A human factors approach to snowsport safety: Novel research on pediatric participants' behaviors and head injury risk

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ABSTRACT

Objective: This study applied a human factors approach to snowsport resort systems to contribute to the understanding of the incidence and severity of pediatric snowsport head accelerations.

Background: Previous research indicates low magnitude head accelerations are common among snowsport participants. This study adds to the knowledge of snowsport safety by measuring aspects of participants' snowsport behavior and linking this with head acceleration data.

Method: School-aged students (n = 107) wore telemetry-fitted helmets and Global Positioning System (GPS) devices during snowsport activity. Data was collected over 159 sessions (total hours 701). Head accelerations recorded by the telemetry units were compared with GPS-generated data.

Results: This study found speeds attained normally exceed the testing rating for which helmets are designed; lower rates of head accelerations compared to earlier studies and that when head accelerations did occur they were generally below the threshold for concussions.

Conclusion: Pediatric snowsport head accelerations are rare and are generally of low magnitude. Those most at risk of a head acceleration >40 g were male snowboarders. Given the recorded speeds in first time participants, increased targeting of novice snowsport participants to encourage education about the use of protective equipment, including helmets, is warranted. Post event recall was not a good indicator of having experienced a head impact. Consideration should be given to raising the standard design speed testing for snowsport helmet protective devices to reflect actual snowsport behaviors.

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1. Introduction

There are more than 90 million annual snowsport participants worldwide (Vanat, 2014) and, as with many sports, there is a risk of injury and even death. Traumatic brain injury has been suggested as the leading cause of death in snowsports (Levy et al., 2002; Shealy et al., 2008; Warda and Yanchar, 2012). Helmets are promoted internationally as effective protection against snowsport head injuries (Cusimano and Kwok, 2010; Hagel et al., 2005a, 2005b; McCrory, 2002), yet there are some concerns about the evidence base upon which to build this claim (Finch et al., 2011). With the growing concern over the long-term sequelae of sport-related head injuries and repeated sub-concussive head accelerations (Cusimano et al., 2013; McCrory et al., 2013a,b) the call, publically and politically, for mandatory helmet use in snowsports has increased (Bussewitz, 2010; Cundy et al., 2010; Ellis, 2013; Langran, 2011; Munro, 2006; Ruedl et al., 2011). However, more research is needed to clarify what the risk of head injury is, as well as under what circumstances snowsport helmets are effective in preventing injuries.
2. The inherent character of snowsports

Unlike other activities where the aim may be to minimize risks through engineering or design (Gao et al., 2008), snowsports involve risks, perceived and real, that may be part of the attraction (Dickson et al., 2012; Eccles et al., 2011). The discussion of risk is broader than just the consideration of safety, and includes elements that can have either a positive or negative impact upon one’s objectives (International Organization for Standardization, 2009). The diverse objectives of a snowsport participant may include fun and excitement, social time with family and friends, enjoyment of nature, and even health and wellbeing across one’s life (e.g. Amesberger et al., 2012; Dickson and Terwiel, 2013). A risk which can also have a positive impact upon those objectives may be the pleasure of fresh snow or the physical effort involved in increased fitness, while a risk associated with a negative impact may be high cost of participation or the chance of incurring an injury. Minimizing negative impacts, including injuries, and maximizing positive impacts, such as fitness, may result in an increased enjoyment of the activity and thus overall retention and participation – something of interest to resort operators and allied businesses in light of other challenges faced by the industry from climate change and an aging participation base (Steiger, 2012).

2.1. Sport injury risk, causation and underpinning disciplines

The risk of sustaining a sporting injury is the result of the interplay between the likelihood of an unplanned event and the consequences or severity of that event (Velani et al., 2012); this reflects the risk analysis matrix in the field of risk management (International Organization for Standardization, 2009). Developing strategies to reduce the risk and/or severity of sport injuries involves 4 steps: i) an evaluation of the extent of the problem, ii) identification of risk factors and mechanisms of injury, iii) implementation of evidence-based prevention strategies and iv) evaluation of those strategies (van Mechelen et al., 1992). Further, in order to implement effective sport injury prevention strategies a multifactorial approach may be applied that considers the interactions of both intrinsic and extrinsic risk factors along with the event itself (Bahr & Krosshaug, 2005; Meeuwisse et al., 2007). This article investigates the first and third steps, as informed by the extant literature, and contributes to the second step by applying a human factors approach that reflects the multifactorial nature of snowsport injuries. Table 1 expands upon examples of sport injury risk factors (e.g. Bahr & Krosshaug, 2005; Gissane et al., 2001) to demonstrate snowsport injuries’ multifactorial nature and suggests underpinning disciplines that may be used to investigate ways of modifying or minimizing injury risk.

