Player and Game Characteristics and Head Impacts in Female Youth Ice Hockey Players

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Context: Despite the growing popularity of ice hockey among female youth and interest in the biomechanics of head impacts in sport, the head impacts sustained by this population have yet to be characterized.

Objectives: To describe the number of, biomechanical characteristics of, and exposure to head impacts of female youth ice hockey players during competition and to investigate the influences of player and game characteristics on head impacts.

Design: Cohort study.

Methods: Twenty-seven female youth ice hockey players (mean age = 12.5 ± 0.52 years) wore instrumented ice hockey helmets during 66 ice hockey games over a 3-year period. Data specific to player, game, and biomechanical head impact characteristics were recorded. A multiple regression analysis identified factors most associated with head impacts of greater frequency and severity.

Results: A total of 436 total head impacts were sustained during 6924 minutes of active ice hockey participation (0.9 ± 0.6

impacts per player per game; range, 0–2.1). A higher body mass index (BMI) significantly predicted a higher number of head impacts sustained per game ($P = .008$). Linear acceleration of head impacts was greater in older players and those who played the forward position, had a greater BMI, and spent more time on the ice ($P = .008$), whereas greater rotational acceleration was present in older players who had a greater BMI and played the forward position ($P = .008$). During tournament games, increased ice time predicted increased severity of head impacts ($P = .03$).

Conclusions: This study reveals for the first time that head impacts are occurring in female youth ice hockey players, albeit at a lower rate and severity than in male youth ice hockey players, despite the lack of intentional body checking.

Key Words: concussions, mild traumatic brain injuries, adolescents, helmets, sports injuries

Key Points

- Head impacts occurred in female youth ice hockey players despite no permissible body checking.
- When the female ice hockey players were hit during a game, their heads moved at a slower rate than that reported in male youth ice hockey players.
- After an impact, a player's head rotated at a higher rate if she was older and heavier and either played the forward position or spent more time on the ice.
- Older female ice hockey players who had a higher body mass index and spent more time on the ice in the forward position experienced increased frequency and severity of head impacts, suggesting that these factors should be examined more closely as potential modifiers for injury exposure.

Inherent to the sport of ice hockey is the potential for head impacts. High rates of speed combined with a variety of obstacles and hard surfaces (eg, other players, ice, boards) increase the likelihood of collisions and contact to both the body and head. To date, few researchers have specifically examined the number and nature of head impacts or concussions sustained by female youth ice hockey players and the risk factors for these impacts and injuries. In North America, the popularity of ice hockey among female youths has grown exponentially. In the United States alone, the number of registered youth female players has grown from 5068 in 1990–1991 to 48 781 in 2010–2011.¹ Although much the same as male ice hockey with regard to the rules of play, a significant difference is that intentional body checking is

prohibited at all levels in female ice hockey. Despite this, collisions do occur and have been reported to account for 50% of all injuries,² indicating that impacts to the body and head are taking place.

Many investigators exploring head-impact biomechanics during sport participation use the Head Impact Telemetry (HIT) System (Simbex; Lebanon, NH). The HIT System equips commercially available sport helmets with accelerometers designed to measure the number and biomechanical characteristics of head impacts sustained during sport participation. To date, this work has been primarily conducted in male high school and collegiate football players,^{3–5} where the technology is employed as part of the

Sideline Response System (Riddell, Elyria, OH), and more recently in youth and collegiate ice hockey players.^{6–14}

The severity and frequency of head impacts sustained during youth ice hockey participation are likely influenced by several factors, including age, position, game type, and body size. When comparing high school football players with collegiate football players, age influenced the number and magnitude of head impacts (ie, older college-aged athletes sustained more impacts and higher-acceleration impacts than high school athletes).¹⁵ Position⁸ (ie, forwards playing the wing position sustained more head impacts) and game type (ie, a greater number of head impacts were sustained during tournament play than during other types of games)⁸ also play roles. Further, the authors of a previous study⁸ on male youth ice hockey players suggested that physical characteristics, such as variability in player sizes, may influence one's susceptibility to head impacts (eg, a taller player in contact with a shorter player; a heavier player may be less able to avoid opponents). To date, the relationship between body mass index (BMI) and head impacts among female youth hockey players has not been examined. In addition, age,^{16–18} variability in body size,^{17–19} and tournament play have also been found to be associated with higher injury rates^{18–19} among youth ice hockey players, warranting further exploration of the influence of age and body size on the head impacts sustained by the female youth ice hockey population.

