

Head Impact Biomechanics by Ice Zone and Athlete Role in Youth Ice Hockey

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ABSTRACT

There are nearly 1 million ice hockey players under the age of 20 worldwide. Hockey is a popular collision sport where athletes face a high risk of concussion and additional exposure to frequent subconcussive impacts (i.e., impacts not resulting in signs or symptoms of concussion). There has been increased concern regarding athletes' exposure to subconcussive head impacts, as evidence suggests repetitive head impacts are associated with neurocognitive and microstructural brain changes, even in the absence of concussion. Contact characteristics influence resultant head kinematics in ice hockey, including the type of contact (e.g., board check, mid-ice collision) athletes are engaged in. Previous research has suggested that athletes' apparent anticipation of contact may influence resultant kinematics; therefore, we evaluated the effect of the athlete's role in the contact (i.e., target or initiator, or incidental contact), as well as where on the ice surface they occurred (i.e., ice zone). Results show that intentional impacts were more frequent than incidental contacts and resulted in greater peak resultant kinematics. Furthermore, contact among athletes was more common in offensive and defensive zones than the neutral zone, but peak resultant kinematics were similar across ice zones. Results of this study motivate further understanding of head kinematics in ice hockey to reduce head impact exposure in the sport.

INTRODUCTION

Ice hockey is a popular collision sport, and participation has increased in recent years, particularly at the youth level (International Ice Hockey Federation, 2019). Hockey is characterized by frequent contact among players, with the ice surface, and against the surrounding playing boards; men's and boys' ice hockey is additionally characterized by intentional collisions, known as body checking (USA Hockey, n.d.). Body checking in boys' youth hockey is associated with increased risk of injury. In a study comparing checking versus non-checking boys' hockey teams, Emery et al. observed a threefold increase in risk of injury among athletes playing in leagues allowing body checking compared to a non-checking league (Emery et al., 2010). Similarly, Black et al. found that elimination of body checking in a youth league resulted in a threefold reduction in injury and concussion risk (Black et al., 2016).

In addition to a relatively high risk of concussion, hockey players are exposed to frequent subconcussive head impacts (i.e., impacts that do not result in overt signs and symptoms of concussion). Subconcussive head impacts are of rising concern, as evidence suggests repetitive exposure to subconcussive impacts may be associated with both neurocognitive and microstructural brain changes, even after a single season of play. One study of collegiate football and ice hockey athletes found that compared to non-contact athlete controls, collision athletes performed worse on measures of new learning, with greater exposure correlating to worse performance (McAllister et al., 2012). Additionally multiple studies have observed changes in diffusion-based imaging metrics among youth and high school football athletes that are correlated with the amount of cumulative head impact exposure experienced over a single season of play (Bahrami et al., 2016; Davenport et al., 2014, 2016).

These findings have motivated the need to better understand athletes' exposure to subconcussive head impacts. There have been several studies of head impact exposure in ice hockey (Mihalik et al., 2019; Reed et al., 2010; Schmidt et al., 2016; Wilcox et al., 2014). However, these studies have been limited; many focus on collegiate samples, which may not be representative of all ice hockey athletes. Additionally, these studies have largely utilized helmet-mounted sensors to assess the magnitude of head impacts occurring in hockey, which are limited in accuracy due to poor skull coupling (Beckwith et al., 2012; Jadischke et al., 2013). In an effort to accurately describe head kinematics and characterize exposure at the youth level, we used a previously validated instrumented mouthpiece sensor, which is associated with improved skull coupling (Rich et al., 2019). Prior research in ice hockey has demonstrated that apparent anticipation of contact affects head kinematics, while player position may not (Mihalik et al., 2010, 2012). Location on the ice (i.e., ice zone) during an impact may be a better discriminator of exposure than position. Additionally, athlete role during checking may be of interest as well. Therefore, the objective of this study was to evaluate the effect of ice zone and athlete role on peak head kinematics in a sample of boys' youth ice hockey athletes.

METHODS

Subjects

This study, approved by the Wake Forest School of Medicine Institutional Review Board enrolled 15 athletes (age 12-14, representing 18 player-seasons) from a local boys' ice hockey team (Table 1, see next). Participant assent and written parental consent were acquired prior to participation.

Table 1: Height, weight, and age at preseason of athletes by position, and mean \pm standard deviation (SD) of all athletes

Position	N	Average Height (cm)	Average Weight (kg)	Average Age (years)
Center	2	169.0	61.2	13.4
Defender	7	166.7	58.1	13.3
Goalie	1	170.2	62.6	13.1
Wing	8	166.6	61.8	13.6
All Athletes	18	168.2 \pm 9.8	60.2 \pm 12.0	13.4 \pm 0.74

Instrumentation

Device Fabrication

Athletes were provided with a custom fit instrumented mouthpiece measuring linear acceleration and rotational velocity of the head (Rich et al., 2019). During the 2018-2019 season, dental impressions were obtained from each athlete by a trained dental professional; dental molds were poured from dental impressions. During the 2019-2020 season, a 3D dental scan of each athlete's upper dentition was collected by a trained dental professional using an intraoral scanner and a dental mold was 3D printed (TRIOS intraoral scanners, 3Shape A/S, Copenhagen, Denmark). Mouthpiece instrumentation, embedded in acrylic, was fit to the mold of each athlete's upper dentition. A soft elastomer overlay was bonded to the mouthpiece to form a mouthguard (Figure 1).

