An examination of the brain trauma in Novice and Midget ice hockey: Implications for helmet innovation

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Abstract—**Ice hockey helmets are currently not designed for youth players, but rather reduced in size to fit smaller heads. As a result they are not as effective for youth protection. In order to target youth specific helmet protection and innovation, there needs to be an understanding of what characteristics contribute to brain trauma in youth ice hockey. The purpose of this research was to compare the frequency and magnitude of head contact events that occur in Novice and Midget ice hockey age categories. 30 Novice and 30 Midget youth boys' ice hockey games were analyzed to determine the frequency of event type, velocity of contact, and location of contact for head impacts. These events were then reconstructed in laboratory using physical and finite element modelling to determine the maximum principal strain of the events. The results identified that the Novice category helmet design should be focused on reducing impact from hard surfaces, while Midget focused on impacts from collisions with players and the glass.**

Keywords— **Ice hockey, youth, brain trauma, biomechanics, helmet**

I. Introduction

Youth ice hockey has been identified as having a high rate of concussion per participant [1], with up to 1.31 per 1000 player hours. Youth ice hockey is an environment that differs from that of adult elite ice hockey and as a result may require unique protective innovations to effectively manage brain injury risk [2]. Youth ice hockey players are less skilled and engage in game play differently from their adult counterparts. As a result it is important to gain an understanding of how they incur brain trauma so that new helmet technologies and innovations can be developed that can protect against this type of injury.

Brain trauma can occur in ice hockey from many different sources [2.3]. Players can hit their heads on the boards, ice, and glass, or collide with the shoulders, elbows of other players and from pucks. Each of these sources of impact produce a unique loading environment that is measured in terms of linear and rotational acceleration [4]. Linear acceleration has been correlated with more severe traumatic brain injuries, while rotational acceleration is associated with diffuse brain injury such as concussion, or brain trauma from repetitive loading [5,6]. While both of these kinematic measures are useful in determining the severity of an impact, strain in the brain tissues has been shown to be the best measure to determine risk of trauma to the brain tissues [6].

While it has been demonstrated that risk of brain injury from an impact is different in youth and adult ice hockey [7], it is currently unknown if there are differences in how brain trauma occurs within different youth age categories. The purpose of this research was to investigate the difference in brain trauma loading between Novice and Midget youth ice hockey players to determine the frequency and types of events that create brain trauma so that improved helmet technologies and test methods may be developed.

II. Materials and methods

A. Overview

30 Novice (6-7 years) and 30 Midget (17-18 years) ice hockey games were videotaped to identify when head contact occurred. These events were then reconstructed in the laboratory to determine the kinematics of the event for use in finite element modelling of the brain to determine the strain for the impacts. From this procedure, the frequency and magnitude of strain for head contacts in Novice and Midget ice hockey were determined.

B. Head contact identification

Each youth ice hockey game was reviewed in its entirety by two primary reviewers. The reviewers watched the video to determine when head contacts occurred. A head contact was defined as when the head made contact with a person or object in such a way that the contact resulted in head motion. This head contact was classified into two categories: confirmed or suspected. A confirmed head contact was a contact where the head was clearly seen to have been impacted, whereas the suspected head contact was a contact where the impact was occluded in some way and thus could not be confirmed (player crossed in front of the camera view at point of contact). When a head impact was identified, the video of the contact was clipped and the event was logged. The logging recorded the impact location, event type (shoulder, ice, boards etc), the player's position, jersey number, time of impact event, and if the contact was confirmed or suspected. Once a game analysis was completed by both reviewers a third reviewer examined the confirmed and suspected clips for agreement between the reviewers as well as adherence to the inclusion criteria. The third reviewer would then create a final list of confirmed and suspected head contacts for that game that would then be used for further analysis.

C. Categorization of impacts for reconstruction

Once the impacts were identified, the impact characteristics were determined. The event types analyzed were: shoulder, elbow, boards, glass, ice, puck, and head to head. The locations of the impacts were separated into: front, front boss, side, rear boss, rear, and crown, and also if the impact occurred above the center of gravity (cg), below the cg, or at the cg. These definitions provided the prescribed impact locations that would be used for the reconstructions. Only the confirmed impacts were part of this analysis as the suspected impacts could not have a defined impact location. Once the head had been categorized, the frequency of impacts in terms of impact location and velocity (from Kinovea) for the Novice and Midget games were determined. This allowed for the laboratory reconstructions to be conducted so that the strain in the brain associated with these head contacts could be determined.

