Analyzing the Causes and Risk Factors for Head Contact Events in Youth Competitive Bodychecking Hockey: A Descriptive Observational Video Analysis

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Abstract

Across minor hockey contexts, concussions and head injuries have become a growing concern as stories of professional athletes sustaining debilitating injuries are frequent across all media platforms. These stories have prompted stakeholders (parents, coaches, policy makers) to take action, in an attempt to ensure safe participation for youth hockey players. Although decades of research across minor hockey have clearly noted the frequency and risk for youth to sustain concussion injuries across varying levels and age groups, few studies have actually explained how and why these injuries happen in gameplay. The research conducted in this thesis seeks to address these research gaps by alternatively employing descriptive observational video analysis to explain how and why injuries occur. Further, although concussive injuries are a serious matter, issues relating to diagnostics do not yield a simple interpretation of results, and moreover concussions do not reflect the entire scope of brain injury. For this reason, among others, our research group and partners from the Neurotrauma Impact Science Laboratory (NISL) at the University of Ottawa have been examining all head impacts that occur in gameplay, which identifies frequency of head contact and how they occur in gameplay. The research in this thesis takes advantage of implementing a descriptive video analysis design of verified head impacts; with unique objectives respective to the two articles presented (Chapters IV & V), significant insight into how and why head contact occurs in gameplay. This study focuses on bodychecking hockey at the AA and AAA under-15 and under-18 levels because of the known increased risk of head trauma in bodychecking hockey in comparison to non-bodychecking hockey. In sum, this research seeks to address contextual gameplay factors that precipitate head contact occurring at these levels of play. Specifically, questions surrounding aggression, rule violations, player vulnerability and preparedness, technique, and prevention will be addressed in this thesis in hopes of contributing stakeholder efforts that may address player safety in Canada's game.

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List of Acronyms

AA/AAA – refers to competitive level

AEs – athletic exposures (a measurement for injury rates)

CHIRPP – Canadian Hospitals Injury Reporting and Prevention Program

CTE – Chronic Traumatic Encephalopathy

ED – emergency departments

IRF – injury report forms

ISS – Injury Surveillance System (specifically implemented by the NCAA)

NCAA – National Collegiate Athletic Association

NCCP – National Coaching Certification Program

NISL – Neurotrauma Impact Science Laboratory

NSERC – Natural Sciences and Engineering Research Council

RHI – repetitive head impacts

SRC – sport-related concussion

U15, U18 – under-15, under-18 (refers to the age group in hockey)

WES – weekly exposure sheets

Declaration of Research & Statement of Contribution

This research is part of a larger study funded by CCM Hockey and the Natural Sciences and Engineering Research Council (NSERC). CCM Hockey and NSERC have been supporting the Neurotrauma Impact Science Laboratory (NISL) at the University of Ottawa since 2016, identifying head contact events across a variety of hockey levels and age groups. The research for this study involves information gathered from NISL, specifically head contact events observed at the competitive bodychecking levels of ice hockey, which comprises under-15 (U15) and under-18 (U18) levels (formerly Bantam and Midget respectively). Further, it is of note that I helped in the data collection process at the U15 level from 2018-19 during my undergraduate honours research project at the University of Ottawa. This study involves members of NISL, including supervision of the laboratory's director, Dr. Blaine Hoshizaki, and other assisting hockey researchers involved with myself and Dr. Michael Robidoux (thesis supervisor). Ethics were approved through the University of Ottawa's Research Ethics Board (REB) file number H08-15-06.

I, Connor S. McFaul, was responsible as the first author of both articles herein submitted in the thesis. As both of my studies included secondary data of verified head impacts that were collected, analyzed, coded, and catalogued by NISL, I held no responsibility over primary video analysis, other than my assistance in recording and analyzing game film at the U15 level during my undergraduate honours research project. Dr. Robidoux, Dr. Hoshizaki, and Dr. MacIntosh provided valuable conceptual and structural feedback during the thesis proposal, our annual/semi-annual research meetings, and during informal "thesis progress meetings".
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logistics of the project. The three of us coordinated a group of undergraduate student researchers to aid in video analysis of head impacts according to our penalty and aggression criteria. I was also responsible for analysis at both the U15 and U18 levels, while Benjamin and Jarett were responsible for being third-party supervisors/reviewers. In sum, Benjamin assisted significantly in both articles (Chapters IV/V) through conceptualization, data curation, methods/methodology, investigation, project administration, reviewing and editing. Jarett assisted solely with the first article (Chapter IV), on top of the tasks mentioned prior, he also aided with data curation, data validation, and formal analysis. Dr. Robidoux assisted significantly as a main supervisor for the entire thesis, he provided guidance and project administration, aided in conceptualization, methodology, visualization, and was primary reviewer/editor for both articles (Chapters IV/V). Dr. Hoshizaki also assisted with methodology, software/data curation, resources, supervision, and the review/editing of all my written work. As the primary researcher for both studies, I assert that I was involved in the research process from A-Z: that is to say all the way from conceptualization to the final articles and content presented in this thesis.

For both articles (Chapters IV/V), no authorship group will be presented as each individual manuscript are yet to be accepted for publication.

Chapter I: Introduction

Ice hockey[1] in Canada is not only one of its national sports, but a culturally significant pastime and a symbol of national pride for many Canadians. Due to the sport's popularity and status within Canada, research on hockey has become a popular pursuit in academia, with increasing attention on player safety and injury. Much of this research has focused on concussion and head trauma, which continues to identify the serious health risks associated with head contact, particularly amongst youth. In youth hockey, head injuries represent the biggest concern (Emery & Meeuwisse, 2006), as the developing brain is at an elevated risk of injury (Marchie & Cusimano, 2003). Canadian minor hockey[2] has been studied considerably in relation to head trauma and concussions at these youth levels, with much of the literature focused on injury rates, and assumptions or suggestions regarding the risks that players face surrounding head trauma (Black et al., 2016; Chen et al., 2020; Cusimano et al., 2011; Emery et al., 2010; Emery et al., 2020; Karton et al., 2021; Krbavac et al., 2024; Williamson & Goodman, 2009).

In Canada, there were 589,012 players registered in organized hockey for the 2023-24 season, comprising a variety of leagues, both competitive and recreational (Hockey Canada, 2024). As the majority of these registered hockey players are considered youth participants (<18 years old), it has become paramount for Hockey Canada and hockey stakeholders to ensure a safe environment for participants to play, seeking to prevent injury if possible. Youth sport is often considered beneficial for the development of emotional, physical, and cognitive abilities – in Canada, however, sport related injuries account for 66% of the national youth injury burden (Billette & Janz, 2011). Hockey has consistently been noted amongst the sports with the highest

[1]May also be referred to solely as "hockey" henceforth.

[2]Minor hockey is a reference to youth age-groups below the "Junior" division/level in the hierarchy.

risk for youth to sustain injuries via participation in Canada (Black et al., 2021; Emery & Meeuwisse, 2006; Emery et al., 2006; Fridman et al., 2013). Further, paediatric concussion visits to medical health professionals in Ontario have been linked to high seasonal variation, as most occur during fall and winter months when hockey participation is at its peak (Zemek et al., 2017). Due to these factors, hockey participation may pose a certain threat to youth development in terms of increased injury risk in comparison with other sports, and a heightened potential for head injury.

Sport-related concussion (SRC) has become increasingly recognized as a medical and social issue, with direct concerns related to long-term brain health (Malcolm, 2018). This is due to SRC and brain trauma that is commonly observed in adolescent athletes having direct impacts on brain development, accruing deficits for youth in academics, social life, and athletic success (Semple et al., 2015). In youth hockey, players are frequently exposed to head impacts in gameplay (Aguiar et al., 2020; Hoshizaki et al., 2013; Karton et al., 2021; Meliambro et al., 2022). This is significant as any head impact carries potential damaging and lasting effects on developing brains (Goulet & Beno, 2023). Yet, most of the research on Canadian youth hockey focuses on quantifying injury in terms of rates (Darling et al., 2010; Emery et al., 2006; Hagel et al., 2006; Kukaswadia et al., 2010; Willer et al., 2005), including concussion rates (Cusimano et al., 2011; Emery & Meeuwisse, 2006; Emery et al., 2010; Tuominen et al., 2017; Williamson & Goodman, 2006, 2009) which is a problematic injury measure that will be expounded upon in Chapter II. Studies that attempt to quantify injury are important, as they give us a sense of the risk of one being injured; however, unless the information provided helps people understand why injuries are occurring, little can be offered in terms of prevention. Alternatively, observational and descriptive research that documents injury *in situ* can provide important qualitative details to

help better understand how and why injuries are occurring. Thus, improved evidence-based research that focuses on the most common and severe types of head contact players sustain in gameplay may help foster preventive efforts related to protective equipment, player training and rules of play (Aguiar et al., 2023).

As research on minor hockey has provided limited insight on how and why head contact events occur in gameplay through situational or contextual factors, there is a clear gap to be addressed in injury research (Aguiar et al., 2023). This study thus sets out to analyze head impacts occurring in minor hockey, specifically at competitive AA/AAA bodychecking levels of play, which encompasses the under-15 (U15) and under-18 (U18) age groups (formerly "Bantam" and "Midget" respectively). These age groups and competitive levels were identified due to elevated risks of head trauma in bodychecking hockey, measured in terms of magnitude, frequency, mechanisms leading to head contact (Chen et al., 2020; Karton et al., 2021; Krbavac et al., 2024; Robidoux et al., 2020), and "concussion" incidence (Black et al., 2016; Emery et al., 2020; Marchie & Cusimano, 2003). The research in this thesis is delineated into two articles (Chapters IV & V) which use a descriptive analytical approach of verified head impacts collected by the Neurotrauma Impact Science Laboratory (NISL) at the University of Ottawa. The purpose of this thesis is to build off of previous research conducted by NISL and minor hockey injury studies to understand gameplay situations leading to head contact events in an effort to understand why and how they occur, and/or if they can be prevented. Thus, each article comprises their own discrete aims and goals related to minor competitive bodychecking hockey.

Article 1 (Chapter IV) addresses two research questions: 1) Are head contact events occurring as a result of legal or illegal play as determined by external evaluation based on rules set forth by governing body Hockey Canada? and 2) Is head contact the result of aggressive or

non-aggressive play, based on four contextual definitions of aggressive/non-aggressive gameplay behaviours developed for the study. As hockey has been characterized as an aggressive and violent sport, this study evaluates both U15 and U18 levels of play to understand if head contact occurs as a result of play execution according to the rules, or violent and/or aggressive play. Article 2 (Chapter V) builds off observations from the first study and employs a rich inductive descriptive analysis on head contact occurring from bodychecking events specific to U15 hockey, the first year that bodychecking is introduced. This study analyzes factors leading up to and during the bodychecking event to determine if and how head contact could be prevented in gameplay.

The intention of this research is to better understand the contextual factors surrounding head contact events in youth competitive bodychecking hockey and analyze how potential issues surrounding rule enforcement, player behaviour, and gameplay characteristics can enhance player safety for youth participants.

Chapter II: Literature Review

The State of Injury in Canadian Minor Hockey

Injury research in contact sports has become increasingly popular, due to the known risks associated with physical play and increased attention to youth athlete safety. Injuries amongst youth sport participants in Canada are of serious concern, with hockey being of increased risk (Black et al., 2021; Emery & Meeuwisse, 2006; Emery et al., 2006; Emery et al., 2011; Fridman et al., 2013). This can be attributed to the sport's popularity, but more importantly the intensity and physical characteristics of hockey as a contact sport (Donskov et al., 2019). For example, hockey has been compared to American football as both sports include legal bodily contact and have been shown to represent the highest incidences of brain injuries at youth levels (Meliambro et al., 2022). Further, hockey is amongst the most common sports for central nervous system injuries, alongside American football, and boxing (Toth et al., 2005). Due to these factors, contemporary youth hockey injury research has focused on different aspects of head trauma, as head injuries are known to pose the greatest health risk for players (Emery & Meeuwisse, 2006).

Research across different levels of hockey has also identified bodychecking to be the most common cause of all injuries (Cusimano et al., 2011; Emery & Meeuwisse, 2006; Goulet et al., 2016; Hagel et al., 2006; Kukaswadia et al., 2010; Toth et al., 2005). Many studies on injury in Canadian minor hockey have concentrated on comparing bodychecking and non-bodychecking leagues[3], often in relation to concussion and historical changes in legislation surrounding when bodychecking is introduced (McKay et al., 2014). Research by Cusimano and colleagues (2011) noted increased injury incidence, especially head injuries, during the first year

[3]Bodychecking is used to separate an opposing player from their possession of the puck, using bodily force in a tactical and legal manner (King & Leblanc, 2006; Krbavac et al., 2024). It is legal in some contexts, differentiated by age group and competitive level.

of exposure to bodychecking hockey. Further, a systematic review by Emery and colleagues (2010) noted a 2.5-fold increased risk for all injuries, including greater concussion incidence amongst U13 bodychecking leagues compared to non-bodychecking hockey. This was also observed at the U13 level in comparison of similar levels of play, where a threefold greater risk of all injuries and concussions was observed in Alberta bodychecking hockey (Black et al., 2016). At the U15 level, a cohort study in western Canada discovered a 54% lower rate of injuries in U15 non-bodychecking leagues compared to their bodychecking counterpart, including a 40% decrease in concussions (Emery et al., 2020).

These rates of injury in hockey have also been noted to change by age group and level of competition, with higher rates among more elite levels of play and older age groups (Darling et al., 2010; Toth et al., 2005). This is of significant concern when analyzing head trauma parameters, which help identify the unique characteristics of injury in terms of magnitude and frequency of head impacts across different age groups and levels of play (Chen et al., 2020; Karton et al., 2021; Krbavac et al., 2024). Evidently, research has indicated significant injury risk across youth levels of hockey, with bodychecking being a leading mechanism and head injury being of particular concern. For this reason, the methods by which researchers have studied and observed injury must be further explored to understand how their results have been collected, analyzed and interpreted.

Injury Reporting Systems

When undertaking injury prevention research, it must be noted how complex and difficult injury reporting is. This can be directly attributed to the absence of a “one-size-fits-all” system, as there is no widely adopted single method of reporting injuries. Instead, there are multiple approaches for injury surveillance, each with their own strengths and weaknesses. Further, there

are diverging definitions of what constitutes an injury (e.g. time-loss, medical treatment), which convolutes the data when compared across different studies. It is virtually impossible to compare injuries across a vast array of data sets, ranging from hospital records, sports organization injury reporting systems, and direct observational analysis. In this section, different methods of injury surveillance will be highlighted, their strengths and weaknesses identified, and definitions of injury assessed to provide an overview on the scope of injury prevention research.

