Comparing concussion rates as reported by hockey Canada with head contact events as observed across minor ice-hockey age categories

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Abstract
Head injuries in elite and youth sport have garnered growing public attention in part because of high-profile cases of professional athletes suffering career-ending/threatening concussions and because of the increase in medical studies identifying how repeated concussive events can lead to long-term health problems, most notably degenerative brain disease. Public concerns around youth ice hockey are intensifying in light of recent evidence which suggests that effects of head injury are worse for youth than they are for athletes in later stages of life. To better understand concussion injury rate trends across all levels of youth hockey, this paper provides a retrospective analysis of concussion related hockey injury as recorded in Hockey Canada’s Injury Reporting System from the period covering 2009 to 2016, combined with two years of observational research documenting head contact events in minor hockey in the Ottawa and Gatineau regions of Ontario and Quebec. By comparing two different data sets through different methodological designs, it provides important insight into the levels of head contact in youth hockey, how head contact is occurring, and offers commentary about the levels of risk players are exposed to in minor hockey in Canada.

Keywords
Concussion, ice hockey, head trauma, injury, sport, youth

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Head injury in youth hockey

Historically, injury rates in hockey have been amongst the highest in North American sport, prompting hockey organizations to implement measures to reduce the risk of injury.\(^{11,12}\) In the 1960s, the majority of severe injuries in hockey occurred as a result of head contact, mainly attributable to a lack of quality protective equipment and regulations to protect the head and face. In Canada, it was not until 1978 that amateur hockey players were required to wear helmets approved by a technical standards committee. The enforced use of a helmet and face mask was remarkably successful, virtually eliminating facial lacerations and skull fractures.\(^{13}\) However, reports of injuries involving youth and adult hockey players show that, despite advances in equipment design, the number of concussions remain an important concern in the sport today.\(^{14}\) In fact, a study from Covassin, Swanik, and Sachs stated that approximately 20% of hockey players sustain a concussion during their playing career.\(^{15}\) These numbers could even be higher according to King and Leblanc who suggest that what is reported in hockey “is likely the tip of the iceberg, since many injuries, particularly concussions, which may have long-term consequences on the developing brain, are underreported.”\(^{16}\) One explanation of this underreporting is offered by Juhn et al.: “it is likely that players under-report concussion, as most concussions do not involve loss of consciousness, and players are concerned that they will be removed from practice or games”.\(^{17}\) Perhaps even more alarming is the fact that sport-related concussion is being reported with increased frequency among children and adolescents.\(^{18}\) It has been reported that around 10–12% of minor league hockey players aged 9–17, who are injured, report a head injury, most commonly a concussion.\(^{8}\) These numbers are disturbing for parents whose sons/daughters are participating in sport, especially at a young age where the developing brain is at an even higher risk of injury. Pre-adolescent youth with a traumatic brain injury may never fully develop the social and cognitive skills characteristics of adults and maybe more violent than those without such an injury.\(^{8}\) Moreover, repeated concussions may lead to permanent learning disabilities and other neurological and psychiatric problems.\(^{19}\)

Methods

Hockey Canada insurance data

Hockey Canada participates in a national insurance program to compensate participants injured while playing the sport. The coverage ranges from areas of commercial general liability, sexual misconduct to accidental death and dismemberment.\(^{20}\) To file a claim, participants must complete a “Hockey Canada Injury Report” within 90 days of an injury event, which describes the type of injury and how the injury occurred. The form also serves as an injury-reporting mechanism by which teams/individuals document any injury that receives medical attention. There is a section of the form that must be completed by a medical doctor providing details about the injury, how it was treated, and prognosis for recovery. The physician-signed form is then submitted to the specific hockey branch which is then pooled and stored in a central database managed by Hockey Canada.

For this study, injury data from the 2009 to 2016 seasons were provided by Hockey Canada. All participant information is anonymous, along with geographic region, making it impossible to identify players. Data dating back to 2009 were requested because it is the year prior to Hockey Canada introducing a modified head contact rule, whereby any contact to the head, voluntary or involuntary, would receive a minimum 2 min minor penalty. The information was organized in an excel sheet by age division. For the purpose of this study, only youth age groups from the Initiation Program (IP) (5–6 years old) to Midget (15–17 years old) were included. Descriptive statistics were used to analyze all concussion-related injury by age level. The information was then grouped by injury mechanism and then compared by age level. Concussive injury rates for the different age levels were determined using the annual registration numbers for each particular age group. Concussive injury rates per mechanism of injury were derived from the number of concussive injuries for a particular mechanism over the total number of concussive injuries.