Thus, the purpose of our study was to (1) describe the number and biomechanical characteristics (linear acceleration, rotational acceleration, Head Impact Technology severity profile [HITsp]) of head impacts, as well as exposure to head impacts (time on the ice) of female youth ice hockey players during competition and (2) investigate the influence of and interaction between player characteristics (age, playing position, BMI, and time on the ice per game) and game characteristics (game type: regular season, playoff, and tournament games) on head impacts. Based on our previous research conducted with male youth hockey players, we hypothesized that a greater number of head impacts would affect those in forward playing positions and those participating in tournament games.⁸ We also anticipated that BMI might influence head-impact characteristics due to the increased variability of body sizes, with competition levels being organized according to 2 calendar-year cohorts in our participants (see next section).⁸

METHODS

A convenience sample of 27 female youth ice hockey players on 3 representative-level ice hockey teams in the Ontario Women's Ice Hockey Association was recruited. Each participating team was followed for 1 ice hockey season within a 3-year period. Within the Ontario Women's Ice Hockey Association, female youth representative ice hockey teams participate in different age categories and at different levels of competition. Each age category consists of 2 age cohorts (eg, Pee wee contains 11- and 12-year olds). From least competitive to most competitive, the levels of competition are C, B, BB, A, and AA. We aimed to exclude female youth ice hockey players who did not play representative-level ice hockey (eg, house league, select) and who played at either the lowest (C) or highest (AA) levels of competition in order to provide a more

Table 1. Demographic Information of Female Youth Ice Hockey Players

Characteristic	Female Youth Ice Hockey Players (n = 27)	
	No.	Mean ± SD
Age, y		12.5 ± 0.52
Height, cm		156.5 ± 8.9
Weight, kg		49.0 ± 9.8
Body mass index, kg/m ²		19.8 ± 2.69
Level of play ^a		
Pee wee (11–12 y) A	20	
Bantam (13–14 y) BB	7	
Position of play		
Defense	10	
Forward	17	

^a In female hockey, the terms *Pee wee* and *Bantam* describe the age range of the players and the terms *A* and *BB* describe the level of play; the order from highest to lowest skill level is AA, A, BB, B, C.

accurate representation of the typical female youth ice hockey player. As no instrumented goalie helmets were used, players in the goalie position were also excluded from the study. Participant demographic characteristics are listed in Table 1. Ethics approval was obtained from the University of Toronto Health Science Research Ethics Board. Informed consent was obtained from all participants' legal guardians, and assent was obtained from all participants before data collection.

Sustained head-impact data were collected using HIT System technology for ice hockey helmets.^{6–14} The HIT System equips commercially available and approved Stealth S9 ice hockey helmets (Easton-Bell Sports, Van Nuys, CA) with accelerometers designed to continuously measure head-impact accelerations during ice hockey participation. The instrumented helmet units were certified by the Hockey Equipment Certification Council and Canadian Safety Association. All helmets were new (eg, never worn) at the start of this research study. Each helmet unit consisted of 6 spring-loaded accelerometers embedded into the foam liner of the helmet to maintain constant contact with the head to ensure that accelerations of the head, rather than the helmet, were recorded.²⁰ The helmet unit also contained a removable battery pack, a wireless transceiver (903–927 MHz), and onboard memory and data-acquisition capabilities (8 bit; 100 Hz/channel).²¹ For all head impacts with an acceleration greater than 10g, data were collected for 40 milliseconds (8-milliseconds pretrigger and 32-milliseconds posttrigger) to ensure the capture of a complete waveform.^{9,20} Head accelerations were recorded in real time for the entire team, data were time stamped and wirelessly transmitted through a radiofrequency telemetry link to an off-ice laptop computer, and head-impact biomechanical measures, including linear and rotational acceleration as well as HITsp, were computed. *Linear acceleration* is the change in velocity of the estimated center of gravity of the head resulting from an impact and is measured in g, whereas *rotational acceleration* is the angular velocity of the head in a given direction after an impact, with the estimated center of gravity of the head acting as the origin, and is measured in radians per second squared (rad/s²). Here, HITsp is a weighted measure of head-impact severity that includes linear and rotational acceleration, impact duration, and impact location.⁵ A more