Retrospective Designs

Retrospective injury reporting studies encompass large-scale data sets which are established to document injuries that are presented to hospitals, emergency departments (ED), insurance claims, and/or other organizations who establish a catalogue of injury reports. Retrospective reporting is reliant upon the use of secondary data, meaning that injury rates and trends are often looked at over numerous years at a time. From a sport-specific lens, this data is commonly contingent upon athletes, trainers, coaches, and parents among other stakeholders to disclose and report injuries, which ultimately leads to underreporting. One of the most popular methods for researchers pursuing secondary reporting in youth sport comes from hospital and ED records, which are established by governments and authorities who oversee healthcare responsibilities.

The Canadian Hospitals Injury Reporting and Prevention Program (CHIRPP) is an example of a reporting system reliant upon hospital and ED data, as it is a database of reports from participating paediatric and general hospitals across Canada. CHIRPP data has notably been used specific to Canadian minor hockey, often as a tool to evaluate the changes in policy surrounding what age groups bodychecking was introduced in minor hockey and to evaluate its correlation to injury incidence (Cusimano et al., 2011; Macpherson et al., 2006; Kukaswadia et

al., 2010). When analyzing policy change specific to injuries caused by bodychecking, in the levels and age groups where it is permitted, there are certain criteria that should be distinct. However, due to how emergency department claims are recorded, there are often methodological differences and difficulties in reporting. First, across some studies there is a clear focus on the inclusion of bodychecking events leading to injury (Cusimano et al., 2011; Kukaswadia et al., 2010), yet due to the grey area of what constitutes a bodycheck and the lack of rigid criteria for gathering ED data, reports may include injuries occurring from unintentional body contact (Hagel et al., 2006; Macpherson et al., 2006). Further, when analyzing large data sets on youth hockey as it relates to hockey injuries, some studies have followed strict guidelines to focus on organized hockey as it relates to changes in bodychecking policy (Hagel et al., 2006; Kukaswadia et al., 2010). That being said, these guidelines can be overlooked, as surveillance from hospital and ED records may account for injuries that occur in recreational play or unstructured environments (Macpherson et al., 2006; Yard & Comstock, 2006; Zemek et al., 2017).

Although these limitations surrounding the adherence to certain inclusion criteria may only lead to minor differences in data presentation, it reveals other key information about retrospective reporting from hospital and ED data. A significant limitation is that injuries requiring medical attention only represent the most severe cases, and do not comprise the entire scope of sports-related injuries (Cusimano et al., 2011; Ekegren et al., 2016; Maak et al., 2020; Yard & Comstock, 2006). This means that mild and non-traumatic injuries are left underreported, and their importance can be understated (Maak et al., 2020); which may include other forms of serious injury that are difficult to assess, namely concussions. An additional limitation in this type of reporting is the consistent absence of injury specifics reported to

hospitals which may in turn have the potential for researchers to draw biased conclusions (Maak et al., 2020). This can be observed in the categories of injury mechanisms associated with the injury (e.g. contact with another player, stick, fall, etc.) being incomplete in large data sets (Yard & Comstock, 2006), which is indicative of a lack of understanding surrounding the situational factors leading to injury. Conversely, the advantage of these larger data sets is that they point to injury trends across large populations, and the injuries presented are of ample severity to be documented, which signal the need for intervention and/or prevention (Macpherson et al., 2006).

The use of hospital and ED data are not the only forms of retrospective surveillance systems, as some involve survey methods. For example, retrospective surveys have been implemented in a Canadian minor hockey context to gather information on injury history and severity over the course of a season (Emery et al., 2006; Williamson & Goodman, 2006). These surveys can be an effective research tool to help evaluate specific measures related to injuries, such as mechanisms related to bodychecking (Emery et al., 2006), or to verify and corroborate injuries reported in a retrospective or prospective design (Williamson & Goodman, 2006). Questionnaires do have limitations in regard to injury reporting though, mainly because they rely on recall and are subject to bias from the athlete/participant (Emery et al., 2006).

An additional example of a largescale retrospective design is the Injury Surveillance System (ISS) implemented by the National Collegiate Athletic Association (NCAA). The ISS was created to exist as a centralized set of secondary data to be used for injury research in collection and exposure of injuries, evaluating trends over time. It differs from traditional retrospective designs as it was created in 1982 with the purpose of being used to amass a large sum of injury reports spanning multiple decades to be used for future research; further, it is not contingent on hospital records but requires voluntary participation from NCAA team safety

managers, namely athletic therapists (Dick et al., 2007). The centralized injury data of the ISS is thus the subject of retrospective injury research paradigms that have evaluated trends of injury across sports, including collegiate ice hockey (Chorney et al., 2017; Covassin et al., 2003; Dick et al., 2007), and studies specific only to hockey injury epidemiology (Agel et al., 2007). Research using this ISS data has recommended risk and injury prevention initiatives, which have in turn been adopted into hockey rule and policy modification in the NCAA. Specifically, regulations in reducing checking from behind and direct contact to the head have been implemented to help curb injury rates, including concussion (Dick et al., 2007; Hootman et al., 2007). Despite providing tangible change in the form of interventions, the ISS is subject to several limitations. There are inconsistencies in injury rates, which are recorded in terms of athletic exposures (AEs) where individual playing-time is not accounted for (Covassin et al., 2003). Further, the injury data is often analyzed over long periods of time, where increased awareness, identification, and reporting of injuries due to growing interest and knowledge have not been taken into consideration (Agel et al., 2007; Dick et al., 2007). This has been noted as an inconsistency across retrospective designs that span many years, as there have been increased scientific and media attention of concussion injuries in particular (Zemek et al., 2017).

Although there are varying types of retrospective studies that can be done, each have their own limitations. The core strength of this type of surveillance system are the massive data sets accrued which can help identify trends (Laflamme, 2018). Despite this, injuries still tend to be underreported, which will be expounded on below. In order to better understand the full scope of sports injuries there should be more emphasis on surveillance at the team and organizational level (Ekegren et al., 2016), which is where prospective methods are employed.

Prospective Designs

While the use of secondary data in retrospective designs can help identify injury trends and quantify injuries in youth hockey, many researchers have opted for prospective injury surveillance systems. Prospective designs often function with smaller pools of primary data, and a more hands-on approach conducive to researchers being involved in design, implementation, and collection of injury data. As opposed to retrospective designs, prospective systems are implemented prior to measurements of outcomes (i.e. injury), which allows for follow up with participants in real-time. This also permits more emphasis to be placed on specific injury details to be identified and analyzed (Ekegren et al., 2016). Prospective surveillance systems are often multifaceted, with a strength being that the researcher can choose from a variety of data collection methods. In research on Canadian minor hockey specifically, researchers have drawn from the following data sets: Hockey Canada designated injury report forms (IRF) (Darling et al., 2010; Willer et al., 2005); organization/association-wide IRF (Williamson & Goodman, 2006, 2009); preseason assessment, weekly exposure sheets (WES), and individual IRF (Emery & Meeuwisse, 2006; Emery et al., 2010); *in situ* observer reports (Williamson & Goodman, 2009); and game video observational analysis (Goulet et al., 2016; Mihalik et al., 2010a, 2010b; Williamson et al., 2021). However, each method comes with their own set of strengths and limitations as to what is represented by the researcher in their results; thus, there is no one-way to effectively execute a hockey-specific prospective injury observation system.

The involvement of researcher(s) in the design, implementation, and collection of injury data from sports organizations and teams is a strength of prospective designs, with some of the data collection methods allowing for a more consistent and timely flow of information between a research group and the teams or organizations being studied. However, in many prospective

designs, the WES and IRF are completed by team-specific personnel or minor hockey volunteers, which comprises coaches, trainers, and volunteer parents (Darling et al., 2010; Mölsä et al., 1997; Tuominen et al., 2017; Willer et al., 2005; Williamson & Goodman., 2006). This means that some of the responsibility may be taken away from the researchers to collect and synthesize data, which can be potentially problematic. An example of such is the Hockey Canada IRF, which holds team trainers responsible for reporting each injury (Darling et al., 2010; Willer et al., 2005); similar to retrospective designs, this allows for larger pools of data to be collected but offer less in direct involvement throughout the research process. Conversely, large-scale IRF reports from specific hockey associations or districts can be combined with other prospective methods. Research by Williamson and Goodman (2006, 2009) used different methods to verify that the IRF reports from the British Columbia Amateur Hockey Association were not representative of the true scope of concussion and head trauma, and that head injuries are often underreported to hockey governing bodies and team personnel.

As mentioned, if most of the responsibility is being placed upon team-specific personnel and volunteers to collect data rather than the researchers themselves, or trained staff, there are potential inconsistencies with injury reporting. To help moderate this, researchers may choose to assign an athletic therapist, physiotherapist, or a therapy student to attend weekly practices and/or games of specific teams to help collect injury data and verify the injury assessments made by team volunteers (Emery & Meeuwisse, 2006; Emery et al., 2010). However, this depends on the resources available to the researcher(s). Youth sport injury surveillance designs typically do not have the resources of elite and professional sport, which has created a greater reliance on volunteers and untrained personnel to document injuries (Ekegren et al., 2016; Emery & Meeuwisse, 2006; Williamson & Goodman, 2009). In contrast, Tuominen and colleagues (2017)

provided an analysis of all concussions over a nine-year period that occurred in World Championships and Olympic Games, sanctioned by the International Ice Hockey Federation (IIHF) who have a surveillance system and stringent methods in place for all their tournaments. Notably, all team medical personnel, who have professional experience, meet prior to each tournament to review all appropriate data collection procedures (Tuominen et al., 2017). As mentioned, the minor hockey programs function off volunteer safety managers being responsible for data collection and submission, which may or may not be overseen by the researcher directly. Who is collecting the data and how closely it is being monitored then has direct implications on the effectiveness of a representative dataset in prospective designs.

Many prospective designs in minor hockey focus on concussion and head injury specifically because it is a predominant injury within the sport associated with negative health outcomes (Emery & Meeuwisse, 2006; Emery et al., 2010; Williamson & Goodman, 2006, 2009). Although concussion underreporting has been mentioned as a potential limitation across hockey injury studies (Cusimano et al., 2017; Juhn et al., 2002; Konin & Horsley, 2017; Robidoux et al., 2020; Smith et al., 2017), there is clear evidence for concussions to be underreported at the team personnel and governing body levels (Williamson & Goodman, 2006). It has also been noted that athletes who sustain reported concussion injuries at the organizational level do not pursue further medical attention from healthcare professionals (Emery et al., 2010). This exemplifies clear gaps in the injury data provided by prospective designs, and a common weakness of all reporting methods, retrospective or prospective, which is the capacity to underreport injuries, most significant of which to this study are concussions/head injury.

Injury Definitions & Presentation of Injury Rates

As the strengths and weaknesses of retrospective and prospective designs have been explored, it is worth noting how injury data is often presented in research. Injuries are often defined in terms of medical treatment, and time-loss from participation. A proponent of many retrospective designs, medical treatment is problematic as a definition of injury as it requires the athlete to have their injury verified by a doctor or team physician. Although these injuries are of significant severity and warrant being examined (Macpherson et al., 2006), they do not represent a full scope of injuries that may occur (Cusimano et al., 2011; Ekegren et al., 2016; Maak et al., 2020; Yard & Comstock, 2006), and are subject to injury underreporting (Maak et al., 2020; Williamson & Goodman, 2009). Time-loss from participation has become a preferred definition of injury, as requiring medical attention can be construed as too broad for application (Emery & Meeuwisse, 2006). However, what time-loss includes is also complicated. Often the time-loss definition is attached to certain caveats, namely that injuries must be present for more than 24 hours (Darling et al., 2010; Willer et al., 2005) or affect the athlete's ability to participate in an upcoming game, practice, and daily activities (Dick et al., 2007; Ekegren et al., 2016; Emery & Meeuwisse, 2006; Emery et al., 2010). It is believed that these different provisions can be avoided by the inclusion of a consensus statement, which clearly states the injury definitions and collection procedures in one's research (Williamson & Goodman, 2009). Yet consensus statements are more insufficient for injury surveillance implementation in non-professional sport settings (Ekegren et al., 2016), and there is currently no consensus statement on injury definition in ice hockey (Donskov et al., 2019).

Another important factor to consider when using time-loss as an indicator of injury is that many sport cultures (including hockey) valorize playing through pain. Researchers studying

professional hockey describe this as a learned behaviour of traditional hegemonic masculinity reproduced through the coded values of the sport (Allain, 2008; Miele, 2020; Robidoux, 2001). Athletes may attempt to participate in games and practices despite being injured (Turkeri-Bozkurt & Bulgu, 2020), and the importance of the competition, pain tolerance, motivation, and external social pressures may affect athlete's continued participation (Emery et al., 2010). Due to these limitations, injury comparison across differing surveillance strategies and definitions of injury is methodologically naïve, and beyond the scope of this study. Therefore, research endeavours surrounding injury need to re-focus in a new direction, namely *in situ* observation with measurable criteria. This will also shift emphasis from injury reporting, in terms of rates, towards injury prevention/intervention – how and why injury occurs.

Emerging Trends in Injury Prevention: Observation and Video Analysis

Research into injury surveillance systems have shown the methods commonly used are not providing enough information to develop strategies towards injury prevention. The research in this thesis offers a different path forward by focusing on video observation methods, and a shift from injury reporting to analyzing head contact events in youth hockey. Direct observational methods have been used in previous research, as seen in Williamson & Goodman (2009) where they trained research assistants to document *in situ* injurious situations. However, observations alone are limited as researchers rely on their abilities to record information in real time; in a fast-paced sport like hockey injuries are almost certain to be missed. To accompany observations, researchers have increasingly incorporated video capture and analysis for more complete assessments of injury events (Aguiar et al., 2020, 2023; Goulet et al., 2016; Hutchison et al., 2015; Mihalik et al., 2010a, 2010b; Williamson et al., 2021). This also allows for detailed analysis of gameplay situations leading to injuries such as penalties or infractions (Mihalik et al.,

2010b) and the intensity of physical play being executed (Goulet et al., 2016). Further, observable criteria like head contact events, or head impacts, have been used as an alternative strategy as opposed to confirming/diagnosing injuries in hockey (Williamson et al., 2021).