Observational data collection

Separate from the Hockey Canada analysis, observational methods were conducted to document the frequency and contextual factors surrounding head contact events that are being experienced across different age groups in Canadian minor hockey. The intention was not to document or attempt to diagnose
concussive-related episodes, but rather understand how and why head contact events are occurring and to determine if there were any correlations between the observed head contact events and the rates of concussions as reported in the Hockey Canada data. An observational research design was implemented to document minor hockey games that occurred over the course of the 2016–2017 and the 2017–2018 seasons. For the purpose of this study, a head contact event was described as any clear observable contact to a player’s head that occurred as a result of participation in organized game play, by way of person to person contact, head to boards/glass, head to ice, stick to head, puck to head, or any combination of these factors. The hockey teams recruited were from all categories of minor hockey from the IP level to the midget level from both male and female leagues in the Ottawa (Ontario, Canada) and Gatineau (Quebec, Canada) regions. A total of 201 games (21 IP, 30 Novice, 30 Atom, 30 Peewee girls, 30 Peewee boys, 30 Bantam, 30 Midget) were observed and video recorded. In order to effectively document game action, a team approach to data collection was implemented, similar to that what was conducted by Dumas and Laforest. The team of volunteers in charge of the data collection was made up of undergraduate and graduate students from the University of Ottawa’s School of Human Kinetics. A team composed of three researchers attended each game to provide detailed notes pertaining to all aspects of head contact events, filled out observation grids, and video recorded the games to categorize and analyze head contact events. The cameras were set up in the rink prior to the game to ensure a wide field of view so that as much of the gameplay as possible could be recorded. Once the recording was complete, the researchers measured all ice markings at each rink, so that the dimensions could be used to calibrate the field of view for the video analysis.

Head contact events were only confirmed after extensive video analysis was conducted. Two primary reviewers watched each game video at slower than normal speed, using Kinovea software zoom in tools to identify when head impacts occurred. A head impact was defined as when the head made contact with a person or an object in such a way that it resulted in head motion. Each identified head impact was classified into two categories: confirmed or suspected. A confirmed head impact was when the head was clearly seen to have been impacted on the video, whereas the suspected impacts were those where the impact was thought to have occurred, but the point of contact was occluded in some way and could not be confirmed (e.g. player crossing in front of the impact as contact occurred). When a head impact was identified, the video of the contact was clipped and the event was logged using a logging form. The log recorded the impact location, event type, the players position, jersey number, time of impact event, and if the impact was confirmed or suspected. The event types were recorded in the log as follows: shoulder, elbow, ice, boards, glass, head to head, punch/fist, puck, and “other” type of impact. Each event was subsequently analyzed to determine how the event occurred, whether by (1) Body to body collision; (2) Body to body collision leading to head hitting the ice; (3) Body to body collision leading to head hitting the ice; (4) Body to body collision leading to head hitting boards/glass; (5) Player falling on their own leading to head hitting the ice; (6) Player falling on their own leading to head colliding with boards; (7) Hit by puck; (8) Hit by stick; and (9) Punch. If contact to the head occurred more than once on a single play, it was treated as a separate head contact event (e.g. body to head followed by head to ice). Once the game analysis was completed by both reviewers, a third reviewer examined all the confirmed and suspected impact videos and logs for agreement between the clips and logs as well as adherence to the head impact identification criteria. The third reviewer then created a final list of confirmed and suspected logs and videos. Only events listed as “confirmed” were used for this analysis. The parameters of this study were approved by the University of Ottawa’s Health Sciences and Science Research Ethics Board, file #H08-15–06.

Results

Hockey Canada injury report data

Total concussions. Over the six-year period, Hockey Canada registration numbers rose from just under 600,000 (585,004) in 2009–2010 to slightly over 600,000 (635,539) in 2015–2016. Registration numbers exclusive to minor hockey (IP to Midget), however, have declined since 2009–2010 with just over 500,000 participants (511,149), compared to the past four years where the numbers have been steadily below 500,000. The amount of reported concussions for this age group rose for the first two years after 2009–2010, but has steadily declined over the next three years. By way of percentages, the lowest rate of concussion was in the 2009–2010 season, with 0.12% of participants reported receiving a concussion, with the highest percentage of reported concussions occurring in the 2011–2012 season at 0.21%. By 2015–2016, the percentage of reported concussions dropped to 0.18% (see Figure 1).

