

6th Asia-Pacific Congress on Sports Technology (APCST)

Technology applications to enhance understanding of real-time snowsport head accelerations

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Received 20 March 2013; revised 6 May 2013; accepted 9 May 2013

Abstract

With the increasing concern about the long-term effects of concussive and sub-concussive head accelerations in sport, this research applies two technologies initially developed for team-based sports to snowsports to understand the characteristics of snowsport head acceleration. Results indicate that pediatric snowsports participants regularly achieved speeds over 23 km/h; snowsport head accelerations are rare and that when they do occur they are generally of low magnitude; and those most at risk were make snowboarders.

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Selection and peer-review under responsibility of the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University

Keywords: Concussion; head injury; snowsport; snowboarding; skiing

1. Introduction

There is increasing concern about the long term effects of repeated sub-concussive head accelerations, particularly within sport [1], and Dashnaw et al have suggested that ‘it will be imperative to appropriately model concussive and even sub-concussive injuries in an attempt to understand, prevent, and treat the associated chronic neurodegenerative sequelae’ [1]. This is sympathetic with the calls by Bahr et al [2], Meeuwse et al [3] and Finch et al [4] for more robust and multivariate sport injury research.

A challenge to anyone seeking to model these behaviors, particularly within snowsports, is to also understand what are current actual behaviors and how that may vary across time and place, from which

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models or analogs may be developed. Snowsports presents a different challenge than when trying to model behaviors in other concussive-sports such as ice hockey and football, in that snowsports are conducted across large geographic areas, that has variable terrain, changing snow conditions and a wide range of climatic conditions across a season and even within a day. However existing technologies currently utilized in football have the potential to enhance the understanding of real-time concussive and sub-concussive snowsport head accelerations and behaviors that may be able to inform future modeling of snowsports behaviors [5, 6]. Additionally, insights from this research will help inform future snowsport safety messages [7], the efficacy of current helmet design testing upper limits of c. 23km/h and future sport technology developments.

1.1. Sport head injury research and concussion prevention

Van Mechelen et al [8] suggested that injury prevention strategies should be informed by a clarification of the problem and an analysis of the mechanism/s of injury. More recently Bahr et al [2, 9] and Meeuwisse et al [3] indicated that sport injury prevention research design and analysis needed to identify the many factors that may influence injury incidence and severity, with a particular focus upon those risk factors, intrinsic or extrinsic, that are modifiable. This was expanded upon by Finch who advocated multidisciplinary approaches in evaluating injury causation, including epidemiological, biomechanical and behavioural [10]. Additionally, in the broader safety research, it has been recommended to move beyond single immediate causes of incidents to a consideration of multiple and systemic causes in the chain of events [11]. Issues in sport injury prevention research may occur in both the design and analysis of the research, but also in the dissemination and adoption phases.

In the design phase it has been suggested that sports injury research is plagued with the lack of consistent injury and exposure definitions [10], which is exacerbated by the inappropriate choice, or lack of adequate controls in the dominant case-control study design [4]. For example, Finch et al described four snowsport head injury studies assessing the effectiveness of helmet use [12-15] none of which used biomechanical matching of controls to the head injured cases. The controls included people who did not experience either a head injury or a head impact. As a result of this design issue it was suggested that ‘the strong conclusions about the effectiveness of helmets must be treated with caution as the controls are not fully comparable to the cases’ [4]. However a later review of the same data by Cusimano and Kwok [16] did not critique the research design nor the selection of controls in these studies and it was readily accepted that helmets reduced head injuries even though there was no evidence that the controls had experienced similar fall mechanisms to the cases.

In the analysis phase it has been suggested, that with enhanced research design, more robust multivariate analysis may be completed^[9]. To date there has not been a range of studies with this level of analysis for snowsport head impact research. In addition to the need for robust design and analysis, program evaluation of interventions is essential [8, 10], first by clarifying the problem, then evaluating the effectiveness of any intervention strategies, such as education, protective equipment usage or environmental modification.

The recent *Consensus statement on concussion in sport* indicated that ‘there is no good clinical evidence that currently available protective equipment [i.e. helmets and mouthguards] will prevent concussions ... For skiing and snowboarding, there are a number of studies to suggest that helmets provide protection against head and facial injury and hence should be recommended for participants in alpine sports’ [17].

1.2. Current snowsport helmet standards

There is much debate about the current range of sport helmet standards, including snowsports, that questions the relevance of the testing limits as well as considering the future of helmet design given emerging materials [18, 19]. The three main international voluntary helmet standards for snowsports are: ASTM 2040[20], Snell RS-98[21] and CEN 1077[22] (Table 1). Recently the Canadian Standards Authority has developed a fourth standard, CSA Z263.1-08 [23], though to date no helmets have been manufactured to this standard. The standards have many similarities including the maximum velocity at which helmets are tested on a flat anvil (c. 22.5 km/h for both Snell RS-98 and ASTM 2040), yet it is known that snowsport participants easily exceed these speeds in normal activity [24, 25]. Also, an acceptable design is one where peak accelerations of the test head forms reach 250-300g, yet it has been suggested that head accelerations must be reduced to below 100g to prevent concussions [26]. It is clear from these standards that they are not tested at levels that may replicate what may be considered normal snowsport behaviors, and the question should be asked, should they, or should other prevention strategies, be applied? And, if they are not tested at those levels, should they be advocated as the primary head injury prevention strategy?