2.2. The nature of the problem: head injuries in snowsports

Head injuries include fractures, subdural hematomas and concussions; the latter is a subset of traumatic brain injury (TBI), and the term is sometimes used interchangeably with mild TBI (McCrorry et al., 2013a,b; Rughani et al., 2011). Head accelerations do not always result in a head injury and may occur without an impact, e.g. a fall without a head impact, where a sudden deceleration causes the brain to move inside the skull. Alternatively, a fall with a head impact may only lead to low-level head accelerations.

While TBI in sports, including snowsports, are concerning, an Australian study revealed a low incidence of TBI in snowsports; patients presenting to Canberra Hospital with a snowsport-related head injury revealed an incidence of 1.8 per 1,000,000 skier days (n = 25). Snowboarders had three times the incidence of head injuries as skiers (Siu et al., 2004). Compared to other sports, head injuries from snowsports occur at a much lower rate. In Australia in 2002–03, in one of the few international studies where International Classification of Diseases coding (ICD) and information identifying the sport were available, 45,452 sport/recreation-related hospitalizations (0.7% of all hospitalizations) were recorded (Flood and Harrison, 2006). Across the three versions of contact football played in Australia (rugby union, rugby league and Australian rules), head injuries were the main reason for hospitalization, with an average of 24.4% of injuries being head injuries within the three disciplines. In ice and snowsports (grouped together in Australian data), head injuries were the reason for admission in 9.9% of cases. By sport, ice-skating had over four times the proportion of hospitalizations due to head injuries (25.8%, similar to football) compared to skiing (6.3%) and snowboarding (5.9%). Thus, hospitalizations for sport/recreation injuries are rare (less than 1% of all injury admissions), 18% of those hospitalizations were head injuries and only 6% of snowsport injury-related hospitalizations (n = 53) were due to head injuries. A problem with hospital data however, is that there is likely to be no

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>Underpinning professions and disciplines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Intrinsic risk factors</td>
<td>Health, demographics</td>
</tr>
<tr>
<td>Age, gender</td>
<td>Sports science</td>
</tr>
<tr>
<td>Fitness</td>
<td>Social sciences, economics, law</td>
</tr>
<tr>
<td>Skill level</td>
<td>Engineering and industrial design, education</td>
</tr>
<tr>
<td>Previous injury history</td>
<td>Geography, geotechnical engineering, business &amp; finance</td>
</tr>
<tr>
<td>Motivation</td>
<td>Engineering, psychology</td>
</tr>
<tr>
<td>Perception and appeal of risk</td>
<td>Chronology</td>
</tr>
<tr>
<td>2. Extrinsic risk factors e.g. equipment, environment</td>
<td>Meteorology</td>
</tr>
<tr>
<td>Protective equipment design</td>
<td>Psychology, sociology, marketing</td>
</tr>
<tr>
<td>Protective equipment use</td>
<td>Engineering, psychology</td>
</tr>
<tr>
<td>Equipment (e.g. ski, boots) design</td>
<td>Biomechanics, chronology, human factors</td>
</tr>
<tr>
<td>Resort/trail design</td>
<td>Epidemiology, health economics, law</td>
</tr>
<tr>
<td>Trail preparation and grooming</td>
<td></td>
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<tr>
<td>Exposure time</td>
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<td>Weather</td>
<td></td>
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<tr>
<td>Social context and culture</td>
<td></td>
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<tr>
<td>3. Inciting event</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
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<tr>
<td>Mechanism of injury</td>
<td></td>
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<tr>
<td>Event outcome</td>
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</tbody>
</table>
data on mechanisms of injury that might help inform prevention strategies.