Concussions reported by age level. The percentage of reported concussions by age level steadily increases with age level, with the Bantam level being the
exception (see Figure 2). Bantam had the highest percentage of reported concussions at 0.33%, followed by Midget at 0.30%. The percentage values dramatically decrease after Bantam with Peewee at 0.23%, Atom at 0.12%, Novice at 0.04%, and IP at 0.01% (See Figures 3 and 4).

Mechanisms of reported concussive injury. The Hockey Canada Injury Report organizes injury mechanisms into 11 predetermined categories that participants check when filling out the form. They include: hit by puck; collision with boards; non-contact injury; hit by stick; collision on open ice; collision with opponent; fall on ice; checked from behind; collision with net; fight; and blindsiding. The categories are in part mechanism of injury and part situational factor. A hit from behind is an illegal play in minor hockey, where a player initiates contact to the back of an opponent who is facing the boards. In this case, hitting from behind is a situational factor, but the actual mechanism of injury is collision against boards. The situational factors and mechanisms of injury from the Hockey Canada Injury Report form were therefore reorganized into six categories: (1) collision with opponent (originally collision with opponent, collision open ice, blindsided); (2) collision leading to contact with hard surface (originally collision with boards, checked from behind, collision with net); (3) falls to ice; (4) hit by stick; (5) hit by puck; and (6) fight. Non-contact injury was eliminated from the list, since there were no concussive-related injuries that fell under this category. The three predominant mechanisms of injury based on the adjusted categories were collision with opponent (24.8%), collision leading to contact with hard surface (20.2%), and falls to the ice (5.5%).

Primary mechanism age-level comparisons. When comparing the three primary mechanisms of reported concussion injury by age level, injury by collision with an opponent increases by age, whereas injury by falls decline. Injury as a result of collision with a hard surface remains constant through all age groups.
Observed head contact events in minor hockey

Head contact events by level of play. The level of play had a significant role in the number of head contact events documented. At the IP and Novice levels, there was a much higher rate of head contact than expected with IP reporting eight head contact events per game and Novice at 8.1 (see Figure 5). The rate of head contacts dramatically decreases at the Atom and Peewee girls level and then begins to rise from Peewee boys all the way through to Midget. Midget was the only age category that recorded a higher rate of contact at 10.5 contacts per game than what was reported at IP and Novice.

Point of contact. Shoulder and elbow to the head were by far the most frequent points of contact at every level except at the IP level where head to ice was the leading point of contact (Figure 6). Shoulder and elbow combined to make up 23% of the head contacts at the IP level, whereas head contact by should and/or elbow made up at least 37% of head contacts for all other levels, peaking at 50% with Peewee girls. Head-to-head collisions was another major point of head contact which steadily decreased by age level, with 18% at the IP level and dropping to 14% at Midget. Contact along the perimeter of the ice surface (boards and glass) was consistently high across all levels but in contrast to head to head contact, generally increased by age level with 19% at the IP level and 24% at Midget. The most noticeable trend was the decrease in head to ice contact as age categories rose. At the IP level, head contact with the ice was reported at 23%, which steadily declined until Midget where head to ice contact was reported at only 4%. The category of “other” refers to less frequent head contact with parts of the body other than shoulder/elbow or head, or with the net. They were not independently categorized because of the rarity of the event.

Mechanisms of injuries. Similar to data reported by Hockey Canada, the three primary causes for head contact (collisions, collision with hard surface, and head to ice) were the most observed forms of head contact, but body-to-body contact was responsible for a much higher rate of head contact than what Hockey Canada reported (see Figure 7). Based on in game observations and video analysis, 62% of head contact was the result of players colliding together, whether by purposive body checking or incidental collisions. Collision against the boards/glass was the second highest mechanism for head contact, representing 16% of total head contact events. Falls to the ice were the third highest mechanism of head contact, with 6% precipitated by a collision and then a fall to the ice, and 5% with players falling to the ice on their own and their head making contact with the ice.