Table 2. Literature Reporting Biomechanical Head-Impact Characteristics in Youth Ice Hockey Players^a

Study	Population	Mean Linear Acceleration, g	Mean Rotational Acceleration, rad/s ²	Mean Head Impact Technology Severity Profile
Current study	Female youth hockey players (n = 27; age = 11–14 y)	16.6	1329.4	12.5
Mihalik et al ⁷ (2008)	Male youth hockey players (n = 14; age = 13 y)	Forwards ^b 18.8 (+12%) Defense 18.4 (+10%)	NA	NA
Cubos et al ⁶ (2009)	Male youth hockey players (n = 13; age = 13–14 y)	15.8 (–5%)	NA	NA
Reed et al ⁸ (2010)	Male youth hockey players (n = 13; age = 13–14 y)	22.1 (+25%)	1557.4 (+15%)	NA
Mihalik et al ¹⁰ (2010)	Male youth hockey players (n = 16; age = 14 y)	21.5 (+23%)	1441.1 (+8%)	15.8 (+21%)
Mihalik et al ¹¹ (2012)	Male youth hockey players (n = 52; age = 13–16 y)	18.4 (+10%)	1464.5 (+9%)	14.1 (+11%)

Abbreviation: NA, not available.

^a Percentage difference from current study is reported in parentheses.

^b No combined mean linear acceleration (forwards + defense) reported.

complete description of the HIT System and related algorithms,^{21,22} along with its use for measuring head impacts sustained during youth contact ice hockey, can be found elsewhere.^{8,10–11}

Data specific to time on the ice per game for each participant during ice hockey competition were collected using a computing utility designed to measure time on task when examining injury in sport participation.²³ This computing utility is a standalone personal computer program that is based on an integration of a Web server application and the scripting features of JavaScript and Perl.²³ Using a touchscreen tablet computer and a start-stop mechanism, this utility allows one to record in real time when each player on a given sport team is actively involved (eg, on the ice) versus not actively involved (eg, on the bench) during competition. Time-on-task data were entered into the computing utility at rink side by graduate students trained on the device and familiar with ice hockey. Time-on-ice data have been collected using this computing program for male Atom-aged²⁴ and male Bantam-aged⁶ youth ice hockey players.

Data were collected during 3 consecutive hockey seasons from 2008–2009 through 2010–2011. Starting and ending times for each ice hockey game and individual periods were recorded by the study investigators to exclude any head impacts occurring outside of ice hockey game play (eg, before or after the game, between periods) from the data analysis. Data were automatically recorded by the instrumented helmets when the sensors were in contact with the participant's head and recording stopped when the helmet was removed. Using the time-on-task computing utility, exposure data at all ice hockey games were collected by clicking the “start” button on the program's interface using a touchscreen-enabled pen each time a given participant stepped on the ice. The “stop” button was clicked when the participant stepped off the ice or when play was stopped after a whistle.

We used multiple regression analyses to determine factors associated with head impacts (frequency and severity) sustained by the female youth ice hockey players. Separate models were created for each criterion variable (linear acceleration, rotational acceleration, HITsp, and number of head impacts per game). Player position, player age, player BMI, time on the ice per game, and game type were included as predictor variables in each model.