2.3. Mechanisms of injury

Only one study has investigated the biomechanical characteristics of snowsports head impacts and accelerations, concluding that ‘head impacts in recreational riding are not rare, but are typically low level in magnitude’ (Greenwald et al., 2009). Greenwald et al. (2009) recorded 674 head impacts across 46 pediatric snowboarders (mean age 13.7, range 9–20) riding in Whaleback, New Hampshire USA between February 2007 and March 2008 (average of 14.7 impacts per participant). None of these impacts resulted in a medically diagnosed concussion. More than 95% of the impacts were less than 50.2 g’s, with peak linear acceleration of 113 g’s and rotational head acceleration of 9515 rad/sec². They suggested that the data demonstrated similar accelerations to other helmeted sports such as American football and ice hockey. In the absence of other data, it was not possible to identify where in the resort the impact occurred, nor what the person’s speed was at the time of impact.

Even though snowsport-related head injuries may occur at a much lower rate and frequency than other sports there remains significant interest in snowsport-related head injuries leading to calls for mandatory snowsport helmet usage (Bussewitz, 2010; Cundy et al., 2010; Ellis, 2013; Langran, 2011; Muñoz, 2006; Ruedl et al., 2011; Terwiel and Dickson, 2015); however, one must question whether helmets are the solution.

2.4. Prevention strategies: are helmets the answer?

The hierarchy of controls model, as seen in ‘healthy places’ and workplace health and safety literature (Dannenberg et al., 2011; Standards Australia, 2001) begins with the most effective element of removing the hazard and ends with amelioration via protective equipment, such as helmets, as the least effective – tantamount to a ‘last line of defense’. Previous research has explored the role of helmets in reducing TBIs in snowsports (e.g. Cusimano and Kwok, 2010; Hagel et al., 2005a, 2005b), using epidemiological approaches, with an emphasis on quantifying injury type, frequency and severity, often via incident reports (Finch et al., 2011). However, in most circumstances the controls chosen were other injured participants who may have presented with any other injury such as a wrist or lower limb injury. There is no evidence that they were ever at risk of a head injury, yet they have been used as evidence that helmets protect against head injuries. A further study reviewed pediatric TBI in snowsports and concluded that helmet use may need to be promoted, even though the research couldn’t compare TBIs with helmet-use as the helmet-use data was not available in their data set (Graves et al., 2013). The problem with the extant literature is that there is insufficient research that explores the mechanism of TBI and/or matches cases with controls with similar mechanism of injury (Finch et al., 2011). Finch et al. (2011) concluded that ‘the strong conclusions from these studies about the effectiveness of helmets must be treated with caution’ (p. 68).

Additional concerns about the use of the helmets as a primary injury prevention strategy relate to their design, testing, certification process and use. First, helmets may not be designed to be effective, and certainly are not tested as to their effectiveness, in an impact with a solid object at speeds greater than 23 km/h (Shealy et al., 2008), a speed that is well-below the maximum speeds observed in several studies (Dickson et al., 2012; Shealy et al., 2005; Williams et al., 2007). Second, there is some resistance to wearing helmets, particularly as people may not believe they are necessary (Dickson, 2008; Terwiel and Dickson, 2015), and finally, people may not wear them as they are not required by laws or resort management policy (Cundy et al., 2010; Ellis, 2013). Thus, it may be questioned whether a snowsport helmet is fit for purpose, and whether wearing a snowsport helmet can do what the wearer (or the wearer’s parents) thinks it will do; that being to prevent or mitigate a head injury.

To better inform the public about the value of wearing a helmet and to contribute to debate as to whether helmets should be compulsory, it is imperative to understand the characteristics of snowsport head accelerations. This particularly relates to biomechanical considerations such as velocities and impact characteristics (e.g. magnitude and location on the head) as well as incident location and participant behavior, upon which to develop evidence-based injury prevention recommendations.

This current research, which builds upon Greenwald et al. (2009) research, is the first to combine data on snowsport behaviors with head acceleration data in a real-world scenario and thus provides insights into who is at risk of higher-level head accelerations, the biomechanical factors involved, as well as the extrinsic risk factors that may contribute to pediatric snowsport head injuries. The importance and relevance of this research for those who manage snowsport resorts and snowsport participants alike was reinforced during the data collection period when two young females died from traumatic injuries while participating in snowsports in the resorts where the research was being conducted. Both of the victims were wearing helmets at the time of the incident (“Inquest into the deaths of Hannah Taylor and Amelia Catherine McGuiness”, 2011).