![Figure 5. Head contact events rate across age categories.](image-url)
When breaking down mechanisms of head contact by age group, body-to-body contact remained the highest mechanism of head contact across all age levels, but differences were observed with head to boards/glass contact and head-to-ice contact (See Figure 8). At the IP level, the second highest mechanism for head contact resulted from players simply falling to the ice—without previous contact with other players. Head contact as a result of players falling on their own into the boards shared the third highest mechanism of head contact, along with head contact to the ice as a result of a collision with another player. In all other age categories, head contact with boards/glass as result of a collision with another player was the second highest head contact mechanism, other than at the Novice level where falls to the ice as a result of a collision was the second highest head contact mechanism.

Discussion

The issue of concussion and traumatic brain injury (TBI) is a growing concern in youth sport, and sport leagues/organizations are facing scrutiny about the risks athletes face participating in their specific sports. In Canada, hockey has received considerable public attention because of the apparent high risk of injury at both the elite and grassroots levels. The high injury rates are often associated with body checking and a physical style of play, which is routinely described in the media and in public reports as violent and/or aggressive. Cusimano et al. state that “injuries are common in all contact sports, but those who play ice hockey are at particular injury risk.” These characterizations of the sport as violent, aggressive, and unsafe have triggered public outcry about Canada’s national winter pastime. National and local media have been quick to report that Canadians are “Shunning Hockey” and that “The future looks bleak for Canadian minor hockey.” National organization such as the Canada Safety Council posted an opinion piece entitled, “Hockey – Our most dangerous game.” while the Canadian Sports Insurance Brokers published a blog entitled “Melting Ice: Canada’s Hockey Crisis.” In an interview by Canadian news anchor Peter Mansbridge, he asked hockey legend
Wayne Gretzky what his response was to the apparent hockey crisis. Gretzky responded:

What do you say to parents today who would love their kids to be playing hockey, girls and boys, but they say two things, they say: it’s just too expensive... and it’s too rough. And I don’t mind them playing in leagues where there’s no hitting, but I’m not going to let them go through the potential of serious injury, concussion, what have you.29

Without wishing to dismiss concerns about player safety, the characterization of hockey as a violent and unsafe sport that Canadians are “shunning” is not consistent with data as reported by Hockey Canada, nor does it reflect the observational data reported in this paper.

To start, the reported declines in hockey participation rates are not evidenced by Hockey Canada’s registration data which has remained relatively consistent from 2009 to 2016. The independent statistical research platform Statista,30 using numbers provided by the International Ice Hockey Federation, report even higher levels of hockey registration totals for Canada which are well in excess of 600,000 participants from 2010 to 2018. The reported concussion rates also put into question the characterization of hockey as a dangerous sport with high levels of head injury. Considering the increased awareness of concussions and head injury, it is perhaps not a surprise that there was a rise in reported concussions from 2009 to 2012, but the rate steadily declines from that point forward. The numbers themselves are relatively low, as Bantam reported having the highest rate of concussion with less than half a percent (0.33%) of the registered participants reporting a concussion over this six-year period. This number falls as low as 0.01% at the IP level where concussions were rarely reported. With this said, what must be taken into consideration when analyzing this data is that despite Hockey Canada’s injury reporting system being an important tool for capturing reported head trauma, the information that is provided is voluntary and based on individual recall of the experience (as either reported by the player, parent, or team trainer), which likely leads to under reporting of injury and limited details about the event itself. For this reason, we compared the data reported by hockey Canada with observational data collected via a systematic reporting system which provides more detailed description of how head impacts are occurring in youth hockey. By comparing the two data sets, it provides an important means of analyzing head impact trends by determining what similarities/differences exist in concussion-related injury in the Hockey Canada data and the observed head contact events across the same levels of play. The assumption is that with an increase in head contact events, there would likely be an increase in reported concussions, which is in part supported by the results presented here.

Figure 8. Percentage of impact mechanisms per age group.
When comparing the injury data from the Hockey Canada’s Injury Reporting System with observational data, there are important similarities and differences. First, Hockey Canada reports a steady increase in concussive injury as players advance through the levels, with the lowest rate of concussion observed at the IP, where youth first enter the minor hockey system. The rate of concussion increases at each age level, peaking at the Bantam (13–14 years) level and then slightly decreasing again at Midget (15–17 years). The results reported from the observational data in part support the Hockey Canada injury data with two important distinctions. First, rather than a steady increase in head contact events from IP to Midget, the observational data recorded higher than expected rates of head contact at the IP and Novice levels. Second, the observational data did not record the spike of head contact events at the Bantam level, but rather the spike in head contact events did not appear until Midget, where the rate of head contacts increased from 7.63 head contact events per game in Bantam to 12.71 at midget. The manner in which head injury/head contacts is occurring was consistent with both data sets. The primary cause of head injury/contact was a collision, whether as a result of intentional body checking or incidental contact. The collision would either produce head-to-body contact (contact with the shoulder/elbow/head) or a collision which led to the head hitting a hard surface (boards/glass/ice). There were important age-level distinctions in both data sets which identified head-to-ice contact occurring at a much higher rate at the earliest ages and gradually declining as age rises. Head contact as a result of a collision increased by age category as did the rate of collisions followed by head to boards/glass. The observational data, however, did report a much higher rate of body to body collision across all age categories compared to Hockey Canada data.