Head Trauma Research: From Symptom-based to Objective Measures

Across injury reporting systems and injury prevention research specific to hockey, two key themes have been identified about concussion. First, concussions are reported to be the most frequent injury in hockey across all levels and age groups, and even more prevalent in youth competitive bodychecking hockey (Cusimano et al., 2011; Emery & Meeuwisse, 2006; Emery et al., 2010; Hagel et al., 2006). Second, there is significant potential for underreporting injuries in youth hockey, namely concussions (Emery et al., 2010; Williamson & Goodman, 2006, 2009). As explained, this may be due to a variety of methodological issues surrounding injury surveillance strategies. However, the complexity of concussive injury is another important factor that must be taken into consideration to help explain (under)reporting, and the need for a more inclusive strategy that moves beyond injury reporting to document the conditions for head trauma more broadly.

Concussions

There has been increased awareness and concern surrounding concussion in contact sports such as hockey. High profile cases of concussions amongst professional athletes across media platforms have raised public and scientific apprehension (Zemek et al., 2017). Further, sensitivity and concerns toward concussion incidence and avenues for prevention in youth hockey have grown amongst researchers, sport administrators and stakeholders in the community (Goulet et al., 2016). These concerns can be attributed to numerous short- and long-term risks associated with concussion. Noted long-term complications include increased susceptibility for

youth athletes to sustain multiple concussions across their athletic career(s) (Semple et al., 2015), and lingering post-concussive symptoms (Williamson & Goodman, 2006; Engström et al., 2020). While the short-term risks are mostly attributed to the symptomatic expressions of concussions by individuals, there continues to be challenges surrounding strategies to diagnose and treat concussive injuries (Smith et al., 2017).

There are several different symptoms individuals can experience from concussions, and many players, coaches, parents, and other stakeholders may not be aware of the different signs and symptoms. Since the responsibility of identifying these symptoms primarily rest upon the (young) athlete (Karton et al., 2021), youth participants who have sustained head injuries may have difficulty recalling or recognizing the appropriate symptoms and seeking proper medical attention. Moreover, young athletes may choose to ignore signs of concussion to continue participation. This can be linked to the (mis)comprehension of health risks from concussions, including short- and long-term consequences (Cusimano et al., 2017), and a lack of adherence for return-to-play guidelines (Black et al., 2020; Cusimano et al., 2009; Cusimano et al., 2017). The athlete, parents, and/or coaches may also not want the player to be removed from sports participation (Konin & Horsley, 2017) for varying reasons, such as players being concerned about losing their place to another athlete on the team (Juhn et al., 2002). Notably, athletes may attempt to participate in games and practices while injured as they are encouraged to play through pain, and risk-taking behaviour is reinforced as a normative behaviour in the sporting world, including but not limited to concussion injuries (Turkeri-Bozkurt & Bulgu, 2020). These are learned behaviours, which are supported and reproduced by teammates, coaches, and dominant coded ideas of professional hockey values which may permeate into youth levels of play (Adams et al., 2015; Allain, 2008; Cusimano et al., 2009; Miele, 2020; Robidoux, 2001).

Despite these factors being identified as reasons for concussion underreporting, there is still a larger issue at hand. Essentially, concussion only captures a small part of the entire scope of brain trauma. Concussions are diagnosed contingent on the presence of symptoms, which is not an objective measure of brain trauma (Karton & Hoshizaki, 2021; Krbavac, 2022). The symptomatic expressions of a concussion are also individualized, or subjective, to each person, meaning that two individuals who sustain the same traumatic event may have different reactions to that trauma. Further, one does not have to experience concussion symptoms to have sustained brain damage that may result in imminent or future health complications. Goulet & Beno (2023) explain this phenomenon by identifying concussions as mostly representing a functional impairment as opposed to a structural brain injury. This is supported by Hoshizaki et al., (2013), who found that injuries reported as concussions are not shown through significant mechanical brain damage, which can present challenges on injury diagnosis and treatment. Therefore, to avoid the elusiveness of concussion reporting, this study will focus on documenting head contact events as they occur in minor hockey, to better understand how and why impacts are occurring in an effort towards recognizing potential avenues for prevention.

Repetitive Head Impacts (RHI)

The main limitation to research on brain injury is that concussions are not objectively quantifiable (Malcolm et al., 2021). SRC numbers often cited and reported in academia fail to account for two factors, concussion underreporting and RHI exposure (Karton & Hoshizaki, 2021); this means that SRC data only encapsulates a small part of the trauma that is occurring. Conversely, head contact magnitude and frequency are two variables that are observable and linked to negative brain health consequences in the short- and long-term (McKee et al., 2023; Meliambro et al., 2022; Montenigro et al., 2017). Notably, high-magnitude events are often seen

in bodychecking hockey (Chen et al., 2020). These high-magnitude collisions are significant, as they are more easily recognized as collisions, or "big hits" in bodychecking hockey, which yield more severe strain on the brain tissue (Hoshizaki et al., 2013; Karton & Hoshizaki, 2021; Karton et al., 2021). Despite this, frequency and the accumulation of all head impacts are just as important to identify and understand as high-magnitude events. Critically, the cumulative effects of low-magnitude events may not be noticeable by athletes or observers (Fickling et al., 2021). RHI is thus a more complete measure of head impact accumulation, or frequency, of head contact events (both high-, and low-magnitude), which can help develop brain trauma profiling (Karton & Hoshizaki, 2018, 2021).

Repeated low-magnitude impacts have often been neglected, as research has only recently identified the potential detrimental effects for athletes to develop long-term neurodegenerative diseases from the accumulation of these "subconcussive" impacts (Hoshizaki et al., 2013; Karton & Hoshizaki, 2018; Meliambro et al., 2022). Athletes in hockey are frequently exposed to these low-strain RHI (Hoshizaki et al., 2013; Hunter et al., 2019). Through observational and video analysis research, a study by Meliambro and colleagues (2022) found that youth players between the ages of 9 and 14 experienced between 0.48 and 0.61 head impacts per game, per player. With hockey players being exposed to RHI at early stages of brain development, there is a high level of concern for their health during adolescence and early adulthood. Recent research has noted links between RHI and CTE, namely McKee and colleagues (2023) identified that over 97% of CTE cases were attributable to individuals with known exposure to RHI, mostly through athletic participation in contact sports. Further, each additional year of participation in hockey has been found to increase the risk of developing CTE by 34%, due to the accumulation of RHI (Abdolmohammadi et al., 2024).

To summarize, as opposed to concussions mainly comprising a functional brain impairment (Goulet & Beno, 2023; Hoshizaki et al., 2013), RHI can result in both structural and functional neurological injury (Fickling et al., 2021). This means that cumulative exposure to RHI is linked with concussion susceptibility, cognitive impairments, and the risk of neurodegenerative diseases such as CTE (Karton & Hoshizaki, 2021). Since medical science has shown exposure to RHI can cause neurological damage that may affect brain function and cognition in athletes, it is clear that frequency of head contact is equally as important as high-magnitude events.

Summary – Literature Review

Injuries, and more specifically, head injuries are of serious concern in hockey. Studies have continually identified the risks for youth players to sustain head injuries in Canadian minor hockey, with increases in incidence often linked to bodychecking. As identified, injury reporting is highly complex, with few studies providing injury prevention strategies through observational and video methods which actually identify how and why injury occurs in gameplay. Concussion identification and reporting is even more arduous, as these types of injuries are often underreported due to a myriad of factors. Instead, the efforts of minor hockey injury research should be concentrated on more objective measures of brain injury – head impacts, as any head contact event may result in adverse neurological health. Across this thesis I am not attempting to document injury but instead focus on head contact events at the competitive bodychecking levels of minor hockey, where players are at increased risk for head contact and injury. The intention of this specific research area and scope is to help provide situational and contextual understandings and observable criteria surrounding the susceptibility of head injury in youth athletes and utilize verified head impact data to inform my research.

Chapter III: Methods

As identified in the literature review, injury reporting is difficult and becomes even more challenging because of the complexity of head injury. This study offers a shift in direction by documenting head contact events because of the known health risks associated with head impacts both in terms of magnitude and frequency. The research from this thesis involves observational research and video analysis to detect head contact events in youth hockey, which were collected and verified by NISL. This descriptive observational approach has been designed to best observe and analyze head impacts from U15 and U18 competitive bodychecking hockey to understand how and why head contact events occur at this level of minor hockey. The use of this methodological approach is in response to a shift across some hockey injury scholars, which focus on observational video analysis of head contact events in gameplay, as opposed to studies that merely record injury rates (Aguiar et al., 2020, 2023; Hutchison et al., 2015; I. Williamson & Goodman, 2009; R. Williamson et al., 2021). Further, research has consistently shown increased risk for injuries in games as opposed to practices due to increased intensity and physical contact (Donskov et al., 2019; Emery & Meeuwisse, 2006; Hootman et al., 2007; Toth et al., 2005; Willer et al., 2005). Since injuries are more applicable to be observed during games, which produce actual playing behaviours, head contact events from gameplay only will be observed and analyzed in this thesis. As the identification and confirmation of head contact events (to produce a dataset for analysis) require stringent methods and procedures, these will be explained below.

Head Contact Identification

The methods for this study build off the research conducted by NISL studies which have diligently observed, identified, and recorded head contact events across different levels of youth

hockey (Chen et al., 2020; Hoshizaki et al., 2013; Karton et al., 2021; Krbavac et al., 2024; Robidoux et al., 2020). This research utilizes a direct observational approach, where youth hockey games are video recorded, either through in-person filming by members of the University of Ottawa's research team, or publicly accessible online databases. Full games are then reviewed by trained research assistants in NISL through Kinovea© video analysis software. Two research team members analyze a single game, reviewing footage for any suspected head impact that occurs. Head impacts are identified through clear external contact with the head, and an identifiable mechanism, being an external surface or object, impacting the head, such as a body part (e.g. shoulder), or an environmental playing surface (e.g. boards) (Post et al., 2019). Using WM Capture©, any suspected head contact event is clipped into a shorter video form by NISL research team members. Following the clip creation of a suspected head impact, the research team members log specific criteria to the event into a spreadsheet, repeating this process until all suspected head impacts from the same game have been identified and coded. The head impact criteria in the spreadsheet are as follows (Appendix A): video name, time of impact, clip code, jersey colour of player receiving head impact, jersey number (where applicable), player position, event type, and situational factor. The spreadsheet of suspected head impacts for an entire game are then subject to a third review from the Lab Supervisor, who confirms (or rejects) the suspected head impact. All verified head impacts from the same game are then catalogued and further grouped based on the following characteristics: age group, minor hockey'[4] and girls' minor hockey, level (competitive or non-competitive), and inclusion of bodychecking. All head

[4]Minor hockey as stated here is technically not a distinction as it can include girls. Girls' hockey is distinct as bodychecking is not permitted in youth contexts.

impact data is kept on file by NISL, and any research that is subsequently done functions from verified, confirmed head impacts.

Head Impact Classification

Briefly, it is important to outline the different event types catalogued in our research method procedures. In hockey, there are numerous types of mechanisms that contribute to the head contact events players receive (Fickling et al., 2021). Each of these differing head impacts possess unique biomechanical responses and distinct characteristics that put hockey players at certain risks for brain trauma (Chen et al., 2020). As this proposed study will use confirmed head impact data collected by NISL, events will be classified according to prior research (Chen et al., 2020; Karton et al., 2021; McMunn et al., 2020; Meliambro et al., 2022; Post et al., 2019; Robidoux et al., 2020). The impacts will be categorized as head to: ice, head, shoulder, elbow, boards, glass, glove, puck, and other. These events are classified by what creates primary contact with a player's head, where the "other" category includes events not specified (e.g. stick, trunk, knee). With such a variety of potential event types, there must be an effort to understand the different head contacts players receive in an effort towards risk mitigation and prevention (Meliambro et al., 2022). Therefore, the impact classification assists in identifying specific situational factors that occur in hockey gameplay leading to head contact. Further, these event types helped inform the research for both articles presented in Chapter IV and Chapter V.

Head Contact Observations & Primary Analysis

When undertaking the research for this thesis, sharpened attention was brought to the different types of head contact events that players receive across differing youth levels. Prior research from NISL has identified increased head impact frequency at the youngest level of minor hockey (U7) to be predominantly the result of falls into the boards and ice, as players

develop the skills of skating and balance during gameplay (Karton et al., 2021; Robidoux et al., 2020). However, as skating skills are refined and bodychecking is introduced to the sport at the U15 and U18 levels, there is a significant difference in the head contact event classification data. Amongst these older age groups, a greater proportion of direct collisions to opponents causing head contact has been observed, which is correlated to intentional contact as opposed to unintentional falls. Notably, the mechanism(s) of head contact events amongst these age groups (what makes primary contact with the head) are most frequently head-to-shoulder, glove-to-head, and head-to-glass events (Karton et al., 2021; Robidoux et al., 2020). It has been inferred that the glass being a primary surface in lieu of ice or boards in these older age groups represents body contact or checks being executed on the perimeter of play, resulting in the head contacting the glass. These observations by NISL have thus identified differences in head contact events across age groups, which in turn narrowed the analytical focus to a specific/target sample (bodychecking hockey).

Inclusion Criteria: Youth Competitive Bodychecking Hockey

This research examines bodychecking minor hockey in Eastern Ontario, comprising U15 and U18 age groups. Further, only AA and AAA competitive levels were included for analysis as they represent the top levels of competitive hockey. Competitive bodychecking minor hockey was chosen as it builds off prior observations of elevated head contact and injury risk. Research has shown that the inclusion of bodychecking in youth hockey increases concussion rates in comparison to a non-bodychecking counterpart (Black et al., 2016; Emery et al., 2020; Marchie & Cusimano, 2003). More specific to the focus of this study, head contact events in youth hockey resulting in higher magnitudes are directly associated with impact characteristics commonly found in bodychecking hockey (Chen et al., 2020). Principally, the event types of

head-to-shoulder and head-to-glass impacts are associated with a bodycheck; when combined, these head impacts were found to constitute 37% and 45% of the total event types observed in U15 and U18 levels respectively (Karton et al., 2021). Further, these event types can occur in rapid succession, creating a complex and compounding head contact event that pose unique head trauma risks (Robidoux et al., 2020). Due to the inherent risks of bodychecking competitive hockey, and the head impact event types observed at this level, a sharpened focus on this group merits inquiry and inclusion in this study.