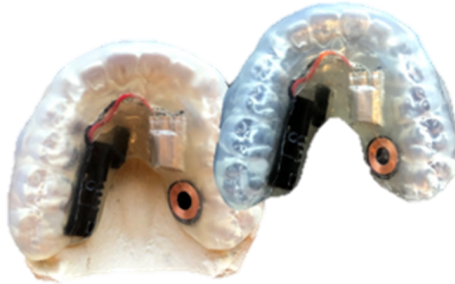


Figure 1: The instrumented mouthpiece and soft mouthguard overlay shaped to the dental stone of an athlete's upper dentition.

Data Processing

Devices were set to trigger for any event during which linear acceleration exceeded a 5 g threshold for at least 3 milliseconds (ms); when triggered, kinematic data from 15 ms pre-trigger to 45 ms post-trigger were saved to the mouthpiece. Head kinematic data collected by the mouthpiece were processed according to the methodology described by Rich et al. (Rich et al., 2019). Data were filtered, zero-offset, rotated to match a conventional coordinate system, and transformed to each athlete's head center of gravity using subject-specific transformation matrices. Resultant time histories and peak resultant linear acceleration (PLA), rotational velocity (PRV), and rotational acceleration (PRA) were calculated from transformed data using MATLAB R2020b (TheMathWorks, Inc., Natick, MA, USA).

Film Review

Kinematic data collected by the mouthpiece was verified with time synchronized film of each practice and game by matching timestamps of mouthpiece-recorded events with timestamps of contact scenarios observed on film. All contact scenarios were coded for impact type, including board check, fall, mid-ice collision, punch, unintentional wall collision, or other head impact. For the purpose of this study, only body checking impacts were analyzed further (board checks, mid-ice collisions). Contact scenarios were reviewed to determine the instrumented athlete's role in instigating contact (Table 2, see next): initiator (i.e., the instrumented athlete instigates contact) or target (i.e., the opponent instigates contact). Initiator and target type impacts were regarded as intentional contact. Incidental contact (i.e., an unintentional collision) was coded as such.

Table 2: Criteria for determining athlete role

1. Does instrumented athlete approach opponent?
If yes – instrumented athlete coded as 'initiator'
2. Does the instrumented athlete lead into the collision with their shoulders?
If yes – instrumented athlete coded as 'initiator'
3. Does the instrumented athlete have control of the puck?
If yes – instrumented athlete coded as 'target'
4. Is the instrumented athlete pinned between the boards and their opponent during a board check?
If yes – instrumented athlete coded as 'target'

Lastly, contact scenarios were also coded for the ice zone where they occurred (i.e., ice location of the collision; Figure 2). Zones were coded as defensive, neutral, or offensive, based on the direction of play relative to the instrumented athletes.

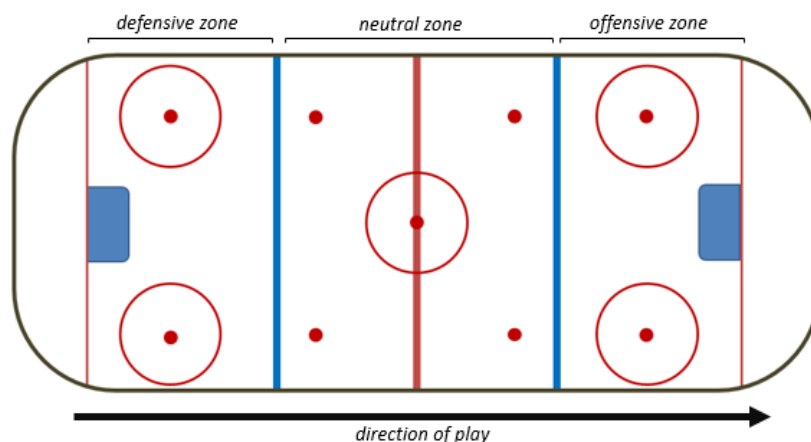


Figure 2: Diagram of ice zones.

RESULTS

Kinematic data were collected during 127 sessions of play across 2 seasons (52 practices, 75 games). A total of 585 body checks were identified for analysis from the 892 video-verified

mouthpiece events. Most body checks occurred in games (n=533, 91%) compared to practices (n=52, 8.9%). Median and 95th percentile peak resultant head kinematics by athlete role and ice zone are provided in Table 3.