These differences from the observational data and the Hockey Canada injury reporting data point to important methodological considerations when documenting injury in sport. The secondary reporting provided through a monitoring system like what is provided through Hockey Canada relies on retrospective accounts of injury that are occluded by memory and line of sight. Head impacts are difficult to discern because of the potential points of contact on any given play. A collision for example, might create a head contact event but there are many potential points of contact, whether it be body to body, head to boards/glass, or subsequent head to ice. In many cases, video analysis was able to detect contact that occurred as a result of a collision, followed by a fall and subsequent head to ice contact. Collisions along the boards/glass frequently led to secondary head contact to the boards or glass. Field observations, even with a trained group of researchers, often could only detect head contact as a result of the collision, but not the secondary head contacts. In some cases, the head contact by way of collision was not even detected. Being able to confirm point of contact has important implications when trying to understand how concussive injuries are occurring in hockey. The different forces at play impact the potential levels of head trauma, with less compliant surfaces like boards and glass posing greater risk than contact with the body alone. Therefore, determining the exact point or points of contact provide crucial information when determining the source of trauma.

The observational component of this study also revealed important findings regarding the level of head contact occurring at the earliest age categories of youth hockey. From the Hockey Canada injury reporting system, it appears as though head trauma is not a concern at the IP, and Novice levels as concussions are rarely being reported. While our study did not record concussions, it did document higher levels of head contact at the IP and Novice levels, which do raise levels of concern around the vulnerability of players at this age. It is not simply the higher rates of head contact that occurred at these levels, but that a high percentage of head contacts were to the ice. This is interestingly captured in the Hockey Canada Injury Reporting System that showed a disproportionately higher rate of concussion as a result of head contact to the ice at the IP and Novice levels compared to older age categories where body-to-body collisions were the primary source of reported concussions. Through in-game observations, it was apparent that the fall to the ice category was not always a collision-based injury, but rather a situation where a player falls on their own. Injury by way of collision with an opponent was the highest reported mechanism across all age levels, as age increases, injury by way of falling to the ice declines. This is likely due to players gaining better balance and skating proficiency and falling less. In addition, players develop more strength and coordination that helps protect themselves when they do fall, often preventing their heads from the hitting the ice. This increased strength and skill, however, does mean an increase in skating speed and bodily mass which means when collisions occur, the force of impact is much higher than at the initiation and novice levels. The increase in head contact at the Novice level can likely be explained by the fact that IP is an initiation program, not an actual league. Novice is a league with regular season games and playoff competition which sees greater intensity than at the IP level. Moreover, players are generally faster and slightly bigger, but are still early in their balance, coordination, and positional development, which we argue make them more vulnerable to collisions and falls. By Atom, players
begin developing greater strength, improved positioning, and spatial awareness which leads to fewer collisions and falls, evidenced by the decline in the “head to head” contact events from the observational data. This also suggests that the players are better prepared to manage collisions and falls when they do occur.

Finally, through in-game observations, it was apparent that prior to body checking hockey IP through to Peewee, collisions were observed to be incidental, or more rarely illegal contact (intentionally hitting an opponent), a result similarly reported by Darling et al.\(^{31}\) In most cases, players made every effort to avoid colliding with an opponent or teammate, but in pursuit of the puck, inadvertent contact would occasionally occur. It is not until the introduction of body checking, players intentionally collide with opponents to remove opponents from the puck, which would logically increase the level of head contact events—shoulder/elbow to head, head to head, and head to boards/glass. The increase in age, competition, and the introduction of body checking did appear to lead to an intensification of game play and aggressive play, especially at the midget level where recorded highest punch to the head events than any other age category. With this said, the majority of head contact events occurred as a result of instrumental contact to remove players from the puck. It was purposive execution of game rules as opposed to aggressive play. Dangerous plays such as hits from the behind or blind-side hits (hitting a player in a vulnerable position to inflict harm) were rarely recorded. This is not to say that aggressive or violent does not occur in hockey, but to universally characterize youth hockey as violent or aggressive is not consistent with the observations conducted in this study.