D. Head contact reconstruction parameters

To conduct head contact reconstruction in the laboratory the parameters of impact location, mass, compliance, and velocity were required. The impact location was determined from the video. The head contact mass was determined from anthropometric tables and/or impact research using ice hockey players [4]. The velocity measure was determined through the use of Kinovea (Kinovea, Open Source) software. This software allowed for the determination of the head contact velocity by creating a calibration grid on the ice using the ice markings [4]. To be sure of the ice marking dimensions researchers went to the rinks and conducted measures to be sure of the reference grid accuracy. Once this grid was placed in the video, the movement of the player, or players in the case of player to player collision, was digitized and the distance over time was calculated. Research has been conducted on this method and it has been found to have errors between 5 and 15% depending on the angle of player relative to the camera which is similar to the error found in other published works [4].

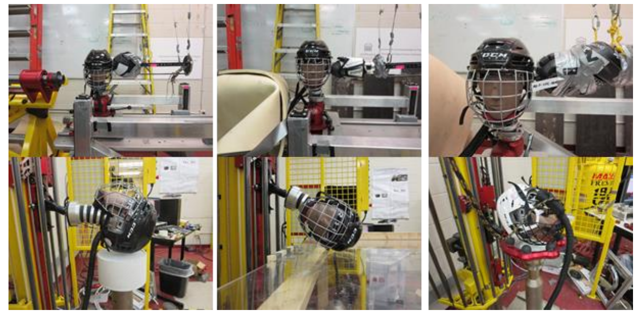

Fig. 1 Reconstruction images for (top left to bottom right): Shoulder, elbow, punch, ice, glass, and boards impacts.

E. Head contact reconstruction and finite element modelling

The shoulder impacts were reconstructed using a pendulum (3.9 kg) for the Novice and the linear impactor (13.1 kg) for the Midget with a compliant impactor to simulate a shoulder impact. The elbow impacts were conducted using a pendulum for both the Novice (1.9 kg) and Midgets (4.8 kg) with an elbow impact cap to simulate the compliance of an elbow. The boards impact used a monorail drop rig that dropped the helmeted headform into a piece of ice hockey boards. This same method was used for the glass and ice impacts, with a section of glass and frozen ice anvils respectively. The puck impacts were conducted using a pneumatic puck launcher. The head to head impacts were conducted using a pendulum system where a helmeted headform was swung into the target instrumented headform (Fig. 1).

The headform used was a Hybrid III 5^{th} for the Novice and 50^{th} for the Midget ice hockey players. The headforms were fitted with a caged helmet for each impact. The headforms were fitted with nine Endevco 7264C-2KTZ-2-300 accelerometers (Irvine, CA, USA) arranged in a 3-2-2-2 array for measurement of three dimensional motion. An unbiased neckform was used to attach the headform to the equipment. The sensors were collecting at 20 kHz and were filtered using a CFC 180 filter. The data collection was conducted using a TDAS module via computer.

Three impacts were conducted per event type, velocity, impact location, mass, and compliance condition.

The impacts resulted in linear and rotational acceleration time histories that were then used as input to the University College Dublin Brian Trauma Model (UCDBTM) [8]. This model represents the geometry and material properties of the human head and brain. Validation of the model was conducted using pressure and brain motion research and was found to be in good agreement with those cadaveric responses [8]. The model was over 23,000 elements. The model was adjusted and sized to the anthropometrics of the head and brain of the average Novice and Midget aged boy for this analysis.

The model output for each head contact reconstruction was in maximum principal strain (MPS) which then allowed for the frequency distribution of those events to be reclassified into categories of MPS that reflected proposed levels of risk based on brain injury research:

Risk Category	MPS magnitude
Very low (VL)	0 - 7.99%
Low (L)	8.0 - 16.99%
Medium (M)	17.0 - 25.99%
High (H)	26.0 - 34.99%
Very high (VH)	35% +

The very low strain category has had little evidence to support immediate or long term neural damage. The low category has been found to have some implications for the pathophysiological neurological cascades associated with some neural dysfunction, as well as a risk on the low end of concussion [5]. The medium category represents the region where structural damage may occur to axons and is the region where risk of concussion is thought to occur [6]. The high and very high categories represent region of severe risk where long term symptoms of concussion have been reported to occur along with more extensive structural damage to axons and neural tissues [9]. Differences in frequency, magnitude, and event type between the Novice and Midget age categories were determined by Mann-Whitney U test.

III. Results

The frequency analysis was conducted per game for this dataset. In terms of total frequency, Novice had significantly higher ($p<0.05$) total very low impacts than Midget, with the two categories similar for the remaining magnitude levels.