To account for differences in the number of ice hockey games at which data were collected for participants, all data

were normalized by analyzing the data for each player per game. For all models, the predictor variables were entered simultaneously, and the model was simplified by removing the least significant term and ensuring that this deletion resulted in an insignificant increase in deviance. This process was followed until all remaining factors were statistically significant ($P < .05$). Values for linear acceleration and impacts sustained per game were log transformed, whereas rotational acceleration values were square-root transformed due to skew. Descriptive statistics and multiple regression analyses were carried out using the statistical programming environment R (The R Foundation, Vienna, Austria).²⁵ The threshold for statistical significance was set at $P < .05$. Averages are reported as mean $\pm$ standard deviation. Secondarily, to determine if participants with lower or higher BMI had similar exposure characteristics, a correlation analysis was conducted between BMI and total time on the ice and time on the ice per game.

RESULTS

Over the course of 66 ice hockey games (29 regular season, 18 playoff, and 19 tournament games) across the 3-year study duration, 27 female youth ice hockey players sustained 436 head impacts during 6924 minutes of active ice hockey participation (time on the ice). On average, participants spent 14.4 ± 2.2 minutes (range, 8.7–17.8 minutes) on the ice per game and sustained 0.9 ± 0.6 (range, 0.00–2.1) head impacts per game. When considering the individual factors of BMI, player position, time on the ice, and game type, a multiple regression model accounted for 9% of the variance in the number of head impacts (adjusted $R^2 = 0.09$, $F_{1,68} = 7.44$, $P = .008$). Only BMI was found to predict head impacts (estimate = 0.90, $SE = 1.04$, $t = -2.73$, $P = .008$), such that having a higher BMI resulted in a greater number of head impacts sustained per game. No significant interactions between the other factors were found. Further, a secondary correlation analysis determined small ($r = 0.13$, $P = .03$) to fair ($r = 0.43$, $P = .03$) relationships between BMI and total time on the ice and time on the ice per game, respectively.

For all head impacts recorded across all participants, the mean linear acceleration was $16.6g \pm 7.3g$ (range, 10g–61g), where 94.0% (410) of all impacts were less than 30g (see Table 2). When exploring the effect of player and game characteristics on the linear acceleration of head impacts, our multiple regression model accounted for 29%

of the variance (adjusted $R^2 = 0.29$, $F_{23,46} = 2.25$, $P = .01$). In support of our original hypothesis, game type affected the linear acceleration of head impacts. However, greater acceleration was predicted by both tournament (estimate = -5.19 , $SE = 0.01$, $t = -2.12$, $P = .036$) and regular season games. These findings can be further explained by examining the interaction effects for position type. More specifically, with increased age and for players in the defense position, playing in tournament games predicted greater linear acceleration of impacts (estimate = 1.54 , $SE = 1.19$, $t = 2.39$, $P = .021$), as revealed by a 3-way interaction. However, these findings were again mediated by BMI in a 4-way interaction such that with increased age, players in the forward position who had a greater BMI and spent more time on the ice were more likely to experience greater linear acceleration of head impacts (estimate = 1.00 , $SE = 1.00$, $t = 2.80$, $P = .008$), regardless of game type.

The mean rotational acceleration across all participants was 1329.4 ± 870.6 rad/s² (range, 234.7–5872.1 rad/s²; Table 2), where 84.2% (367) of all impacts were less than 2000 rad/s². Multiple regression analysis generated a model accounting for 41% of the variance (adjusted $R^2 = 0.41$, $F_{15,54} = 4.17$, $P < .001$). Rotational accelerations were higher during regular season games ($P = .035$), for older players ($P = .008$), those with larger BMIs ($P = .005$), and those who were in forward playing positions ($P = .008$) and spent more time on the ice per game ($P < .001$).

A 2-way interaction revealed that, for those players with a greater BMI, regular season games predicted greater rotational accelerations ($P = .04$). This finding was further characterized by 3-way interactions such that older players with larger BMIs who played the forward position experienced greater rotational acceleration of head impacts ($P = .004$) as did those older players with greater BMIs who spent more time on the ice ($P < .001$).

