Design of a Novel Helmet Impact Testing Apparatus Representative of Snow Sports Head Injury

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I. INTRODUCTION

Although original efforts to design helmet certification protocols were aimed at representative impact scenarios, many simplifications were made in adapting such events to a laboratory setting [1-2]. Current snow sports helmet certification testing is characterised by a linear impact of a helmeted anthropomorphic test device (ATD) headform onto a metal anvil from heights of 1.5 m to 2.0 m (5.4–6.3 m/s), with a threshold criteria representative of severe head injury [3]. Although severe head injuries mechanistically related to linear head acceleration are important to prevent against, head injury suffered from snow sports participation includes a spectrum of mechanisms and severities, including minor and more severe concussions.

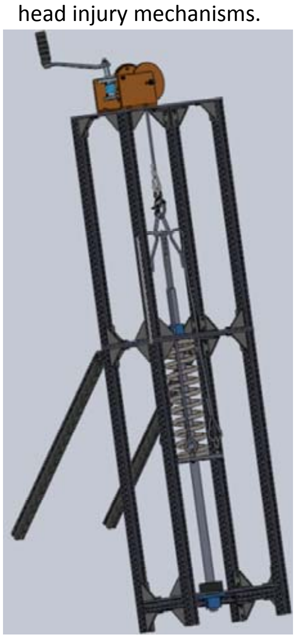
With a better understanding of real world snow sports head impact, kinematic scenarios can be developed to inform the design of more relevant test apparatuses and protocols. In an observational study performed at a ski resort, skiers and snowboarders were determined to be travelling at 45.8 km/h (12.7 m/s) and 30.9 km/h (8.6 m/s) on average, respectively [4-5]. If a fall occurs at such significant travelling speeds, oblique impact is likely, suggesting that helmet testing should include higher velocity, oblique impacts. In a previous phase of this work, which investigated clinical presentation of snow sports head injury, a high prevalence of concussive injuries was found among the injured ski and snow population [6]. In addition, high energy impacts, such as jump impacts (i.e. jump park), falls from height (i.e. cliffs) and impact with objects, were found to be associated with an increased risk of moderate, or worse, head injury. As mechanisms associated with head to snow contact (i.e. falls, jump impacts and falls from height) were found to be the most prevalent, an argument for helmet testing to be performed on snow is compelling. Finally, to represent kinematics that are relevant to all injury types and severities (for the primary impact event), an unconstrained ATD headform should be incorporated.

The objective of this study is to assess the suitability of a proposed test apparatus in representing snow sports head impact. Through verification of this design, an apparatus capable of representative head impact will be confirmed and will help to improve evaluation of snow sports head protection.

II. METHODS

The novel test apparatus to be verified was designed based on the mechanics identified to be relevant to snow sports head injuries through clinical and biomechanical data, as well as requirements identified through stakeholder discovery. The apparatus employs a large compression spring that can be loaded to a specified force, which, when triggered, accelerates a headform carriage that releases the head just prior to impact (Fig. 1).

Fig. 1. Impact test apparatus developed to represent snow sports head injury mechanisms.



In order to verify that the test apparatus is able to meet the overall requirements, a test matrix was developed with the manipulated variables being impact velocity, head orientation and impact angle. Instrumentation was selected to allow for all components to be contained within the headform and free from cable attachments. A Hybrid III ATD (Humanetics, Plymouth, MI) was modified to accommodate a DTS Slice Nano Data Acquisition System (Diversified Technical Systems, Seal Beach, CA) and three, single-axis, Endevco accelerometers (7264C-2K, Meggit PLC, Christchurch, UK), mounted near the centre of gravity (COG) of the head. To measure magnitude and investigate repeatability of impact velocity and head orientation, high-speed video in the frontal and sagittal planes was captured (2000 Hz sampling rate), and motion-tracking software (TEMA; Linkoping, Sweden) was used to track markers on the head.

Once the data was post-processed according to SAE-J211, resultant linear acceleration was calculated and plotted to determine the peak value. For all measured variables (angle, location, velocity), standard deviation (SD) and percent from the desired value was calculated for repeated impact scenarios.

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III. INITIAL FINDINGS

In total, 21 tests were performed in seven different orientations. All tests were performed at 90 degrees to the ground, and the impact surface was a concrete and linoleum floor covered by a 2” low-density foam pad. Average impact velocities and standard deviations are shown in Table I.

To gain an understanding of the repeatability of the impact location, high-speed video was used to understand the kinematics of the head when the head release mechanism was triggered. However, a currently unreliable release mechanism meant measuring this metric was not possible for many tests. Qualitatively, it was observed that when the head release mechanism triggered, the headform was projected linearly downwards with very little rotation. Once modifications are made to ensure the release mechanism triggers reliably, repeatability of the impact location and rotation of the headform will be measured.

Table I
Results from impact testing using a novel test apparatus. Velocity was measured for repeated tests. Average values and standard deviations (SD) were calculated. All tests were performed at 90 degrees to the impact surface.

Head Orientation	Spring Deflection (m)	Meas. Vel. (m/s)	Meas. Vel. Avg. (m/s)	Meas. Vel. SD (m/s)	SD Percent of Meas. Vel.
Frontal	0.030	2.3754			
Frontal	0.030	2.6753	2.509	0.152	6.1%
Frontal	0.030	2.4777			
Frontal	0.045	2.3994			
Frontal	0.045	2.3623	2.393	0.028	1.2%
Frontal	0.045	2.4164			
Frontal	0.060	3.094			
Frontal	0.060	2.9776	3.094	0.116	3.7%
Frontal	0.060	3.2094			
Frontal	0.080	4.2677			
Frontal	0.080	4.3342	4.344	0.082	1.9%
Frontal	0.080	4.4311			
Side	0.045	3.2024			
Side	0.045	3.1033	3.046	0.192	6.3%
Side	0.045	2.8318			
Occipital	0.045	2.8055			
Occipital	0.045	3.1216	2.949	0.160	5.4%
Occipital	0.045	2.9202			
Crown	0.045	3.2764			
Crown	0.045	3.0874	3.106	0.162	5.2%
Crown	0.045	2.9537			

IV. DISCUSSION

Preliminary results show that the apparatus produced a repeatable impact velocity within 7% of the average value. The most significant observation from this preliminary test series is the overall magnitude of the impact velocity not being near to the theoretical value calculated (30% lower). This has been determined to be a result of energy losses by way of the apparatus lifting off the ground during spring release. Fixing or tethering the apparatus to the ground using a plate of significant mass or anchors dug into the snow surface is planned to address this issue in future testing.

As the end goal for this test apparatus is for integration into safety certification testing for snow sports helmets, it will be necessary to verify that the headform kinematics the rig is capable of producing are representative of observed clinical injury. To do this, further testing is necessary to compare the impact responses in several different scenarios to injury threshold data from existing literature.

Through verification testing of an apparatus design to recreate injurious ski and snowboard head impacts, the first steps in proposing a revised protocol for improved snow sports helmet testing have been achieved. Apparatus modification, as well as additional tests, will further strengthen confidence in the proposed design.

V. REFERENCES

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