured rider. Engebretsen *et al*[1] suggested that accidental board and body contact might force the rider to have an unanticipated reaction, loss of control and probably leading to high-risk situations. Taking this view and the results of this current investigation into account, rider contact regularly causes loss of control and high-risk situations.

Methodological considerations

When interpreting the results from this study, there are some limitations. First, only one video from qualification runs was available for analysis. However, recent results from the FIS ISS show that the injury rate is significantly higher in final heats than in qualification runs[4] (12.1 and 6.1 per 1000 runs, respectively). Whether the mechanism of injuries in qualification and final runs differ is unknown, but there should be no contact injuries in the qualifications, as these are all individual runs. Second, one cannot in all cases be sure of the exact moment of injury. Especially for injuries occurring at jumps, the camera view was often less than optimal. However, as shown in table 2, the individual estimates of the index frame were remarkably consistent in most cases.

Third, other performance-determining factors, such as psychological, cannot be analysed from video. This factor may have as much influence on injuries as the physical requirements in SBX.[10]

Further perspectives

In this study, jumping was the most challenging obstacle, where technical errors either at take-off or landing caused the injury. But considering that a limited number of videos were available for analysis in this study, prospective systematic collection of injury videos should continue. Also, video recordings of injuries during qualification runs are needed to fully describe the inciting events in SBX injuries.

Nevertheless, we found a consistent pattern where jumping produced the most injuries. In addition, it appears that riding in heats of four or six is a contributing factor, especially at bank turning. There is, however, according to the FIS WC SBX rules, no standardisation on the height or distance between jumps or the next obstacles except from the start to the first bank.[8] In this study, however, the majority of jumping-related injuries were attributed to a technical error by the rider and not to the design of the jump itself. Nevertheless, if such standards could be developed, it might possibly reduce the energy involved when landing and give the riders more time to prepare for the next obstacle.

CONCLUSION

We identified that most injuries in SBX resulted from jumping, and that a technical error at take-off was the primary cause of the injuries. The second most common inciting event was unintentional board contact between riders at bank turning. In all 19 cases, the error or contact resulted in a rider out of balance leading to a fall at the time of injury.

Contributors AB, TB, LN and RB contributed to study conception, design, and methodology for the video analyses. AB coordinated the study and managed all aspects of the video analysis process, including video recording and processing, as well as organization of the video analyses. AB wrote the first draft of the paper, and all authors contributed to the final manuscript. AB and LN are guarantors.

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Competing interests None.

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

Provenance and peer review Not commissioned; externally peer reviewed.

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