Table 1. Summary of four current volunteer snowsport helmet standards

Impact Testing	Snell RS-98	CEN 1077	ASTM 2040	CSA Z263.1-08
Impact on flat anvil	100 Joules = c. 22.54 km/h	69 Joules = c. 19.52 km/h	6.2 m/s = c. 22.32 km/h	5.40 m/s = c. 19.44 km/h
Impact on hemispherical object & edge Impact	80 Joules = c. 20.16 km/h	No test	4.8 m/s = c. 17.28 km/h	No test
Number of impacts per site	Single	Single	Single	Three
Shell penetration	1 m drop 15.94 km/h	3.84 m/s = 13.82 km/h		15 mm metal dowel through any gap in helmet
Acceptable peak acceleration experienced by head form	300g	250g	300g	250g
Peripheral vision from center	105°	105°	N/A	105°

2. Method

To measure snowsport behaviors and record head accelerations, a descriptive study was conducted during 2009-11 with a convenience sample of pediatric snowsport participants participating in school snowsport programs in the Australian Snowy Mountains. Participants wore Giro-9 helmets fitted with Symbex's Head Impact Telemetry (Fig.1a and b) to measure frequency, location and severity of head accelerations, and also GPSports' Spi Elite data logging system (Fig.1c) to track participants' speed, distance travelled and location. The HIT System uses six accelerometers deployed against the head to model head (not helmet) acceleration and has been used in other sports such as American football and ice hockey to measure head accelerations over 10g [27]. The modified helmets complied with ASTM 2040. The GPSport Spi Elite captured time, distance, speed, heart rate, location, body load and impacts and were synchronized with the helmet data via the use of a single computer. As with the HIT system the Spi Elites, which were created in Australia, were initially developed for use with team-based field sports such as football and rugby union [28].

Data from the helmets was uploaded into the HIT system database for analysis while the GPS data was uploaded onto the Team AMS software via the same laptop computer for analysis. Uploading the data via the same computer enabled data, and thus incident times, from both sources to be synchronized. The questionnaire data and summary data from HITs and the GPSs were entered into PASW 18.0 for Mac for statistical analysis. All impacts recorded via the helmets were crosschecked to the Team AMS software to investigate when and where the event occurred.



Fig. 1. (a) Giro-9 helmet fitted with accelerometers; (b) Giro-9 helmet showing placement of electronics; (c) GPSport SpiElite and harness

The inclusion criteria for a verified fall with a head acceleration that warranted further investigation was:

- Head linear accelerations greater than 40g;
- Confirmation via geospatial data from the Spi Elite unit that it was an on-snow event;
- Body impact greater than 2g recorded by the Spi Elite within five one-hundredth's of a second of the head impact;

A decrease in velocity recorded by the Spi Elite within five one-hundredth's of a second of the head impact.

3. Results

From a technology design perspective, when interpreting the HIT data, three things need to be taken into account, firstly that two different HIT system on-off switch systems were used on the helmets across the life of the project. In 2009, the 'switch' was the press-stud for the goggle strap, while the helmets used over 2010-11 had an on-off switch imbedded into the padding of the helmet over the forehead. The change was to ensure that there was no inadvertent on/off switching when removing or replacing goggles or when the helmet was in transit.

The second consideration is that the HIT system can record multiple head accelerations that may be part of the same impact 'event'. For example, one helmet recorded 17 'impacts' within one minute between the time period 15:26:01 and 15:27:00, yet this would probably be related to the same fall event or a false-positive reading.

The third aspect, as noted earlier, is that the HIT system cannot indicate where in the resort the impact occurred, thus impacts may be false-positives due to on-off switch errors, snowplay, hitting the helmet on a lift, rough-play between friends, or even mistreatment of the helmet after removal. Through cross-referencing of the HITS data to the Spi Elite location data these false-positives may be excluded.

A total of 674 head accelerations over 10g were recorded (average of 14.7 per participant) of which 64% were between 10 and 20g, 6% were over 40g, and only 2 of the recorded accelerations were at a level that may be expected to result in a concussion, i.e. >98g [27]. To confirm that the accelerations

occurred on-snow the HIT system data with cross-checked with the Spi Elite GPS data revealing that only three peak accelerations recorded over 40g could be verified as having occurred while the participant was wearing the helmet on-snow, or 4.2 per 1,000 hours of all snowsport. The threshold of 40g was chosen to reflect the focus on sub-concussive accelerations and that previous research using the HIT system has demonstrated that concussions, as diagnosed by a physician, have occurred at linear accelerations as low as 60g [29]. As all three were male snowboarders, one a novice, one intermediate and one advanced, this would equate to 10.6 head accelerations over 40g per 1,000 hours of snowboarding participation.

4. Discussion

While there is a growing concern about the long-term effects of sub-concussive head accelerations in sport there is little research that characterizes real-time behaviors that may inform future injury prevention strategies and helmet designs. Through the use of two different sports technologies this research has added to our understanding of on-snow behaviors of pediatric snowsport participants, including the characterization of head accelerations. Key insights drawn from this research are:

- Pediatric snowsport participants regularly achieve maximum speeds greater than 23km/h;
- If head accelerations do occur they do occur are generally of low magnitude;
- Those most at risk of a head accelerations > 40g were male snowboarders;

The existing snowsport helmet standards do not reflect current knowledge about on-snow behaviors, nor existing concerns about potential concussion thresholds and the cumulative effects of sub-concussive accelerations. Future snowsport injury prevention strategies may focus upon informing people about the limitations of existing helmet standards, while future adaptations of existing GPS and accelerometer facilities such as in Smart phones may enhance the understanding of real-time head acceleration severity and frequency to inform future developments of helmet standards and design.

Acknowledgements

This research was funded by the New South Wales Sporting Injuries Committee and the National Institute of Sports Studies, University of Canberra, and supported by Simbex Inc., NH.

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