2.5. Research questions

The research questions considered here, from a human factors perspective, address the multifactorial nature of snowsport injury prevention, including intrinsic and extrinsic risk factors and the inciting event. Those questions include:

- What are the characteristics of pediatric snowsport participants’ snowsport behavior?
- How frequent are snowsport head accelerations?
- What are the factors associated with measurable head accelerations, e.g. gender, age, experience level, activity, resort location, terrain and speed?

The University of Canberra’s Committee for Ethics in Human Research granted approval for this research. Either a parent or guardian granted permission for each participant to be involved in the research.

Human factors is a ‘scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design, in order to optimize human well-being and overall system performance’ (Human Factors and Ergonomics Society, 2010). In this research the snowsport ‘system’ would include: the participants (e.g. age, activity choice, skill levels, capacities, experience and personal goals); their personal equipment (e.g. skis, clothing and helmets), the resort infrastructure (e.g. lifts, snow-making); the resort design and maintenance (e.g. trail design, information and signage), as well as the natural environment and elements (e.g. slope angles, weather); and the characteristics of the inciting event. In this study, we consider participants’ behaviors, personal characteristics and the characteristics of any head accelerations in the context of resort design.
3. Methods

A descriptive study was conducted involving a convenience sample of pediatric snowsport participants recruited via public and private schools participating in snowsports programs, including two schools whose weekly sport was snowsports, as well as via contacts known to the researchers. Participants were involved in resort-based lift-accessed snowsport activities of alpine skiing, snowboarding and telemarking. Participants completed a questionnaire providing demographic data, snowsport experience, protective equipment usage and preferred snowsport terrain. For each data collection session the participants were issued with a Giro Nine helmet modified for research purposes, to include HIT System technology (HITS) by Simbex (Fig. 1). These helmets were certified under ASTM F-2040 (ASTM International, 2000). HITS uses six accelerometers deployed against the head to model head (not helmet) accelerations over 10 g (Fig. 1) and has been used in other sports such as American football and ice hockey to measure head helmet accelerations (Greenwald et al., 2008).

After reviewing the 2009 HITS data with Simbex in October 2009 it was determined that in the following seasons (2010–11) more focus would be put on recruiting participants deemed to be most at risk of a head acceleration e.g. beginners, and those using terrain parks, half pipes and slope-style courses (Brooks et al., 2010; Rajan and Zellweger, 2004).

To provide more detailed information about speed, locations and workloads the participants were also issued with a GPSports’ SPI Elite, a data-logging device worn in a mini backpack in the upper thoracic region (Fig. 2). The device can capture time, distance, speed, heart rate, location, and body impacts. As with the HITS, the SPI Elites were initially designed for use with team-based sports such as football (Gizmag Team, 2007).

Data were uploaded daily via the same laptop computer for analysis; the helmet data was uploaded into the HITS database and the GPS data into the Team AMS software. Uploading the data via the same computer enabled the synchronization of data from both sources, and thus incident times. The questionnaire data and summary data from HITS and the GPSs were entered into PASW 18.0 for Macintosh for statistical analysis. All accelerations recorded via the helmets were crosschecked to the Team AMS software to investigate when and where the event occurred.

There is no agreed-upon threshold at which concussions occur as a result of head accelerations during sport. In research conducted with the HITS in other helmeted sports, physician-diagnosed concussions occurred across a range of linear head accelerations from 60 g to 168 g (Guskiewicz and Mihalik, 2011). Differences in sequelae were observed across the location of the impact on the head and the duration of the impact. As this study is motivated by an interest in sub concussive accelerations, the choice made was to explore those accelerations that would have a low risk of resulting in a concussion, thus a choice of a threshold below 60 g but above that may be a result of normal activity/behavior patterns. At head accelerations of just 40 g the likelihood of experiencing a concussion is around 15%, while head accelerations >150 g have a 100% likelihood of resulting in a concussion (McIntosh et al., 2011).

Thus the inclusion criteria for a verified head acceleration that was an on-snow event warranting further investigation was:

- Head linear accelerations greater than 40 g;
- Confirmation via geospatial data from the SPI Elite unit that it was an on-snow event;
- Body impact greater than 2 g recorded by the SPI Elite within 0.05 s of the head impact;
- A decrease in velocity recorded by the SPI Elite within 0.05 s of the head impact.