Sample

There were 249 verified head impacts available for analysis from the NISL database across 48 youth hockey games that fit the inclusion criteria for this study. At the U15 level, there were 164 head impacts over 30 games, and at the U18 level, 85 head impacts over 18 games.

Thesis Format & Analytical Process

As stated earlier, the research in this thesis is separated into two articles which utilize NISL verified head impact data. To provide clarity, the individual analytical procedures for how each article uses the secondary data will be addressed specifically in Chapter IV and Chapter V. It is worth addressing, however, that both studies followed a similar third-reviewer process when undertaking the descriptive video analysis of the verified head impacts, as this was seen as the best practice for producing objective results. Research team members with a background in hockey were recruited for analysis and underwent training surrounding the criteria that would be coded specific to each study. Following training deemed suitable by the core research team, each head contact event, broken up into a segment of games, was assigned to two independent researchers for analysis. After the results were collected from individual analysts, a third senior research team member would analyze the results to solve any discrepancies (different criteria

coded) and had final say over the results. This was then developed into the two articles that will be presented in Chapter IV and Chapter V.

Article one seeks to address characterizations that have been made about hockey surrounding aggression and violence, whilst also understanding if head contact is occurring in gameplay due to rule transgressions. Article two develops previous observations surrounding how bodychecks were executed in game situations; this led to an analysis which addressed the technical execution, preparation, and identification of how/if head contact resulting from bodychecks could be prevented. While this thesis is concerned with descriptive observational research to help understand why and how injury occurs, it must be stated that developing tangible and/or feasible injury prevention measures for stakeholders is beyond the scope of this research. Simply put, this research is intended to provide youth hockey stakeholders with insight on how head contact is occurring in a competitive minor bodychecking context to provide future steps that may help reduce head contact, and injury.

Chapter IV: Article One

"Analyzing the Relationship between Aggression, Rule Violations, and Head Contact Events in Canadian Competitive Minor Bodychecking Hockey"

Connor S. McFaul

Abstract

Background: Hockey in Canada is an immensely popular sport, especially amongst youth participants. Despite evidence on the rates and risk of head injuries, especially in bodychecking contexts, little research explains how and why injury occurs in gameplay through video observational methods.
Objective: To understand if head contact events are occurring in youth bodychecking hockey as a result of play execution according to the rules, or a result of violent and/or aggressive play.
Study Design: Descriptive Video Observational Research
Level of Evidence: Rates of concussion in youth hockey are high in comparison to other youth sports. Increased risk of injury, including concussion, in levels which include bodychecking has been well documented. Hockey, including youth levels, has been characterized as an aggressive and even violent sport.
Methods: This research used verified head impact data from bodychecking minor hockey in Eastern Ontario at AA/AAA levels. In total, 249 verified head impacts were available for analysis across 48 U15 and U18 games. A comprehensive video analysis of head impacts was conducted to identify if play was: 1) penalty vs. no penalty; and 2) aggressive vs. non-aggressive. Penalties were evaluated based on rule definition through video analysis, and not the referee's call on the ice. Similarly, four contextual definitions for aggressive/non-aggressive gameplay behaviours were established for analysis.
Results: Amongst the highest levels in U15 and U18 bodychecking hockey, our results demonstrate that the majority of head contact events were the outcome of non-aggressive play (~68%) and within the rules of the sport (~67%).
Conclusions: Key findings from this study identify that head contact events are mainly a result of legal and non-aggressive hockey gameplay. While the rules do penalize aggressive play, these same rules do not prevent head contact from occurring in bodychecking hockey.
Relevance: This study adds to existing knowledge by identifying contextual factors related to potential injury events (head contact) through video analysis in youth bodychecking hockey. This explains why injuries may happen, to help start moving towards injury prevention rather than simply documenting rates.

Key Terms: ice hockey, aggression, violence, penalties, youth, concussion, head contact, injury

Introduction

Ice hockey[1] in Canada is more than just a national sport, it has immense cultural significance and is widely regarded as a symbol of national pride. With over 500,000 players registered as participants yearly under the governing body Hockey Canada, it is a popular pursuit, especially amongst youth. While participation in youth sports such as hockey is often seen as beneficial for developing emotional, physical and cognitive abilities, it also comes with risks. Hockey is consistently identified as one of the highest risk youth sports for injury incidence in Canada (Black et al., 2021; Emery et al., 2006; Fridman et al., 2013), which is a by-product of high participation numbers, but also the characteristics of how the game is played involving speed, intensity, and physicality (Donskov et al., 2019). Across youth sports, head injuries have become a significant issue as high-profile cases of concussions among professional athletes have heightened both public and scientific awareness (Zemek et al., 2017). In minor hockey[2] head injuries represent the biggest concern (Emery & Meeuwisse, 2006; Fridman et al., 2013) as youth brains are still in the developmental stage and are at increased risk for injury (Marchie & Cusimano, 2003). Although there has been increased attention to head injury in recent years, research has more often focused on reporting injury rates (Darling et al., 2010; Emery et al., 2006; Kukaswadia et al., 2010; Willer et al., 2005) rather than understanding how and why injuries are occurring.

In an effort to better understand how and why head injuries are occurring in minor hockey, this study analyzes how rules of the sport and levels of aggressive/non-aggressive play impact head contact events in bodychecking hockey. Bodychecking hockey was selected because of the increased risk for head contact and related injuries in comparison to non-bodychecking hockey (Cusimano et al., 2011; Emery & Meeuwisse, 2006; Goulet et al., 2016; Hagel et al.,

[1] To be referred to as “hockey” from this point forward
[2] Colloquial used term for youth hockey in Canada

2006; Toth et al., 2005). The research sought to examine if head impacts are occurring as a result of play execution according to the rules or a result of violent and/or aggressive play. Research on gameplay characteristics, specifically aggression, are critical as hockey has been described as an aggressive and violent sport (Adams et al., 2015; Allain, 2008; Cusimano et al., 2013; Goulet et al., 2016) including youth levels where it has been suggested a culture of violence is fostered (Cusimano et al., 2016). Despite the characterizations of minor hockey as an aggressive and violent sport, research on tangible gameplay factors and criteria associated with aggression that cause injury is scarce. Critically, past research tends to conflate notions of bodychecking and aggressive behaviour, and for some, checking is perceived to be a "vector of violence and intimidation" (Goulet et al., 2016, p. 668). To address this gap, this study seeks to understand if Canadian minor hockey rules are protecting players from head contact, and if head contact is occurring due to aggressive play. This research will use secondary data to employ a video analysis of verified head impacts from the Neurotrauma Impact Science Laboratory (NISL) in under-15 and under-18 AA and AA levels.

Context: Aggression in Hockey

Aggression in hockey has been described as an institutionalized behaviour, whereby conduct is reinforced by both the social environment of the team and the norms or expectations of the sport as a whole. It is what Silva (1979) refers to as a product of social learning, where the use of aggression in sports has been legitimated through social processes and are often desired or expected by the normative demands of the sport. In hockey, youth players are said to be exposed to these aggressive behaviours through various mediums (e.g. professional broadcasts, coaches, parents, teammates) and often adopt them as they attempt to continue through organized sport, climbing competitive ranks and age levels (Loughead & Leith, 2001; Smith 1975; Vaz, 1979;

Visek & Watson, 2005). While social learning theory offers explanations about why aggressive behaviour occurs, there continues to be contention about what actually constitutes aggressive behaviour – especially in the realm of sport. For years, researchers have attempted to provide a "one-size-fits-all" definition of aggression, but disagreement remains because each involve some notion of intent which cannot be objectively measured (Bandura, 1979; Baron, 1977; Coakley, 1998). Further, defining aggression is even more elusive within a sports setting, as behaviours are determined according to the rules, both written and unwritten, that are enforced within each unique sports context (Silva, 1983).

To counter these definitional challenges, researchers have offered working definitions of aggression that take sports context and intent into consideration. It has been suggested that the most important facets of aggression are the intent and severity of the actions (Kirker et al., 2000), where intent separates aggressive behaviour from non-aggressive actions (Stephens, 1998). A working definition does not alleviate certain levels of subjectivity when assessing intentional behaviour, as it must be interpreted and/or presumed by an observer (Kerr, 2005; Shields & Bredemeier, 1995). Assessing aggression in sport thus requires an interpretive framework that is sport-specific and distinguishes behaviour as aggressive or non-aggressive but also characterizes the consequence of the actions into different levels of aggression. Sport scholars such as Kerr (2005) have adopted an approach that classifies behaviour as sanctioned versus unsanctioned aggression based on the formal or informal rules of the sport. Within this interpretive framework, unsanctioned aggression is deemed to be any action that transgress the constitutive rules of the sport and normative sport practices. For example, in the sport of hockey where physical contact and checking regularly occur, a hard bodycheck would typically be considered sanctioned as it is

normalized within the sport's culture, but if this same bodycheck were to cross a tolerable threshold of behaviour resulting in a penalty call, it would be deemed unsanctioned.

"Aggressive" terminologies (e.g. violent, hostile, instrumental, assertive) are often used interchangeably which creates confusion as researchers attempt to distinguish different types or levels of aggression in sport (Stephens, 1998). Our interpretive framework draws on previous studies and terminology attempting to categorize behaviour as aggressive or non-aggressive based on the rules of the sport and cultural norms. To distinguish between types of aggression and assertiveness, and to differentiate levels of severity, three concepts have been identified in academic literature. First, hostile aggression has been defined as an action where the sole purpose is to injure another person (Kirker et al., 2000); this action denotes the end point on a continuum of aggressive behaviour, often considered in sport to be a dangerous or violent collision (Smith, 1983). Second, instrumental aggression does not necessarily involve intent to injure but rather a goal-oriented use of intense physicality to intimidate or dominate an opponent in pursuit of winning. Injury is ancillary to the main goal and seen as limiting an opponent's effectiveness, which borders on formal and informal rule transgression (Stephens, 1998). Lastly, assertive behaviour is a significant feature of contact sports that is a physical rule-permitted action without the intent to injure (Silva, 1979), and for this reason it is considered non-aggressive. As intent can only be inferred, assertive play constitutes an action that is sanctioned, typically within the regulations of the sport. This study builds on these three concepts listed above and offers a new interpretive sport-specific framework that includes four contextual definitions to categorize behaviour as aggressive or non-aggressive in bodychecking hockey.

Background to Methods

The research for this project builds off an observational study conducted by the Neurotrauma Impact Science Laboratory (NISL) at the University of Ottawa and research partners CCM Hockey. This study recorded and analyzed head contact events that occurred in youth hockey games across all age divisions in the Ottawa, Ontario region (Chen et al., 2020; Karton et al., 2021; Post et al., 2019; Robidoux et al., 2020). Detailed methods for head contact identification and coding were established by NISL, where head contact events were only confirmed following comprehensive video analysis. Head impact verification was organized through a third-reviewer process, whereby full gameplay footage was examined by two NISL research team members who identified all suspected head impacts and coded head impact criteria for each event, which was then verified by a senior researcher. Head contact events are defined as the head coming into clear contact with any external surface or object; mechanisms can either be body parts (e.g. shoulder) or environmental playing surfaces (e.g. boards) (Post et al., 2019; Robidoux et al., 2020). After confirmation from the senior researcher, all verified head impacts and detailed event description criteria were then catalogued within the same game and subsequent level of play.

Prior analysis and observations by NISL research team members over the past seven years have delineated the different types of head impacts hockey players receive across all youth age groups and levels of play. Notably, increased head contact events resulting from direct body collisions have been observed at the U15 and U18 levels where bodychecking is permitted, in comparison to younger levels (U7) where head impacts are mainly from falls and/or loss of balance (Karton et al., 2021; Robidoux et al., 2020). Head contact event types associated with bodychecks in gameplay, head-to-shoulder and head-to-glass impacts, were found to make up

37% and 45% of the total event types in U15 and U18 levels, respectively (Karton et al., 2021). Further, these head impact characteristics commonly found in minor bodychecking hockey result in high magnitude collisions, measured in terms of maximum principal strain (MPS), which pose unique brain trauma risk (Chen et al., 2020). Thus, additional research specific to gameplay characteristics in bodychecking minor hockey has been urged in order to understand the risks players may face. This study employed a secondary video analysis to verify head impact data from competitive bodychecking minor hockey according to our discrete aims and criteria below.

Methods

This research focused on verified head impact data from U15 and U18 bodychecking minor hockey in Eastern Ontario. Further, only AA and AAA levels were included in the analysis, as they represent the top levels of competitive hockey in each age group. In total, 249 verified head impacts were available for analysis across 48 youth hockey games that met the inclusion criteria for this study. At the U15 level there were 164 head impacts over 30 games, and at the U18 level, 85 head impacts over 18 games.

The objective of this study is to identify and understand the contextual factors surrounding rule violation and levels of aggression in competitive minor bodychecking hockey as it relates to head contact in gameplay. To do so, a video analysis of the verified head impact dataset was conducted, where each head contact event was analyzed frame-by-frame in Kinovea© video software. When undertaking this video analysis, two specific questions were asked: 1) are head contact events in bodychecking hockey the result of legal or illegal play based on the rules and regulations set forth by Hockey Canada? and 2) are head contact events a consequence of athletes playing aggressively, executing hockey tactics, or accidental play?

Three NISL research team members from the University of Ottawa with an extensive background in hockey as players and officials led the study, starting with establishing analytical procedures and constructing working definitions for the study. A team of four undergraduate student researchers within the university's School of Human Kinetics with a background in hockey were then recruited to help with the video analysis and coding of the head impacts according to the given criteria and procedures. Research team members underwent substantial training, including an overview of the study, tutorial, and in-lab demonstration with video examples for various gameplay situations. The researchers were provided with a copy of the Hockey Canada Rulebook for rule evaluations (in relation to legal and illegal play), and the contextual definitions of aggressive and non-aggressive gameplay behaviours. Training games and a test were completed and overseen by the lead researchers in order to progress to formal analysis. During analysis, researchers had access to all prior resources, including pre-evaluated video clips. For the analysis, a third-reviewer process was followed, whereby two separate researchers evaluated a segment of games independently, evaluating the penalty, penalty severity, and contextual definition of aggression. This was then sent to the principal investigator who resolved any disagreements in either rule evaluation or contextual definition of aggression.