**Limitations**

There are important limitations to this study that have been taken into consideration during the analysis and in the reporting of results. First, Hockey Canada’s Injury Reporting System is a voluntary reporting system that requires athletes and parents to report the injury to team trainer/coach and be verified by a physician. Head-related injuries are often difficult to identify and are likely being underreported, either because they were not recognized or not perceived serious enough to warrant medical attention. This type of underreporting of injury is not unique to Hockey Canada’s Injury Reporting system and must be acknowledged when utilizing any voluntary injury-reporting system. There are also limitations with the observational component of this study. Hockey is a fast-paced sport with multiple moving parts which makes verifying if hockey contact occurs difficult. The use of video to capture on ice play was critical to review all incidents of suspected head contact events. Even through use of specialized software that enables frame-by-frame video analysis, certain suspected head contact events could not be verified because of something obscuring lines of vision, whether it be other bodies, the boards, or net. Head contact events were therefore categorized as either “suspected” or “verified”; only verified head contact events are reported in this study. It is important to note that events categorized as “suspected” were rare and would have minimal impact on the rates of head contact being reported. This limitation does, however, suggest that the utilization of multiple cameras would be advantageous for capturing game play to provide more camera angles to verify contact to the head.

**Conclusion**

Considerable efforts have been made by researchers and medical practitioners to raise awareness of the short- and long-term effects of head injury, especially amongst children and youth where brain development is most susceptible to trauma. Contact sport continues to be the most commonly reported cause of head injury in children and youth populations, which therefore requires understanding the risk factors that are contributing to head contact and what measures need to be taken to mitigate head contact from occurring. This requires not simply documenting the rates of head contact/head injury, but comprehensively examining the contextual factors contributing to head contact/injury. The research presented here is derived from two independent databases, one a national database drawing on all levels of minor hockey registration in Canada and the other a two-year observational analysis of IP to Midget levels of minor hockey in eastern Ontario and western Quebec. Despite the unique reporting systems, important similarities are evidenced in both data sets. First, the level of play has important implications when understanding head trauma, not only in terms of frequency of events, but how head contact is occurring. Both data sets identify an upward trend of head trauma as age increases and that collisions are the primary mechanism of injury/head contact. Second, while head contact and concussive injury is being experienced in minor hockey, it is not consistently experienced across age level, and according to Hockey Canada data, slightly decreasing at all levels from IP to Midget. This is indirectly supported through in-game observations which rarely observed head contact occurring as a result of dangerous or reckless play, but rather resulting from instrumental play (execution of a legal body check) or incidental contact as a result of puck pursuit.
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References