Further analysis of the HITS data was required through cross-checking with the SPI Elite’s data. All HITS data was exported to a spreadsheet and compared with the SPI Elite data and individual participants’ HITS reports to provide a detailed picture of context, recorded impact and acceleration history by identifying: date, time, severity, resort location, speed and location on the head of each recorded acceleration. The benefit of correlating the HITS data with the SPI Elite data is that the latter can provide insight into the event. HITS can record multiple head accelerations that may be part of the same event, for example, one helmet recorded 17 accelerations within one minute, yet this may be related to the same fall event or a false-positive reading. Additionally false-positive accelerations may be excluded that are due to on-off switch errors, snow play, hitting the helmet on a lift, rough-play between friends, mistreatment or accidental dropping of the helmet after removal.

4. Results

Data was collected on 107 pediatric participants aged 9–18 years (mean 14 years), over 159 sessions, across two resorts (Perisher, 61.0% and Thredbo 39.0%) Most were alpine skiers (62.9%), then snowboarders (36.5%), with one telemarker (0.6%). 47.8% were females and 52.2% males. In 2009, 51 sessions were collected, 106 in 2010 and 2 in 2011. Participants had a diverse range of snowsports experience via the helmets were crosschecked to the Team AMS software to provide a detailed picture of context, recorded impact and acceleration history by identifying: date, time, severity, resort location, speed and location on the head of each recorded acceleration.

Independent samples t-tests were conducted to compare the maximum recorded speeds for males vs. females, and skiers vs. snowboarders. There was no significant difference in average maximum speeds for females (42.4 km/h, SD = 15.78) and males (42.4 km/h, SD = 14.93). The actual differences in the mean maximum speeds, indicated by eta squared = 0.30, was large.

The total time recorded over 159 sessions was 701 h (range 8 min to 7 h 43 min, mean = 4 h 24 min); total distance traveled (both up and downhill) was 3192.5 km (range = 0.1 km–51.6 km, mean = 20.1 km). The average distance traveled per hour was 4.5 km for all (4.7 km for skiers and 4.4 km for snowboarders) (Table 2). Maximum speeds recorded ranged from 4.3 to 82.2 km/h (mean 42.372 km/h). A one-way between groups analysis of variance (ANOVA) explored the impact of snowsport experience on maximum speeds. There was a statistically significant difference (p < 0.05) in maximum recorded speeds for the two groups: F(3,1) = 19.76, p < 0.001 (Table 3). The actual differences in the mean maximum speeds, indicated by eta squared = 0.30, was large.

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For first-time snowsport participants ($n = 23$), maximum speeds ranged from 6.3 to 53.7 km/h (mean = 30.9 km/h), with 74\% achieving maximum speeds greater than 23 km/h (the speed to which helmets are tested during the certification process). Across all sessions, 88.6\% reached maximum speeds greater than 23 km/h.

### 4.2. Head impact telemetry system (HITS) data

The raw data indicated that there were 970 head accelerations recorded by HITS (46.3\% skiers, 53.7\% snowboarders), or 6.0 per session (4.0 per skiing session and 9.8 per snowboarding session). When compared to the GPS-logged exposure time, this equates to 1.1 head accelerations per skiing hour and 1.9 per snowboarding hour. Based upon this raw data, this would suggest that snowboarders recorded 78\% more head accelerations per hour of participation than skiers.

The distribution of the impact magnitudes of the raw data from the HITS indicated that 61\% of the linear accelerations were less than 20 g, only 9\% were over 40 g (Fig. 3), and only 2 of the recorded accelerations were at a level that may be expected to result in a concussion, i.e. >98 g (Greenwald et al., 2008).

After cross-referencing HITS with the SPI Elite data, there were only three events with >40 g linear accelerations that could be
verified as having occurred while the participant was wearing the helmet on-snow, i.e. 4.2 per 1000 h of snowsport participation (Table 4). All three were male snowboarders, this equates to 10.6 head accelerations over 40 g per 1000 h of snowboarding participation.

5. Discussion

An understanding of human factors can underpin processes of safety and quality improvements, in snowsport resorts where reviews and improvements of safety equipment or resort design would apply a systems-based, user-centered design approach that reflects the multifactorial nature of the user, their interactions with their environment (built and natural), and the equipment they use (Sleet et al., 2011). Thus, this research used a human factors approach that investigated aspects of the snowsport system, such as people and their on-snow behaviors and the characteristics of any measurable head accelerations, within the context of the design of the resort within a specific location.