There were further differences between the frequency of impacts in the Novice and Midget categories when examining each event type (Fig 2). The Novice players received significantly higher head contacts to the ice for all magnitudes, and head to head, elbow, and boards for VL (Fig 2). Novice also had significantly higher head contacts for boards at medium as well ($p<0.05$). Midget players had more head contacts from the shoulder and elbow at medium, glass at VL and L, and punches at VL ($p<0.05$) (Fig. 3). The puck impacts that were logged were all low velocity events that were too slow to be launched from the pneumatic puck launcher and as a result were not included in the analysis.

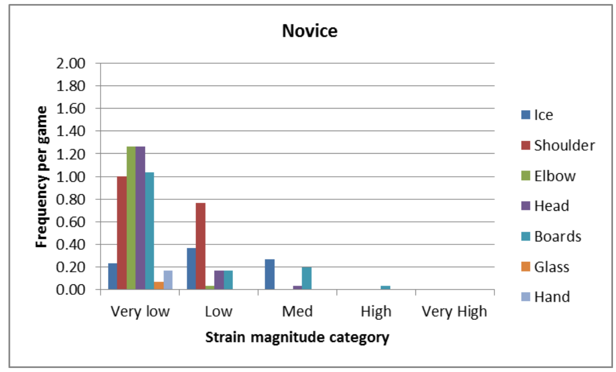

Fig. 2 Frequency by magnitude of MPS for each event type for the Novice category.

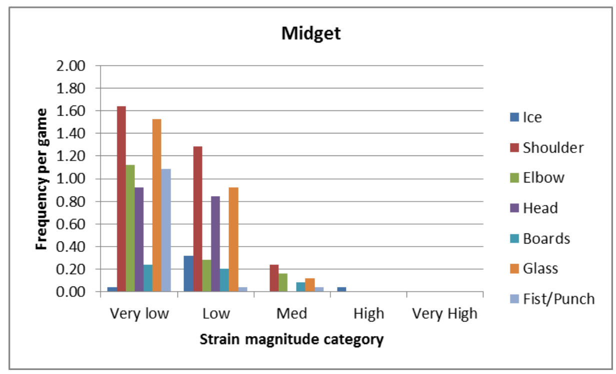

Fig. 3 Frequency by magnitude of MPS for each event type for the Midget category.

IV. Discussion

The results indicate that while there have been reported differences between adult and youth ice hockey in terms of impact event type and risk of brain trauma there are also differences within youth ice hockey itself. The overall frequency analysis shows that Novice players receive more very low impacts than midget players, which is likely a result of the payers being smaller and slower than their Midget counterparts. This would lead to lower velocity and mass impacts, and a resulting lower strain to the brain from each event type. The low and medium magnitudes had similar frequencies between the Novice and Midget categories, but had different distributions of event type.

Novice players had significantly higher frequencies of impacts at the very low magnitudes for ice, elbow, head, and board events. While these frequencies were larger than those of the Midget players, the magnitude of strain was very low, which would indicate a low risk of brain trauma from these events. Novice players did have higher frequencies of medium magnitude events from impacts to the ice and boards; magnitudes of strain that would be indicative of risk of concussion. These results would suggest that the Novice players are at risk of brain trauma from impacts to hard surfaces such as the ice and boards and protective technologies for this age group should be focused on reducing trauma from those surfaces.

Unlike the Novice players, Midget players had shoulder and elbow to head frequencies of the medium magnitude, indicating that these are the event types that could lead to concussion. This is similar to what has been reported in professional ice hockey, with player to player collisions being the source of the majority of concussions [2]. This is a result of the Midget players' higher level of skill, being able to attain higher velocities and aggressively impact each other as part of the play that is not replicated by the Novice players. Midget ice hockey players also impact the glass with their heads more often than Novice players, which is likely a reflection of the differences in height and play style. Midget players also had higher frequencies of very low punches in comparison to the Novice players. This is a result of pushing into the face during the game, where little solid contact between the fist and the players head occurred. This type of combative play is not common in Novice ice hockey, where contact with the hand can occur but it is of an incidental nature. These results identify that the Midget players are at risk of incurring brain trauma from different events than the Novice players and would need protective technologies that would reduce the magnitude of impact for player to player collisions and impacts to the glass.

V. Conclusion

The results of this research show that within youth ice hockey there are differences in how the players are receiving head impacts that can result in risk of brain trauma. In particular, Novice players are more likely to incur a risk of brain trauma from impacts to the ice and boards, whereas the Midget players are more likely to receive trauma from collision impacts. Helmet technology and innovation aimed to reduce risk of brain trauma to youth ice hockey players need to reflect these differences in head loading during game play.

Acknowledgment

Funding for this research was provided by the Natural Sciences and Engineering Research Council of Canada Collaborative Research and Development grant with CCM. Helmets and padding was supplied by CCM.

VI. References

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