Rule Evaluation of Head Impacts

Prior research using direct observational methods to evaluate rule infractions in youth hockey has often reported the challenge of relying on on-ice officiating (Gee & Sullivan, 2006; Mihalik et al., 2010; Stephens, 1998). Notably, officiating in hockey is far from perfect as the speed of the game and complex interactions between participants can often lead to missed or misinterpreted calls by the referee. As a noted limitation, this study took advantage of using a frame-by-frame video analysis to identify rule transgression based on the official rules from the

governing body. Thus, the rule evaluation of head contact events for this analysis was based on verbatim interpretation of Hockey Canada's rule framework, which allowed for enhanced consistency and objective measurement of evaluating gameplay. During analysis, the research team evaluated: 1) Was the head impact caused by legal or illegal play (i.e. no penalty/penalty)? 2) If play was illegal, what would be the appropriate penalty call (e.g. head contact, boarding, charging, tripping)? and 3) If play was illegal, what would be the penalty severity (e.g. minor, double minor, major and game misconduct)?

Contextual Definitions of Aggressive and non-Aggressive Gameplay Behaviours

Historically, two methods have been used to identify aggressive play in hockey: player surveys and rule infractions (Gee & Sullivan, 2006). For the former, self-reporting bias is a well-documented limitation when asking athletes to analyze their own behaviours (Emery et al., 2006; Russell, 1993); additionally, this method only measures individuals' perceptions of their own behaviour (Gee & Sullivan, 2006) and results are likely unreliable when used as the sole dependent measure (Russell, 2008). To curb bias and attempt to produce objective results, researchers have used records of game sheets as a tool to identify aggression, where penalties are deemed aggressive by default as they constitute transgressive play (Kirker et al., 2000; Gee & Sullivan, 2006; Russell & Russell, 1984; Russell, 1993; Stephens, 1998; Widmeyer & Birch, 1984; Vokey & Russell, 1992). Limitations associated with this penalty method include referee bias (Kirker et al., 2000), intentions of the actor, the (mis)classification of different penalty types as aggressive, and the inability to nuance the types and levels of aggression specific to hockey (Stephens, 1998). In addition, aggressive behaviour does not necessarily violate rules; it can comprise legal and/or tactical execution depending on the sport, such as checking in hockey (Silva, 1979; Kirker et al., 2000; Stephens, 1998). A further limitation of both research

approaches is the absence of observation via video recorded gameplay which provides researchers the opportunity to analyze gameplay *in situ*, providing a more detailed understanding of player behaviour (Gee & Sullivan, 2006).

As outlined earlier, due to the definitional and methodological inconsistencies in research on aggression in hockey, this study sets out to use operational definitions to categorize varying levels of aggressive and non-aggressive behaviours within a sport specific context and evaluate them based on both informal and formal rule transgression or compliance (Kerr, 2005; Kirker et al., 2000; Silva, 1979; Stephens, 1998). The operational definitions draw from both sport aggression literature and in-depth understanding of the nuances in hockey gameplay. Despite the recognized level of subjectivity when attempting to categorize aggressive behaviour, the question of intent cannot be ignored. The working definitions in this study acknowledge such subjectivity but provide a rigorous evaluation criteria to minimize the level of subjectivity and includes the term 'intent' in definitions as a means of interpreting the volition of a player in a game situation. As bodychecking hockey is the sport of inquiry, the operational definitions will be in relation to the definition of a bodycheck, where bodily force and contact is used to separate an opposing player from possession of the puck in a tactical and legal manner (King & Leblanc, 2006). The four contextual/operational definitions of aggressive and non-aggressive play that leads to head contact are defined as follows:

Involuntary: An involuntary act with self-inflicted head contact (e.g. fall to ice or boards), caused by others with no intent (e.g. stick tie-up or stick lift resulting in head contact), and unintentional player collisions where both players are unaware of impending contact. Non-aggressive.

Assertive: A voluntary act with intent to separate opposition player from the puck, and/or engagement of contact in pursuit of a puck in order to gain possession. Non-aggressive.

Instrumental Aggression: A voluntary act with intent to intimidate opponent(s), and/or to hit the opponent(s) in a manner that goes beyond the sole purpose of puck separation.

Hostile Aggression: A voluntary act with intent to harm or injure opponent(s), and/or deliberate attempts to take advantage of a defenceless or vulnerable player.

Results

Data for 249 head impacts were analyzed from a total of 48 games, for an average of ~5.2 head impacts per game. There were 164 head impacts at the U15 level across 30 games and 85 head impacts at the U18 level across 18 games.

Head Contact based on Aggressive vs. non-Aggressive Play

59/249 head impacts were identified as "Involuntary", representing 24% of the entire data set. At the U15 level, 35/164 (21%) were involuntary events, and at the U18 level, 24/85 (28%) were involuntary events. 111/249 head impacts were identified as "Assertive", representing 44% of the entire data set. At the U15 level, 77/164 (47%) were assertive events, and at the U18 level, 34/85 (40%) were assertive events. 67/249 head impacts were identified as "Instrumental Aggression", representing 27% of the entire data set. At the U15 level, 45/164 (28%) were instrumental aggression events, and at the U18 level, 22/85 (26%) were instrumental aggression events. 12/249 head impacts were identified as "Hostile Aggression", representing 5% of the entire data set. At the U15 level, 7/164 (4%) were hostile aggression events, and at the U18 level, 5/85 (6%) were hostile aggression events.

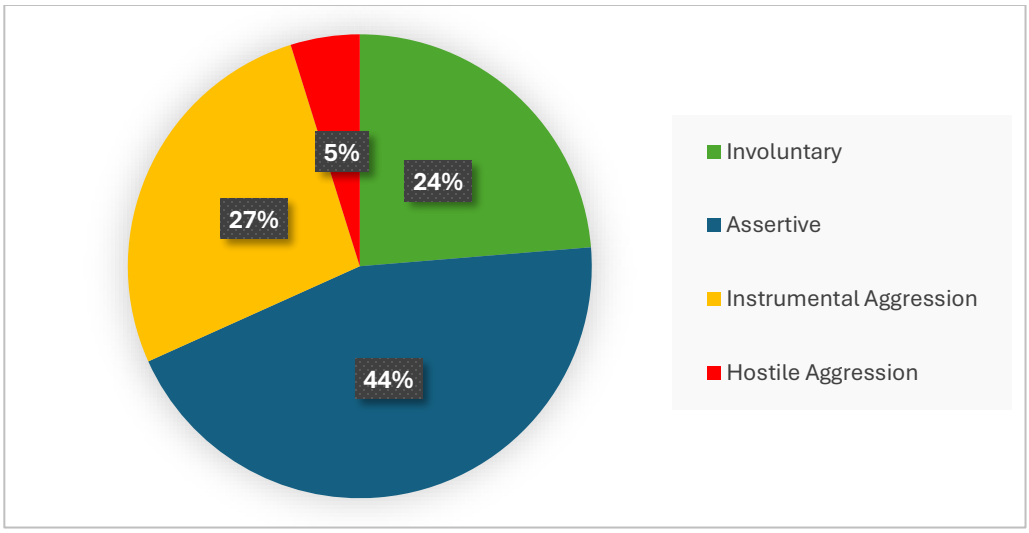

Figure 1. Head Contact based on Aggressive vs. non-Aggressive Play (All Levels).

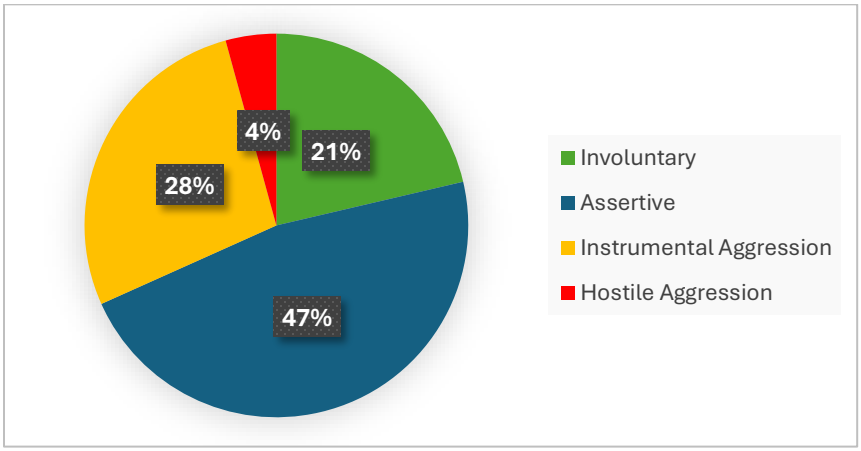

Figure 2. Head Contact based on Aggressive vs. non-Aggressive Play (U15 Level).

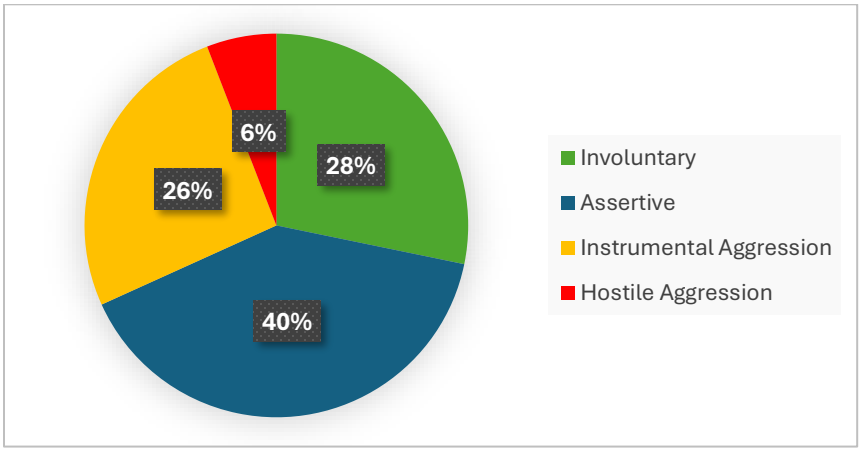

Figure 3. Head Contact based on Aggressive vs. non-Aggressive Play (U18).

Head Impacts as Penalty vs. No Penalty

82/249 head impacts were coded as a play that should have resulted in a penalty, which constitutes 33% of the entire data set. At the U15 level, 56/164 head impacts were coded as a penalty (34%). At the U18 level, 26/85 head impacts were coded as a penalty (31%).

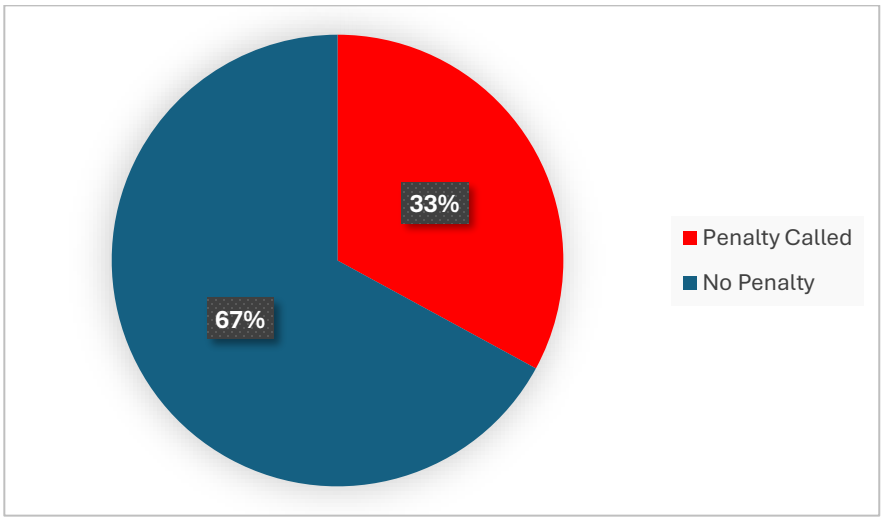

Figure 4. Head Impacts as Penalty vs. no Penalty.

Penalty Typing

A Boarding penalty was assessed 9 times, 6 were coded as aggressive play, and 3 non-aggressive. A Charging penalty was assessed 4 times, all of them were coded as aggressive play. A Checking from Behind (CFB) penalty was assessed 4 times, all of them were coded as aggressive play. Goalie interference was assessed 1 time and was coded as aggressive play. A Head Contact penalty was assessed 51 times, 32 of these penalties were coded as aggressive play, and 19 non-aggressive. Hooking was assessed 1 time and was coded as non-aggressive play. Interference penalties were assessed 5 times, all of them were coded as aggressive play. A Roughing penalty was assessed 4 times, 2 were coded as aggressive play, and 2 non-aggressive. A Tripping penalty was assessed 3 times, 2 were coded as aggressive play, and 1 non-aggressive. In total, 54/82 (66%) penalties were coded as aggressive play, and 28/82 (34%) penalties were

coded as non-aggressive. There were no other penalties observed, for the entire list of other potential penalties consult the Hockey Canada Rulebook (http://rulebook.hockeycanada.ca/english/part-ii-gameplay-fouls/section-7/).

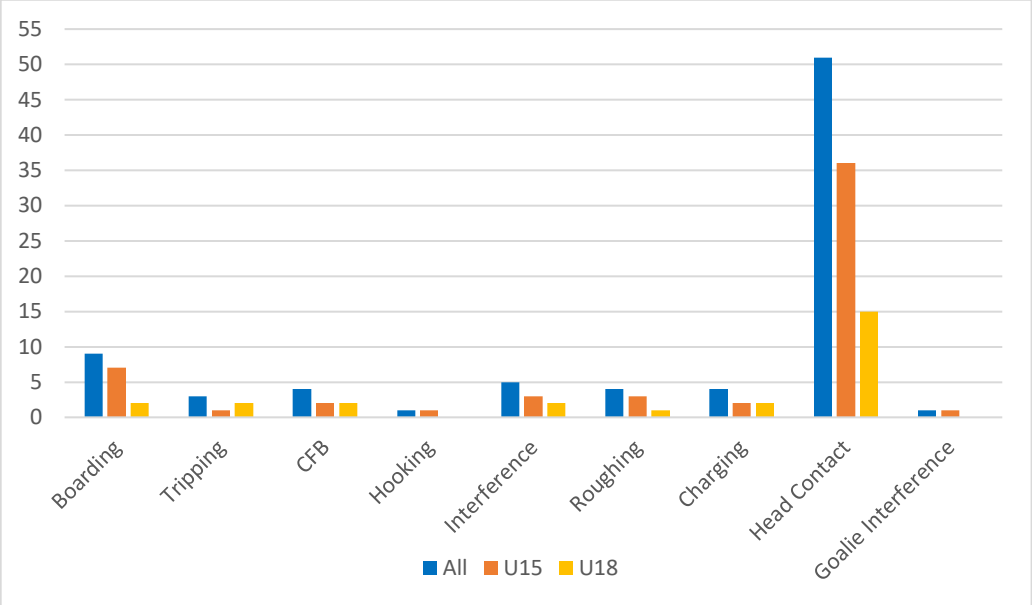

Figure 5. All penalty types observed.