Incurring an injury while participating in sport can have lifelong impacts and the life changing effects of a TBI makes research into the prevention of head injuries, across all sports, an important social and public health issue. However, most sport injury research depends upon epidemiological studies that highlight the type and severity of injuries, but do not necessarily address elements related to variables such as biomechanical factors, behavioral characteristics and the effectiveness of prevention strategies. To contribute to the snowsport injury prevention discourse, this research applied an interdisciplinary human factors approach by investigating research the snowsport injury prevention discourse, this research applied an interdisciplinary human factors approach by investigating research of adults’ snowsport speed in a range of terrains by van Mechelen et al. (1992).

Over the period of the data collection, it was revealed that head accelerations over 10 g were rare (6.0 accelerations per participant), with only three over 40 g being recorded. This contrasts with Greenwald et al. (2009) who indicated that head accelerations were not rare (14.7 per participant). The 94.2% of head accelerations with survey data.

Previous research has highlighted that snowsport head injuries are rare (Flood and Harrison, 2006; Siu et al., 2004), but a problem for the snowsport industry is that the long-term sequelae of sport-related head injuries and repeated sub-concussive head accelerations are under public scrutiny (Cusimano et al., 2013; McCrory et al., 2013a,b), resulting in calls for mandatory snowsport helmet usage that may not be as evidenced-based as would be preferred (Bussewitz, 2010; Cundy et al., 2010; Ellis, 2013; Langran, 2011; Munro, 2006; Ruedl et al., 2011). While the results of some research suggests that helmets are an effective means to reduce snowsport head injuries, (e.g. Cusimano and Kwok, 2010; Hagel et al., 2005a, 2005b), others suggest caution given the lack of biomechanical matching of controls in many of these studies (Finch et al., 2011). So far, there has been no previous research that has explored i) pediatric snowsport behaviors, ii) actual mechanisms of head impacts, and iii) correlated with resort locations/terrain, upon which informed prevention strategies may be based as envisaged by van Mechelen et al. (1992).

This novel research of pediatric participants has revealed that the mean maximum speed for all experience groups was over 30 km/h, including first time participants. For the 88.6% of participants who achieved maximum speeds over 23 km/h, they are exceeding the impact tests of the voluntary helmet standards (e.g. ASTM International, 2000; European Committee for Standardization, 1996). In some cases speeds were up to three times the helmet testing velocity of 23 km/h, or up to nine times the potential kinetic energy (Shealy et al., 2008). This is also consistent with research of adults’ snowsport speed in a range of terrains (Dickson et al., 2012; Shealy et al., 2005; Williams et al., 2007).

Table 4
Analysis of three verified head accelerations >40 g.

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>Male</td>
</tr>
<tr>
<td>Age</td>
<td>12 years</td>
<td>15 years</td>
</tr>
<tr>
<td>Days of snowsport experience</td>
<td>&gt;50 days</td>
<td>6–50 days</td>
</tr>
<tr>
<td>2. Extrinsic risk factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity</td>
<td>Snowboarding</td>
<td>Snowboarding</td>
</tr>
<tr>
<td>Maximum speed achieved during the day</td>
<td>49.8 km/h</td>
<td>38.5 km/h</td>
</tr>
<tr>
<td>3. Inciting event</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date of incidence</td>
<td>4/9/09</td>
<td>10/8/10</td>
</tr>
<tr>
<td>Linear head acceleration</td>
<td>64.5 g</td>
<td>51.2 g</td>
</tr>
<tr>
<td>Head location</td>
<td>Back</td>
<td>Back</td>
</tr>
<tr>
<td>Resort location at time of recorded head acceleration</td>
<td>Terrain park</td>
<td>Blue/intermediate terrain</td>
</tr>
<tr>
<td>Body impact</td>
<td>2.400 g</td>
<td>2.422 g</td>
</tr>
<tr>
<td>Velocity at T.5 (i.e. 0.05 s before the head acceleration)</td>
<td>8.3 km/h</td>
<td>3.5 km/h</td>
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<tr>
<td>Velocity at T.4</td>
<td>8.3</td>
<td>5.6</td>
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<tr>
<td>Velocity at T.3</td>
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<td>10.7</td>
</tr>
<tr>
<td>Velocity at T.2</td>
<td>0.2</td>
<td>13.9</td>
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<tr>
<td>Velocity at T.1</td>
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<td>13.5</td>
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<td>Velocity at time of head acceleration</td>
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<td>Velocity at T.2</td>
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<td>Velocity at T.3</td>
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<tr>
<td>Velocity at T.4</td>
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<tr>
<td>Velocity at T.5</td>
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<tr>
<td>Event outcome: medically diagnosed concussion?</td>
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</tbody>
</table>
below 50.2 gs is commensurate with Greenwald et al. (2009) who reported that over 95% were less than 50.2 gs. In comparing these two studies, it must be noted that Greenwald et al. (2009) research was conducted with riders who mainly participated in terrain parks, while this current research was with participants who traveled throughout the resort areas, including terrain parks, off piste and moguls.