The mean HITsp was 12.5 ± 3.9 (range, 5.7–31.3; Table 2). The distribution for HITsp values was also skewed toward lower values, with 80.0% (349) of all impacts having HITsp values below 15. Our multiple regression model accounted for 16% of the variance (adjusted $R^2 = 0.16$, $F_{4,65} = 4.20$, $P = .004$) in head-impact severity. Age emerged as a significant predictor of head impact severity such that older players experienced greater HITsp ($P = .002$). Furthermore, increased ice time during tournaments significantly predicted increased HITsp ($P = .03$).

DISCUSSION

Considering player and game characteristics in relation to each other and when looking across all head-impact variables collected, we determined that our findings partially supported our original hypotheses: age, BMI, playing position, time on ice, and game type all had some influence on the severity or frequency (or both) of head impacts sustained during female youth ice hockey participation. A critical result of this study is that player BMI predicted head impacts of greater linear and rotational acceleration and frequency. Having a greater BMI, while also being older, spending more time on the ice, and playing the forward position, significantly predicted head impacts of higher linear acceleration; having a higher BMI, while also being older and playing the forward position, significantly predicted head impacts of higher rotational

acceleration. Further, a higher BMI predicted a greater number of head impacts sustained per game. However, the reason for this finding is unclear. Players with a higher BMI would carry more momentum during a collision, accounting for increased linear and rotational acceleration. With respect to frequency, it may be that the players with lower BMIs sustained an equivalent number of head impacts, but they may have been less than 10g, which would have been excluded according to current data-filtering methods.^{7,10,11} Players with higher BMIs could have received more playing or ice time, which could equate to increased exposure to head impacts. However, small ($r = 0.13$, $P = .03$) to fair ($r = 0.43$, $P = .03$) relationships were found between BMI and total time on the ice and time on the ice per game, respectively, within the study sample.

In our study, the mean number of head impacts recorded per player per game across all participants was less than 1 impact per game (mean = 0.85 ± 0.12) and was considerably lower than the 5.19 ± 0.62 head impacts per player per game (5.19 ± 0.62) reported in male Bantam-aged AAA ice hockey players.⁸ The head impacts were also of lower severity (eg, lower linear acceleration, rotational acceleration, and HITsp values) than those noted previously for male youth ice hockey players in all but 1 study referenced (see Table 2).

We demonstrated a higher percentage of impacts of a low linear acceleration (94.0% below 30g) compared with previous findings reported for male youth hockey players (83.1% below 30g)⁸ and consistent with previous research.^{12–14} It is possible that the differences were mitigated by the permissibility of body checking. However, further investigation that incorporates larger sample sizes of both male and female ice hockey players in addition to the influence of other factors (eg, rules, rule enforcement, body size, strength, speed, nature of play) is needed to improve our understanding of this possibility.

Although a concussive event did not occur as a result of the head impacts sustained during our study, the player and game characteristics found to predict head-impact severity—linear and rotational acceleration and HITsp—may be used to proactively mitigate these impacts in female youth ice hockey players who may be at a higher risk (eg, older players with higher BMIs who either spend more time on the ice or play the forward position or both) by delaying positional specificity and limiting competition to 1-year cohorts during development.

Our study had a number of limitations, including helmet discomfort (which resulted in helmet removal for some games) and limiting real-time head-impact data collection to game play (instead of game play and practices) due to limited resources. Specific to ice hockey, however, concussions are more likely to occur during game play than during practice,^{26,27} and when measuring head impacts in youth ice hockey players, a greater number and greater average acceleration of impacts have been found during game play compared with practices.^{7,11} Further, biomechanical measures computed using the HIT System may be overestimated versus laboratory reference systems²⁸ and should therefore be interpreted with caution.

CONCLUSIONS

This study reveals for the first time that head impacts are occurring in female youth ice hockey players, albeit at a

lower rate and severity than in their male counterparts, despite the lack of intentional body checking. The female youth ice hockey community should be aware that head impacts do occur in this population and that identifiable risk factors (high BMI, more time on the ice, regular season games, and players in the forward position) correlate with increased frequency and severity of head impacts.

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