Table 3: Median (95th percentile) peak resultant head kinematics by athlete role and ice zone

		<i>N</i>	<i>PLA (g)</i>	<i>PRV (rad/s)</i>	<i>PRA (rad/s²)</i>
Ice Zone	Offensive	213	7.26 (28.6)	8.77 (18.9)	616 (2585)
	Neutral	103	6.91 (23.1)	8.43 (22.8)	585 (1980)
	Defensive	220	7.68 (33.0)	8.93 (19.5)	629 (2337)
Athlete Role	Initiator	197	7.31 (27.3)	8.33 (17.7)	597 (2092)
	Target	350	7.40 (27.9)	9.08 (19.9)	635 (2404)
	Incidental	38	5.58 (38.2)	4.61 (12.4)	419 (3245)
	All Events	585	7.30 (27.8)	8.62 (19.2)	610 (2147)

DISCUSSION

This study sought to characterize head impact exposure in a sample of boys' youth hockey athletes. Specifically, we evaluated peak resultant head kinematics by athlete role (i.e., initiator, target, incidental contact) and ice zone (i.e., location on the ice) for a sample of 585 body checks. Collisions in the defensive zone were associated with the greatest median peak resultant head kinematics; however, the variation observed between zones was small. Collisions in the defensive zone had the greatest 95th percentile linear acceleration, neutral zone impacts had the greatest 95th percentile rotational velocity, and offensive zone impacts had the greatest 95th percentile peak rotational acceleration. Similarly to trends among median peak kinematics, there was little variation in 95th percentile peak kinematics between zones.

Among mouthpiece-recorded events evaluated in this study, contact occurred twice as often in the defensive and offensive zones as compared to the neutral zone. This could in part be due to gameplay characteristics of different zones, as athletes may be more likely to engage in player-to-player contact in the defensive zone to prevent a goal or offensive zone to score a goal, whereas they may focus on carrying or passing the puck in the neutral zone to set up a play. Although we did not explicitly quantify time spent in each zone, athletes generally spend more time in offensive and defensive zones, as most faceoff plays are conducted in an offensive or defensive faceoff circle; neutral zone faceoffs primarily occurred when a team scored a goal and were less common.

In regards to athlete role and frequency, we found that athletes were more frequently the target of contact (n=350, 60%) than the initiator of contact (n=197, 34%) and were seldom involved in incidental contact (n=38, 6%). This could suggest differences in player ability or player aggression influencing athletes' propensity to engage in contact. Similarly, Schmidt et al.

Observed that high aggression athletes experience greater magnitude head impacts than their low aggression counterparts (Schmidt et al., 2016). However, not all contacts observed on video were recorded by the mouthpiece. In some cases, athletes initiating a check had little to no corresponding head motion due to their body positioning; while peak resultant head kinematics were similar across athlete roles for mouthpiece events, initiating contact may in some cases result in low magnitude head motion that does not cross the mouthpiece trigger threshold, and is therefore not recorded, resulting in missed impacts. As such, additional review of all contact observed on film should be completed, as it may provide additional insight on differences in frequency observed between athlete roles.

Regarding athlete role and kinematics, we observed that peak resultant kinematics were similar whether the athlete initiated or received contact with another player. Differences in median peak resultant linear acceleration, rotational velocity, and rotational acceleration were within 0.09 g, 0.75 rad/s, and 38 rad/s², respectively. Similarly, differences in 95th percentile peak resultant linear acceleration, rotational velocity, and rotational acceleration were within 0.60 g, 2.2 rad/s, and 312 rad/s². There were greater differences comparing intentional impacts to incidental contacts; however, the number of incidental contact events was comparably low. Incidental contact had lower median peak resultant kinematics, but 95th percentile linear and rotational acceleration was greater for incidental contact than intentional contact. This is in line with findings from Mihalik et al. that demonstrated athletes experienced greater head kinematics when they were unprepared for contact (Mihalik et al., 2010). However, given the small sample size, more study is needed to assess these differences.

There were limitations associated with this study. First, our sample was limited to one age group, level of play, and gender, and was relatively small. As such, these findings may be limited when applied to a larger sample of ice hockey athletes. Another limitation is that this study only considered video-verified mouthpiece events. Previous findings have demonstrated that despite the improvements in skull coupling, not all contact scenarios observed on film are recorded by the mouthpiece, possibly because they do not reach trigger threshold (Miller et al., 2019).

CONCLUSIONS

This study aimed to compare head kinematics across ice zones (i.e., location on the ice) and the athlete's roles during contact, adding to the growing body of knowledge regarding head kinematics in youth ice hockey. Median and 95th percentile peak resultant head kinematics were similar between ice zones, but contact occurred approximately twice as often in defensive and offensive zones compared to the neutral zone. We also found that there were differences in the frequency and magnitude of mouthpiece-recorded events by athlete role. Intentional impacts (i.e., target, initiator type) tended to have greater median peak kinematics and 95th percentile rotational velocity than incidental contacts and were more frequent. Incidental contacts had greater 95th percentile linear and rotational accelerations than intentional impacts. Kinematics were similar across intentional contact events, but contact where the instrumented athlete was the target occurred 1.77 times more frequently than when the instrumented athlete was the initiator. These findings motivate future study of head kinematics in hockey and may inform policies on body checking to reduce head impact exposure and improve ice hockey safety.

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