Head Contact Event Classification

68/249 head impacts were classified as "head to glass" events, 23 of which were coded as aggressive play and 45 non-aggressive. 15/249 head impacts were classified as "head to boards" events, 7 were coded as aggressive play and 8 non-aggressive. 17/249 head impacts were classified as "head to ice" events, 10 were coded as aggressive play and 7 non-aggressive. 16/249 head impacts were classified as "head to head" events, 2 were coded as aggressive play and 14 non-aggressive. 32/249 head impacts were classified as "head to shoulder" events, 11 were coded as aggressive play and 21 non-aggressive. 25/249 head impacts were classified as "head to elbow" events, 3 were coded as aggressive play and 22 non-aggressive. 27/249 head impacts were classified as "head to glove events", 14 were coded as aggressive play and 13 non-aggressive. 13/249 head impacts were classified as "puck" events, all 13 were coded as non-

aggressive. 36/249 head impacts were classified as “other” events, 9 were coded as aggressive play and 27 non-aggressive. The “other” event category includes stick to head contact and any other body parts not previously addressed.

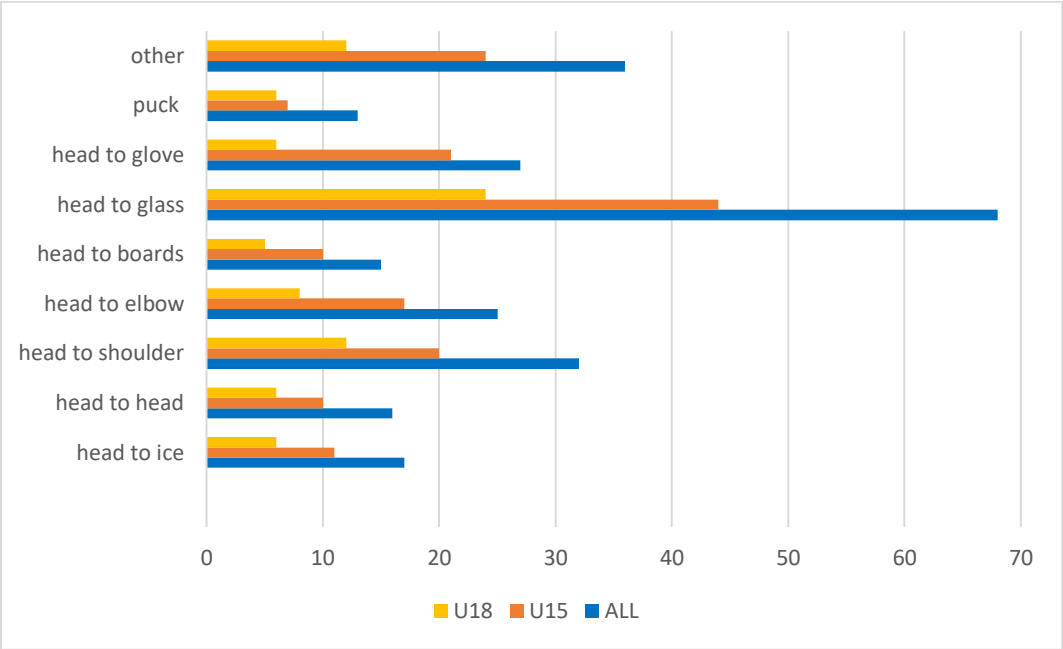

Figure 6. Mechanisms and Classifications of Head Contact Events.

Discussion

This study sought to understand whether the rules set forth by Hockey Canada were protecting players from head contact by analyzing if head contact events were the result of illegal or legal play. In an effort to reduce the frequency of head contact in hockey and deter head injury occurrence, a modified head contact (HC) rule was implemented across minor hockey in 2011, which made any direct contact to the head (intentional or not) illegal (Hockey Canada, 2011). As such, the HC penalty was the most commonly observed penalty by a considerable margin, as there were 51 HC penalties, representing ~61% of all penalties, one fifth of all 249 head contact events in the study. Therefore, if the rules are being executed by officials effectively, players are being disciplined for direct contact to the head which in turn should see reductions in reckless

play leading to head impacts. However, the majority of gameplay situations producing head impacts are occurring when no penalty should be called, ~67%. An observational study on head impacts from 54 games in U15 AAA hockey by Mihalik and colleagues (2010), six amateur coaches concluded that 82.7% of the head impacts were the result of legal body collisions. This is strikingly similar, with the increased penalties observed in our study likely occurring due to enforcement of the head contact rule. Further, our findings indicate the reason for a seemingly low penalty rate are legal bodychecks where the head is not making direct contact with a body segment but with the playing environment (boards, glass, ice), and observations of self-inflicted head contact (player skating into an opponent). The combination of the head to boards, head to glass, and head to ice event types in our head impact classification data make up ~40% of the total verified head impacts which may explain why many of these head impacts occurred during legal play. Notably, head to glass events, which were typically the result of head movement and collision with the playing surface following a legal bodycheck along the perimeter of play, were more common amongst these competitive U15 and U18 bodychecking levels than past studies (Chen et al., 2020; Karton et al., 2021; Robidoux et al., 2020).

Another significant objective of this study was to characterize head impacts according to four categories of aggressive and/or non-aggressive gameplay behaviours. Amongst the highest levels in U15 and U18 bodychecking hockey, our results demonstrate that the majority of head contact events were the outcome of non-aggressive play (~68%) and within the rules of the sport (~67%). Only ~5% of the head impacts were considered serious or violent attempts to injure another player, indicating that hostile aggression is minimal. Due to the evident severity of hostile aggression events, all plays were deemed illegal with more than half warranting a major penalty and game misconduct, which is a significant sanction. Over a quarter of the head impacts

observed in the study were instrumental aggression, ~70% of which were deemed illegal play, indicating that aggressive play is not tolerated by the current Hockey Canada regulatory framework. Observations on penalty type in aggressive categories from this study calls attention to Checking from Behind and Boarding sanctions, which are noted high-risk events that may cause severe brain and spinal cord injury (Mihalik et al., 2010; A. Smith et al., 2017; Tator et al., 2004; Williamson & Goodman, 2009). Not only are these plays illegal and preponderantly aggressive they also pose certain injury risk and should be continued to be deterred by referees in-game. Further, our observations indicated increased head trauma risk on complex or compounding head contact events, where players sustained multiple head impacts as the result of a single play, thus warranting further inquiry as they relate to unique risks of brain trauma specific to bodychecking hockey (Chen et al., 2020). In observing that aggressive and illegal play occurs less frequently than suggested (Cusimano et al., 2013; Cusimano et al., 2016; Gee & Sullivan, 2006), this study asserts that players are simply executing game tasks. This study also posits that if play continues to be monitored and enforced effectively by referees, head impacts of high magnitude severity should continue to decrease.

What should be emphasized here is that bodychecking is a major contributor to head contact events in hockey. Research has repeatedly shown that bodychecking increases the risk of head injury in comparison to non-bodychecking hockey (Black et al., 2016; Emery et al., 2010; Emery et al., 2020). An obvious measure to reduce head contact events would be to remove bodychecking entirely (Adams et al., 2015; Chen et al., 2020; Emery & Meeuwisse, 2006; Marchie & Cusimano, 2003), yet its removal is highly unlikely under the current high-performance sport model that is increasingly normalized in youth sport. In other words, unless bodychecking is removed from professional, semi-professional, Junior and College/University

hockey, those with elite aspirations (parents, coaches, and players) would likely object to its removal. Bodychecking hockey, however, does not necessitate rule violation or aggressive play, as observed in this study. Instead, the majority of head contact events were from assertive play (~44%) where players execute hockey tactics to retrieve the puck from opponents, commonly through legal bodychecks. Even amongst the small percentage of plays that were deemed instrumental aggression (~27%), less than one-third (~30%) of events were not penalized and the result of players "finishing their check", a prominent tactic where the bodycheck is executed in a short timeframe after the puck has been released by the opponent. Thus, bodychecking does lead to increased head contact, but does not, as others report, lead to an increase in rule violation or aggressive play.

Limitations

This study relied on video analysis and there are certain limitations in video capture. At times during gameplay sight lines do not capture the full sequence of play for specific players, and actions or potential head impacts that occurred away from the centre of play (away from the puck) can be missed. Although evaluating referee decisions was not the purpose of this study, the research team's ability to replay each head impact multiple times likely yielded a higher result of penalties than what was called on the ice. There has been advocation for a stricter penalty enforcement by referees regarding HC penalties (Williamson et al., 2021), which may lead to decreases in head impact occurrence; our frame-by-frame video analysis allowed for rule violations to be assessed per the Hockey Canada rulebook.

Conclusion

Contemporary research studying the effects of brain injury in youth sport are raising awareness of the risks participating in contact sports. Despite studies quantifying injury risk in

minor hockey, there has been minimal information about why injuries occur in gameplay and thus little opportunity for stakeholders to make informed decisions about injury mitigation and prevention. In order to understand the elevated rates of head injury in contact sports like hockey, more emphasis must be placed on the comprehension of the contextual and situational gameplay factors that contribute to injury. The analysis from this study presents an extensive evaluation of head impacts in youth bodychecking hockey. The tendency to characterize hockey as an aggressive sport prompted us to investigate the relationship between aggressive and violent behaviour and head contact events. This study also assessed if the current rules in minor hockey are effective in reducing head contact. Key findings from this study identify that head contact events are mainly a result of legal and non-aggressive hockey gameplay; while the rules do penalize aggressive play, these same rules do not prevent head contact from occurring in bodychecking hockey.

This study offers an important contribution to research exploring aggression, rule violation, and injury in youth hockey by establishing a novel method for evaluating player conduct *in situ*. First, establishing four operational definitions to identify aggressive and non-aggressive gameplay behaviours allowed for a more nuanced understanding of bodychecking hockey and how players interact in a sport-specific setting. This complemented the penalty identification component of analysis which sought to identify if the rules protected players from head contact events in gameplay, while also underscoring the interplay between aggression and rule adherence. This model of player behaviour could be implemented at different bodychecking levels to further characterize head contact events in hockey gameplay. Additionally, our results indicated a considerable number of head impacts resulting from contact with the shoulder, elbow, and glove were non-aggressive. Although beyond the scope of this study, future research

is encouraged to identify if these head impacts are the result of improper bodychecking technique. This study highlights the need for continued research on contextual gameplay factors leading to injury and evidenced-based policy decisions if further injury prevention strategies are to be implemented in minor hockey. While aggression certainly can be considered an aspect of competitive minor hockey, it does not universally translate into the intent to injure or rule violations. Instead, at this level of minor hockey head impacts are mainly the result of players executing hockey tasks, not formal or informal rule transgression. This suggests that if future steps are taken towards head contact mitigation, it must involve some degree of rule change, and/or changes in playing style that precipitate head contact from occurring.

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CHAPTER V: Article Two

"Are Youth Players Prepared for Bodychecking Hockey?: A Descriptive Observational Analysis of Bodychecking Events Leading to Head Contact in Minor Hockey"

Connor S. McFaul

Abstract

Background: Youth sport injury has become a growing issue for researchers and sport practitioners concerned about safety. The gameplay characteristics in Canadian youth minor hockey yield high head injury incidence, particularly at bodychecking levels, yet observational video analysis that explain why and how these injuries occur are sparce.
Objective: This study seeks to identify the situational gameplay factors that lead to head contact during bodychecking events in competitive minor hockey, to address questions surrounding bodychecking technique, preparation for contact, and if head contact is preventable.
Methods: Employing an inductive and descriptive observational research design, verified head impact data from an under-15 AAA league in Eastern Ontario was chosen for analysis, representing the top competitive level and players first exposure to bodychecking under Hockey Canada. Of the 164 verified head impacts across 30 games available for analysis, 127 met the inclusion criteria. Three steps were taken during formal video analysis: 1) Each event was analyzed and specific gameplay details related to the bodycheck were coded; 2) Common descriptive details of events across a secondary round of video analysis were gathered, and bodychecking events were grouped; 3) Qualitative details for each event were coded to describe categories of events observed.
Results: Three categories of bodychecking events precipitating head contact were observed: 1) Vulnerability/positioning; 2) Technical execution, further separated into two sub-categories, 2a) Poor technique, and 2b) Aggressive technique; 3) Executed hockey task. Findings indicate that 77% of all head impacts were the result of bodychecking events. While ~48% of head contact events were the result of players executing a bodychecking task, head impacts were also the result of poorly executed checks (~24%), aggression (~19%), or players being in a vulnerable position on the ice (~9%).
Relevance: Novel findings from this study highlight the nuances of different bodychecks players receive leading to head contact in minor competitive hockey.

Key Terms: ice hockey, youth, bodychecking, injury, concussion, head contact, aggression

Introduction

Injury in sport, particularly concussion and brain injury, has become an important public health issue that is receiving increased attention from researchers and sport practitioners concerned about youth sport safety. This is in part due to scientific evidence indicating that long-term brain health and quality of life are negatively impacted by head impacts accrued by youth during the brain's developmental stages (Goulet & Beno, 2023; Marchie & Cusimano, 2003). Sports such as youth ice hockey have been subject to criticism, as the characteristics of speed and intense physical play render it as one of the highest-risk youth sports for injury, in particular brain injury (Black et al., 2021; Cusimano et al., 2011; Emery et al., 2006; Emery & Meeuwisse, 2006; Fridman et al., 2013; Willer et al., 2005). In Canada, there are ~450,000 registered youth minor hockey players, comprising the under-7 to under-18 age groups, according to governing body Hockey Canada (Hockey Canada, 2024). Concussion and brain injury research on Canadian minor hockey is extensive, much of which focuses on competitive levels that include bodychecking, which is the most common mechanism for all head injuries (Cusimano et al., 2011; Emery & Meeuwisse, 2006; Goulet et al., 2016; Hagel et al., 2016; Kukaswadia et al., 2010; Toth et al., 2005). Contemporary studies on head injury in minor hockey have attempted to offer injury prevention measures that could be implemented to reduce concussion rates (Cusimano et al., 2016; Macpherson et al., 2006; Tator et al., 2022; Willer et al., 2005). However, many research designs have used injury reporting methods that focus largely on recording rates and/or frequency, which offers little in terms of understanding how and why injury occurs in gameplay. This gap has led to an increased need for identifying situational or contextual factors for injury using observational and video analysis methods to understand injury *in situ* (Aguiar et al., 2020).