The three incidents that met the inclusion criteria (Table 4) highlight that head accelerations greater than 40 gs may occur at quite low velocities and across diverse social situations and resort locations and that the incidence of a clinically diagnosed head injury is rare. The intrinsic risk factors of those with head accelerations >40 gs were all young male snowboarders with diverse skill and experience levels. The three inciting events occurred in three different locations within the resort on both man-made and natural terrain of beginner and intermediate grade. While all the acceleration levels were below the 98 gs where it is considered a concussion may occur, it is important to note that research and debate in other sports regarding the potential cumulative effect of sub-concussive head accelerations must extend into snowsports in the future (Bigler, 2008; McCrory et al., 2013a,b).

While this research has been able to add to the overall understanding of pediatric snowsport participant behaviors and the characterization of snowsport head accelerations, there have been limitations to the research design:

- Both data logging systems were designed for team sports in controlled environments where all ‘players’ are in view at any one time and potentially under camera surveillance that can support interpretation of the data and thus the biomechanical and behavioral characteristics of an on-field head impact. Camera surveillance may be desirable but is not practical when observing snowsport participants who are free to explore a whole resort, however future research in more confined environments such as terrain parks, half pipes and moguls may be conducive to video analysis;
- Recruiting young snowsports participants to wear helmets that were not the latest design for that season presented a challenge to the researchers and is a consideration for future research designs.

6. Conclusion

This research adds to the snowsport safety discourse by drawing upon a human factors approach that considers the interaction of the person with their equipment and their environment. While TBIs have previously been identified as being the leading cause of death in snowsports, other research indicates that head injuries from snowsports result in a lower proportion of hospitalizations than in other sports. By exploring pediatric snowsport participants’ characteristics and behaviors this research highlights that many pediatric snowsport participants, including beginners, are traveling at speeds that exceed the range of helmet testing standards which, from a human factors perspective, raises questions about equipment design and testing, and safety education and communication.

Through the application of the HITS technology, this research reinforces that snowsport head accelerations are rare and when they do occur they are generally at a sub-concussive speed. However, in light of emerging research in other sports on the potential cumulative effects of such impacts, it should not necessarily be assumed that there is no risk from snowsport head impacts; further research is needed to investigate this area.

While the human factors approach highlights the challenges of resort and equipment use and design to support ‘safe’ participation by people of diverse skill and risk appetites, the approach does not propose that factors work in isolation, as the elements are intrinsically interrelated.

6.1. Further research

Based upon the insights gleaned from this research, further research is warranted to understand pediatric snowsport behaviors, as well as adults’ behaviors, to inform appropriate effective snowsport safety strategies. This would include the following, both in isolation and in concert:

- Further targeted research of those who may be deemed to be most at risk as demonstrated by available injury data.
- The impact on helmet efficacy from mistreatment or blows when helmets are transported or stored outside of their snowsport use.
- Exploring the use of GPS and accelerometer systems in emerging technologies, such as in smartphones, to aid the development of cost-effective data collection and warning systems around impact severity.
- Further investigation of criteria regarding helmet replacement to inform parents, coaches, instructors, retailers and equipment rental.
- Investigation of people’s behaviors and attitudes in relation to helmets: e.g. Why people do or do not wear helmets; how helmet wearing affects behavior; what people believe their helmet will do for them in case of an incident.

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References


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