1. Karton C and Hoshizaki TB Concussive and subconcussive brain trauma: the complexity of impact biomechanics and injury risk in contact sport. In: Hainline B and Stern R (eds) Handbook in Clinical Neurology: sports Neurology. Vol. 158. Amsterdam: Elsevier B.V, 2018, pp.39–49.
2. Daneshvar DH, Riley DO, Nowinski CJ, et al. Long-term consequences: effects on normal development profile after concussion. Phys Med Rehabil Clin N Am 2011; 22: 683–700.
3. Wiebe DJ, Comstock RD and Nance ML. Concussion research: a public health priority. Injury Prevent 2011; 17: 69–70.
4. Johnson LSM. Concussion in youth ice hockey: it’s time to break the cycle. CMAJ 2011; 138: 921–924.
5. Sirisena D, Walter J and Probert J. National Football League concussion lawsuit: what it means for other sports and observations from Singapore Rugby. Br J Sports Med 2017; 51: 696–697.
6. Emery CA, Hagel B, Decloe M, et al. Risk factors for injury and severe injury in youth ice hockey: a systematic review of the literature. Injury Prevent 2010; 16: 113–118.
7. Cusimano MD, Lile G, Mullen SJ, et al. Aggression, violence and injury in minor league ice hockey: avenues for prevention of injury. PLoS One 2016; 11: 1–14.
8. Marchie A and Cusimano MD. Bodychecking and concussions in ice hockey: should our youth pay the price? CMAJ 2003; 169: 124–128.
9. Zemek R, Barrowman N, Freedman SB, et al. Clinical risk score for persistent postconcussion symptoms among children with acute concussion in the ED. JAMA 2016; 315: 1014–1025.
10. Danielle MR, Christopher GV, Lincoln P, et al. Academic effects of concussion in children and adolescents. Pediatrics 2015; 135: 1043–1050.
11. Black AM, Hagel BE, Palacios-Derflingher L, et al. The risk of injury associated with body checking among Pee Wee ice hockey players: an evaluation of Hockey Canada’s national body checking policy change. Br J Sports Med 2017; 51: 1767–1772.
12. Emery CA, Black A, Krolikowski M, et al. The effect of body checking and head contact rule policy changes on concussion risk in youth ice hockey players. J Neurotrauma 2014; 31: A66.
13. Stuart MJ. Managing and preventing ice hockey injuries: the risk of injury cannot be eliminated but can be reduced substantially. J Musculoskeletal Med Sci 2005; 37: 1658–1663.
14. Willer B, Kroetsch B, Darling S, et al. Injury rates in house league, select, and representative youth ice hockey. Med Sci Sports Exerc 2005; 37: 27–38.
15. Covassin T, Swanik CB and Sachs ML. Epidemiological considerations of concussions among intercollegiate athletes. Appl Neuropsychol 2003; 10: 12–22.
16. King WJ and LeBlanc CMA. Should bodychecking be allowed in minor hockey? CMAJ 2006; 175: 163–164.
17. Juhn MS, Brolinson G, Duffey T, et al. Position statement: violence and injury in ice hockey. Clin J Sport Med 2002; 12: 46–51.
18. Bramley H, Kroft C, Polk D, et al. Do youth hockey coaches allow players with a known concussion to participate in a game? *Clin Pediatr* 2012; 51: 283–287.

19. Montenigro PH, Alosco ML, Martin BM, et al. Cumulative head impact exposure predicts later-life depression, apathy, executive dysfunction, and cognitive impairment in former high school and college football players. *J Neurotrauma* 2017; 34: 328–340.

20. Hockey Canada. Ottawa: Hockey Canada; c2019. Learn about Hockey Canada’s Insurance Program, www.hockeycanada.ca/en-ca/hockey-programs/safety/essentials/insurance (accessed 5 November 2019).

21. Dumas A and Laforest S. Skateparks as a health-resource: are they as dangerous as they look? *Leisure Stud* 2009; 28: 19–34.

22. Wattie N, Cobley S, Macpherson A, et al. Injuries in Canadian youth ice hockey: the influence of relative age. *Pediatrics* 2007; 120: 142–148.

23. Cormack P and Cosgrave JF. *Desiring Canada* CBC contests, hockey violence and other stately pleasures. Toronto: U of Toronto Press, 2013.

24. Cusimano MD, Sharma B, Lawrence DW, et al. Trends in North American newspaper reporting of brain injury in ice hockey. *PloS One* 2013; 8: e61865.

25. Ralph D. Canadian families shunning hockey, survey finds. Globe and mail. (2013) August 2: Sect. S:4.

26. Therien E. The future looks bleak for Canadian minor hockey. *The star*, www.thestar.com/opinion/editorialopinion/2012/01/04/the_future_looks_bleak_for_canadian_minor_hockey.html (2012, accessed 4 November 2019).

27. Canada Safety Council. Ottawa: hockey – our most dangerous game, https://canadasafetycouncil.org/hockey-our-most-dangerous-game/ (2010, accessed 4 November 2019).

28. Canadian Sports Insurance Brokers. [Internet]. Melting ice: Canada’s hockey crisis, https://michener.ca/students/library/referencing-writing-help/vancouverstyle/ (2014, accessed 4 November 2019).

29. Blum B. Gretzky doubts he could play in today’s ‘systematic’ game. Toronto: CBC Sports: The national, www.cbc.ca/sports/hockey/nhl/wayne-gretzky-interview-national-1.3800604 (2016, accessed 4 November 2019).

30. Gough C. Total number of registered ice hockey players in Canada from 2010/11 to 2018/19, www.statista.com/statistics/282125/number-of-registered-ice-hockey-players-in-canada/ (accessed 4 November 2019).

31. Darling SR, Schaubel DE, Baker JG, et al. Intentional versus unintentional contacts as a mechanism of injury in youth ice hockey. *Br J Sports Med* 2011; 45: 492–497.