This study sets out to identify the potential injury events occurring in bodychecking minor hockey, by analyzing the in-game risk factors attributable to players when head contact events occur. In particular, this research focuses on identifying the situational factors during bodychecking events that lead to head impact, to determine if and how head contact could be prevented during these bodychecking events. As bodychecking is currently introduced at the under-15 (U15) age group in competitive levels in Canada, this research analyzes bodychecking events leading to head contact at this age group and level, to better understand players preparation and aptitude in giving and receiving contact throughout their first season-long exposure to bodychecking hockey. Although previous studies have shown many head impacts occur due to mechanisms associated with bodychecking (i.e. head-to-shoulder, head-to-elbow, and head-to-glass events) (Aguiar et al., 2020; Aguiar et al., 2023; Chen et al., 2020; Hutchison et al., 2015; Karton et al., 2021; Krbavac et al., 2024), these studies do not explicitly explain why the head is being impacted during bodychecks. This study seeks to address open-ended questions surrounding technique or technical execution of bodychecks and the preparation of players for contact in gameplay, to identify how preventable head contact is during bodychecks and provide information that may help reduce head contact frequency in the sport. The research will offer a descriptive analysis of bodychecking events using an inductive methodological process, whereby multiple phases of video analysis will be conducted to establish gameplay criteria and evaluate head contact events. Secondary data of verified head impacts from the Neurotrauma Impact Science Laboratory (NISL) were used to evaluate head contact events from a U15 AAA bodychecking hockey league in Eastern Ontario.

Context: Bodychecking, Policy and Injury in Minor Competitive Hockey

Prior to outlining the methods for this study, it is important to contextualize minor bodychecking hockey and identify some of the key studies and policy changes that have been implemented in an effort to reduce injury rates. First it is important to point out that Canadian minor hockey operates under two different sets of rules: one with bodychecking and one without[1]. A bodycheck is commonly defined as a defensive tactic where physical contact is exerted to stop a puck carrier's attacking progress and to separate the attacking player from possession of the puck (Hockey Canada, 2022; King & Leblanc, 2006; McKay et al., 2014). Bodychecking is reserved only for competitive levels of minor hockey, as a means of preparation and a path to higher levels of hockey (e.g. Junior, Collegiate, Professional). Across non-bodychecking levels of minor hockey, body contact is still permitted, for which the distinction between a bodycheck and body contact is nuanced. Players are permitted to make "incidental" contact with one another in pursuit of the puck, but bodychecks (via the opinion of the referee) are deemed illegal (Hockey Canada, 2022; Krbavac et al., 2024; McKay et al., 2014). Common characteristics that may distinguish a bodycheck include the overt nature of the contact, mainly visible through physical exertion, follow-throughs, and players skating in opposite directions (Black et al., 2017; Juhn et al., 2002). There are also semantic distinctions between the technical definition, or intended purpose of a bodycheck, versus what people understand bodychecking to be based on contact in professional hockey through media and league marketing. These examples of bodychecks extend beyond the goal of puck separation and use as a defensive tactic and are instead utilized to intimidate and punish opponents (Robidoux & Trudel, 2006; Smith, 1979). This is to say terminology such as (body) contact is applicable only to non-bodychecking hockey as it is rule-bounded, whereas differences in bodychecks observed in bodychecking hockey are

[1]Although true, there are some sanctioned leagues that have implemented modified checking rules, which will be addressed later.

immaterial. Therefore, there are different types of contact that occur in hockey depending on what is permissible or accepted across the different levels or contexts (bodychecking vs. non-bodychecking), with each posing unique types of impacts and risk of injury for players.

Currently, bodychecking is permitted at the U15 age group in competitive hockey. The decision to introduce body checking at this age level and exclusively in competitive hockey came after several years of policy changes, and pilot studies from the 1990s until 2013 (Black et al., 2017; Cusimano et al., 2011; Kukaswadia et al., 2010; McKay et al., 2014). Prior to this, bodychecking was not nationally standardized under governing body Hockey Canada. Several studies were conducted over these years reporting increased rates of injury (in particular concussions) in comparison to non-bodychecking at the "Atom" U11, "Peewee" U13, and "Bantam" U15 levels (Emery & Meeuwisse, 2006; Emery et al., 2010; Emery et al., 2011; Marchie & Cusimano, 2003; McKay et al., 2014; Willer et al., 2005). These studies identified bodychecking as the principal mechanism for all injury, especially concussion, which encouraged the regional organizations under Hockey Canada to delay bodychecking until the U15 level in an effort to protect youth players from injury. However, this decision underwent considerable scrutiny as it was made after decades of debate amongst stakeholders (parents, coaches, academics, media, etc.,) about the age at which bodychecking should be introduced. In Goulet and colleagues' (2016) article, they identify differing positions about the early introduction of bodychecking. Among some stakeholders, it is viewed as more beneficial for youth players to gain knowledge and practice through exposure to become more adept/effective in their abilities to deliver and receive checks in game situations. Conversely, research suggests that delaying bodychecking reduces injury burden and ensures greater youth safety. Additional concerns around the early introduction of bodychecking include the size disparity of the players

through early stages of puberty and adolescence, and the need for players to learn the technical and tactical fundamental skills (e.g. skating, stickhandling, positioning, shooting, etc.) prior to facing bodychecks (Goulet et al., 2016; Robidoux & Trudel, 2006).

As a result of these studies identifying increased injury risk with bodychecking hockey, different injury prevention measures have been proposed to enable youth to adapt safely to bodychecking hockey. Hockey Canada and the National Coaching Certification Program (NCCP) developed a four-step model for introducing bodychecking which recommends the practice and adoption of contact and checking skills prior to participating in bodychecking hockey (Hockey Canada, 2013, 2024). While similar emphasis has been placed on bodychecking skill development through practice by USA Hockey (McKay et al., 2014), the uptake of formal bodychecking training is not being monitored, as implementation is at the discretion of the branches or organizations. What is more pervasive are skill-development camps offered by many local coaches or groups that emphasize skating (e.g. power-skating), stickhandling and shooting, during peak- and off- seasons for minor hockey players. By way of a Google query searching for "minor hockey development camps Ottawa" the first page of results (n=10) focused on skating and puck handling skill development, and none focused on bodychecking. There are, however, some leagues and tournaments that have included modified or hybrid body contact rules. The rules and regulations in these modified contact leagues vary, but the general purpose is to allow players to use the bodycheck as a defensive tactic for puck separation, without permitting dangerous checks that may lead to injury[2] (Hockey Québec, 2019; Krbavac et al., 2024). Modified bodychecking is being implemented sporadically in some youth hockey contexts to help introduce lower-level competitive leagues to the skills required and demands of full-contact levels (e.g. Ligue de Hockey Prépatoire Scolaire). To date there is little evidence identifying how

[2]Common rules dictate that bodychecks are not allowed when players are skating in opposite directions, or when a player is in "open ice", these are enforced at the discretion of the referee.

effective these modified checking leagues are for reducing injury, but instead most research emphasizes that the only real means of reducing injury is to delay, or remove bodychecking altogether (Adams et al., 2015; Chen et al., 2020; Eliason et al., 2022; Emery & Meeuwisse, 2006; Marchie & Cusimano, 2003). Moreover, Hockey Canada has not endorsed or standardized a modified contact option for minor hockey, but instead simply delays the introduction until it is fully adopted at U15 competitive levels.

Therefore, to better understand the decision to introduce bodychecking at this age level, this study sets out to identify and analyze the factors that precipitate head contact during bodychecking events in gameplay in U15 competitive AAA hockey. This level was selected because it is the first opportunity for players to be exposed to bodychecking, which may provide insight on player preparation and technical execution of contact. The research seeks to ultimately understand whether there are actions these players can take to help prevent head contact from occurring in the process of delivering/receiving a bodycheck. Further, we hope to provide insight into gameplay characteristics of minor competitive hockey under the current framework operated by Hockey Canada.

Methods

This study expands on a long-term observational research project conducted by the Neurotrauma Impact Science Laboratory (NISL) at the University of Ottawa documenting and analyzing head contact events across all age divisions of minor hockey in Eastern Ontario (Chen et al., 2020; Karton et al., 2021; Post et al., 2019; Robidoux et al., 2020). Detailed methods and procedures for head contact identification and coding have been established by NISL, and head contact events are only confirmed following thorough video analysis. Head contact events are defined as the head sustaining clear contact with any external surface or object, with mechanisms

either being body parts (e.g. shoulder) or environmental playing surfaces (e.g. boards) (Post et al., 2019; Robidoux et al., 2020). Head impact verification followed a third-reviewer process, where two NISL research team members analyzed full gameplay footage, identified all suspected head impacts, and coded specific head impact criteria for each event. This was then verified by a senior researcher, who catalogued the head contact events and detailed event description criteria to be utilized for future research by the lab. Prior research by NISL has identified the increased risk of head contact events from body collisions in gameplay at the U15 and U18 levels of play, where bodychecking is permitted, in comparison to younger levels of non-bodychecking play (Karton et al., 2021; Robidoux et al., 2020). Specifically, head-to-shoulder and head-to-glass impacts are the most consequential to bodychecking actions, and are most frequently observed among U15, and U18 levels (Chen et al., 2020; Karton et al., 2021; Krbavac et al., 2024). Continued efforts by our research group have focused on gameplay characteristics specific to the youth competitive levels of hockey, to understand the risks youth players face in terms of head contact relative to the demands of bodychecking hockey. Therefore, this study employed a secondary video analysis from verified NISL head impact data at the U15 AAA competitive bodychecking level in Eastern Ontario – the AAA league was selected as it represents the top level of competitive hockey. In total 164 head impacts across 30 games were available for analysis.

Objective of Research & Exclusionary Criteria

The objective of this research was to identify and describe factors leading to head contact in bodychecking minor hockey, with the primary goal of determining if and how head contact can be prevented during bodychecking events. A bodychecking event was defined for this study as “an attempt by a player to gain an advantage on their opponent with the deliberate use of the

body" (Hockey Canada, 2022). This Hockey Canada rulebook definition also highlights a check may be the use of opposite-directional force, a player leaving their skating lane to make contact, and/or extension of arms, shoulders, or hips when making contact or angling the opponent (Hockey Canada, 2022). A descriptive video analysis approach was undertaken to evaluate bodychecking events, which meant removing any head contact event from the dataset that were not the result of a clear bodycheck. The primary researcher undertook a preliminary video analysis of the 164 verified head impacts, utilizing Kinovea© video software which allowed for frame-by-frame analysis of each head impact, with video clips including gameplay time preceding and following the head contact event. In total, 37 head contact events were excluded from the study as they were not related to bodychecking events: puck to head (7), high sticks (11), head impacts to goaltenders (5), punches to head (6), non-bodychecks or unintentional player collisions (6), and falls to ice (2). Punches to head were observed as non-bodychecking actions as all of these events occurred away from the puck during 'scrums'. Accordingly, following preliminary video analysis, 127 verified head impacts from the NISL dataset met the inclusion criteria for this study.

Inductive Risk Factor Analysis

A descriptive analytical design was used to help develop objective measures for analysis and identify contextual factors for head contact occurring during bodychecking events. As multiple stages of video analysis were required, the research followed an inductive methodological process. All steps of the analysis followed a third-reviewer process, whereby two experienced researchers were responsible with all stages of descriptive video analysis, while a third senior researcher helped with discussion and conceptualization at specific stages. For all stages employing video analysis, Kinovea© software was used for frame-by-frame examination,

and all video clips of verified head impacts included significant time of gameplay preceding and following the head contact occurring, permitting in-depth analysis of gameplay and situational factors. Three steps were taken for video analysis: 1) each event was analyzed, and specific gameplay details related to the bodycheck were coded (e.g. positioning, location on ice, location of puck, gaze/field of vision); 2) commonalities across event types were identified through a second round of video analysis and then were grouped; 3) qualitative details for each event were developed and coded to provide rich description of the categories observed.

Results

As research followed an inductive methodological process whereby multiple phases of descriptive video analysis were conducted, results are presented according to the different stages of analysis. First, the three categories of bodychecking events leading to head contact are presented and defined, followed by the frequencies of each category, and finally, a qualitative description to help characterize these categories. In total 127 verified head impacts were analyzed across 30 U15 games, for an average of ~4.2 bodychecking events leading to head contact per game.

Categories of Bodychecking Events leading to Head Contact & Analysis

Through the analytical process, the research team identified three main scenarios where bodychecks led to head contact and developed operational definitions for these categories.

Category 1: Head contact event was the result of a player being in a vulnerable position on the ice, and/or unprepared for ensuing bodycheck.

Category 2: Head contact event was the result of how the bodychecking technique was applied by an opponent. This category was further delineated into two sub-categories: 2a) improper technique, where head contact could have been prevented with better technical execution; and

2b) aggressive technique, where head contact occurs from an opponent executing a bodycheck to a player during a dangerous gameplay situation, and/or taking advantage of player in a vulnerable situation.

Category 3: Head contact event was the outcome of an executed hockey task, with no discernible preventative factor other than being the result of a bodycheck.

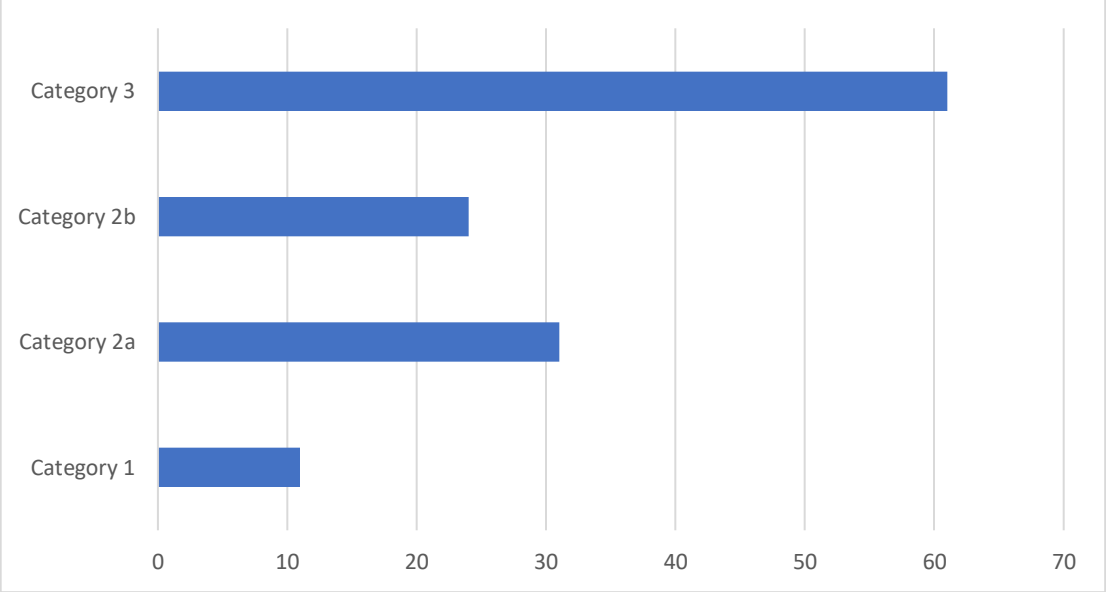

Figure 1. Frequency of each Category Observed in Analysis

11/127 head impacts were identified as Category 1, "Vulnerability/Positioning", representing ~9% of the total events. 31/127 head impacts were identified as Category 2a, "Poor technique execution", representing ~24% of the total events. 24/127 head impacts were identified as Category 2b, "Aggressive technique execution", representing ~19% of the total events. 61/127 head impacts were identified as Category 3, "executed hockey task", representing ~48% of the total events.

Descriptive Criteria of Bodychecking Event Categories

The most commonly observed descriptive criteria from analysis are as follows:

Category 1 Vulnerability/ Positioning	Poor balance, causing player to sustain head contact on a fall from bodycheck into teammates/opponents, or the environmental playing surfaces (ice, boards, glass)
	Player receiving head contact unprepared for contact with opponent based on gaze – player head down or looking elsewhere
	Player receiving head contact prepares body for bodycheck improperly based on assumed body position (lowers head, leads with head)
	Player does not brace for contact with opponent or surface
	Player skating with head down into ongoing play
	Player skating into gameplay situations where there are players already engaged in physical play which leads to unanticipated contact
Category 2a Poor technique execution	Execution of bodycheck with raised hands, shoulders and/or elbows that directly contact head
	Player receiving head contact often prepared for a bodycheck as they brace with the opponent, and/or the playing environment (boards/glass), but opponent delivers check with improper technique leading to head contact
	Player receiving head contact in low body position, lower their head, and/or skate with head down
	Plays where players use their hands instead of body to deliver check during one-on-one situations
Category 2b Aggressive technique execution	Execution of bodycheck with raised hands, shoulders and/or elbows that directly contact the head in an aggressive manner
	Player receiving head contact unprepared for contact with opponent based on gaze – checker comes from outside field of vision, or behind
	Player receiving head contact head down or lowers head to make a play on the puck while opponent executes check
	Opponent executes late bodycheck after the puck has been cleared by player (pass, shot, dump)
	Opponent takes advantage of player attempting to execute demands of play, which places them in positions of imposed vulnerability (head down, off-balance, turn away to play puck)
Category 3 Executed hockey task	Player receiving head contact often prepared for contact with opponent based on gaze
	Player receiving head contact often braces with opponent and/or surface
	Bodycheck frequently being used for intended purpose of puck separation or to impede progress of player
	Player prepares for bodycheck and receives head contact due to body position (lowers head, turns away from check, off balance)
	Players receiving head contact sometimes unprepared for bodycheck as they are executing demands of play with head down to play puck
	Player receiving head contact takes bodycheck in order to make a play
	Bodycheck most frequently occurs along the boards

Table 1. Most Commonly Observed Description of Bodychecking Events per Category

Our analysis identified that head impacts could be attributed to players being in vulnerable positions on the ice when receiving a bodycheck (~9%). In these events, players were unprepared to receive an impending bodycheck, which may have been due to balance, skating with head down, or skating into on-going play (e.g. physical puck battles). While our analysis indicated ~43% of head impacts were attributed to the technical execution of bodychecks, the two sub-categories differentiated how these events occur. Improper technique execution (~24%) comprised events where the head was often a primary point of contact, mostly due to the player

executing the bodycheck high on their opponent. This sub-category highlighted that players were frequently prepared for a bodycheck as the opponent was within their gaze, and the player braced for the check with the playing environment or the opponent. However, in limited cases head contact occurred as the player receiving the check assumed a low body position or skated with their head down. Conversely, in the aggressive technique execution category (~19%), players were often unprepared for a bodycheck, as checks came from outside the gaze of the player and the puck was often cleared from possession. Although the head was also a primary point of contact during these events, bodychecks were performed in an aggressive manner (beyond purpose of puck separation and defensive tactic), as players were taking advantage of an opportunity to apply maximal force to intimidate/injure the opposing player. Despite these results, nearly half of the head impacts observed in the study were the result of the bodychecking task being executed (~48%), which indicates that even when players appear to be prepared for contact or are executing hockey plays, head contact still occurs.

Discussion

This study set out to analyze the situational factors associated with bodychecks in gameplay causing head contact events to help determine how head impacts are occurring and if they could be prevented. Our analysis of 30 U15 AAA hockey games identified that ~77% (127/164) of head impacts occurred as a result of bodychecking. These results are similar to Aguiar and colleagues (2020) who found that 93% of head impacts across 33 games at the University level in British Columbia were the result of player-to-player collisions, with differences likely being due to the exclusion parameters of our study: non-bodychecking events, unintentional player collisions, punches to the head, and head impacts to goaltenders. These findings demonstrate that the inclusion of bodychecking within the sport poses significant risk

for head contact frequency, with ~48% of head contact observed in analysis being attributed to the execution of a bodychecking task. While some studies have used similar video observation methods to identify the circumstances of head impacts/or diagnosed concussion during player-to-player collisions (Aguiar et al., 2023; Aguiar et al., 2020; Hutchison et al., 2015; Mihalik et al., 2010a, 2010b), our research attempted to nuance our sample so that only bodychecking events were analyzed, with focus on the U15 level when bodychecking is first introduced. Bodychecks were chosen specifically in an attempt to address open-ended questions surrounding the vulnerability of players, their preparedness for contact, and their technical execution of bodychecking to understand if and how head contact may be prevented. While our descriptive analysis of U15 AAA hockey yielded similar results to other studies in terms of common mechanisms for head contact (head to glass, head to shoulder), and players not being in possession of the puck during bodychecks, our observations identified differences in location on the ice, as there was frequent head contact occurring during checks in "open ice" and near the boards, in comparison to a University level where "collisions" majorly occurred when a player was in contact with the boards (Aguiar et al., 2020; Aguiar et al., 2023). This finding may indicate significant differences in the style of play amongst minor versus more elite levels of hockey, as the puck is often pushed more to the perimeter of play, and further the unique risk(s) of head injury for players sustaining bodychecks in different locations on the ice. Future research is needed to better understand the relationship between the location of bodychecks on the ice during head contact events in terms of magnitude and frequency across different levels.

Our analysis revealed three categories of bodychecking events that led to head contact: 1) vulnerable for check; 2) applied technique during check; and 3) well executed hockey task. The descriptive observational design allowed for common criteria across the three categories to be

presented in an effort to determine the preventability of head contact occurring from bodychecks in gameplay. Although previous studies have similarly attempted to address players' anticipation for "collisions" using video observation methods to analyze gaze preceding and during the impact (Aguiar et al., 2023; Mihalik et al., 2010a), our analysis differed as multiple factors (including gaze) were considered (e.g. assumed body position of player, player braces for check with environment or opponent, relative location of puck to player) in an attempt to address if head impacts could be prevented. Based on our results, it could be postulated that more practice, knowledge, and coaching on giving and receiving bodychecks would benefit players in the vulnerable position and improper technique categories, as players could acquire the skills for appropriate positioning on ice, and to not raise hands, shoulders, or elbows when delivering checks. The aggressive technique execution category is more complex because of the culture of elite hockey that rewards players who can intimidate opponents by intentionally taking advantage of those in positions of imposed vulnerability based on the demands of the play, as parallel tasks are often being performed. Players often have certain responsibility to collect the puck and release it quickly, and as gameplay is fast paced, opponents can take advantage of players regardless of if they anticipate a bodycheck. In this category, head contact may be more preventable if there were changes to the culture of the sport and regulations that penalized contact for purposes other than puck separation, however, this is unlikely as these types of bodychecks are often seen as beneficial for team success (Loughead & Leith, 2001; Smith, 1975; Visek & Watson, 2005), especially amongst more elite levels of play. What is more disconcerting is that in the third category, which made up nearly half of the head contact events, head contact is not discernibly preventable from either better execution, skill development or rule changes.

The effectiveness of programs such as the NCCP four-step bodychecking model and modified contact rules in reducing the incidence of head impacts are relatively unknown and need to be monitored in terms of their uptake and effectiveness to identify if they can help prevent injury. Despite limited inquiry to date, recent research actually found there were more head impacts (despite at lower magnitudes) occurring in a modified contact league in Québec in comparison to a AAA league in Eastern Ontario (Krbavac et al., 2024). What is clear from our study and others is that the only proven way to significantly reduce head contact, and vis a vis injury, is to remove bodychecking entirely. However, this is unlikely under the high-performance specialized youth sports context that exists today, where young hockey players are encouraged to pursue their dreams of playing Junior, Collegiate and Professional levels of hockey, and governing bodies such as Hockey Canada are responsible for elite hockey development (Robidoux & Trudel, 2006). For this reason, it is highly improbable that bodychecking will be removed from minor hockey unless it is removed from the professional game. Thus, bodychecking will likely continue to exist in some capacity, with added pressures on organizations for balancing the development of elite talent while ensuring youth safety by limiting concussion and brain injury incidence.

Researchers have proposed further delays to introducing bodychecking in order to limit cumulative head trauma, not permitting checking until a minimum 15, or even, 18 years of age (Goulet & Beno, 2023; Tator et al., 2022). While this would decrease pediatric injury such as concussion, it would not lead to players being properly prepared for contact when bodychecking hockey is introduced and would likely lead to similar challenges around players positioning, vulnerability and technique. Additionally, this would cause certain logistical problems as players aged 16-20 can participate in Junior hockey, and any player who enters these levels with no

bodychecking experience would be at a certain risk for checking-related injuries. In the sport of rugby, a completely different approach is taken, where learning how to engage in contact, "wrap", and tackle an opponent are primary instructional tools taught to youth participants (Rugby Canada, 2022, 2023; USA Rugby, 2023). Rugby Canada and the NCCP have specific programs in place, such as "Tackle SMART", for coaches to implement training to newcomers (often at the High School level), safely introducing youth players to contact and tackling in an effort to reduce injury (Rugby Canada, 2023). Further, Rugby Canada completely delineates the process and timeline of when and how contact is introduced through a long-term athlete development plan, where amongst 9–10-year-olds early contact and lower-body tackling is permitted (Rugby Canada, 2022). This is not to equate the two sports but rather illustrates the need to properly prepare players to face body contact and checking if and when bodychecking is to be introduced. If bodychecking is to remain in minor hockey, stakeholders (governing bodies, coaches, parents) must ensure that youth players learn how to give and receive contact and are given the best opportunity to reduce head impact and/or any other form of injuries from occurring. Additionally, there should be certain instructional emphasis on puck separation instead of "aggressive" checking used for intimidation. However, these elements of the sport are taught as effective strategies to dominate an opponent and will be difficult to remove without potential changes in rules or enforcement.

Limitations

This study was reliant upon video analysis, with certain limitations in video capture. A single camera was used in head impact verification which had a broad view of the play while following the puck as opposed to other studies with multiple cameras (Aguiar et al., 2023), which may have limited some head impacts occurring outside of the camera's sight lines.

Additionally, the dataset analyzed only offers insight into one AAA competitive league at the U15 level. Future research is encouraged for other age groups, levels of play, and leagues to identify differences exist in the situational factors of bodychecks leading to head contact.

Conclusion

Recent research and interest on brain injury in youth sports, particularly concussion, have raised questions surrounding the risk of participating in contact sports, and added pressures on governing bodies to balance youth safety with developing talented athletes. While participation in bodychecking levels of minor hockey in Canada leads to increased injury and concussion rates for participants, few studies have addressed why and how these injuries occur through observational methods. The relationship between bodychecking and head injuries in minor hockey as demonstrated by numerous studies suggested that there was a need to analyze these contextual gameplay factors that cause injury. This study thus sought to address how and why bodychecking events in gameplay led to head contact in order to identify if head contact could be prevented. The descriptive observational video analysis from this study reflects a comprehensive review of how and why head contact occurs in U15 AAA bodychecking hockey. Our findings indicated that ~77% of head impacts were the result of bodychecking events, and across 30 games there were ~4.2 bodychecking events that caused/led to head contact. Through multiple phases of video analysis, common descriptive criteria helped develop three different categories of bodychecking events that led to head contact. While almost half of the head impacts were the result of players successfully executing a bodychecking task, ~9% were the result of players being in vulnerable positions on the ice, and ~43% were attributed to the applied technique during a check.

Although findings indicate that some head impacts can be prevented during bodychecks, this poses complex and multi-faceted questions surrounding how bodychecking is introduced in the sport. While introductory training programs and coaching related to bodychecking do exist and could potentially address player positioning, situational awareness, and technical ability in delivering and receiving contact, they are not standardized or monitored. Further, players more adept at playing with contact can utilize bodychecks aggressively to intimidate opponents. This study offers important perspectives about the introduction of bodychecking in youth hockey while highlighting how players are not given an optimal opportunity to acquire the skills required at this level to limit potential injury events. Further, this research provides an important contribution to understanding how bodychecking affects head contact occurrence in minor hockey and underscores the need for continued observational and descriptive research on contextual gameplay factors leading to injury. Although beyond the scope of this study, future research is warranted on identifying the utility of injury prevention measures such as the NCCP introduction to bodychecking 4-step model and modified contact leagues to help players acquire the skills necessary for bodychecking levels. While our results reveal that some head contact may be preventable during bodychecking events, prospective steps to mitigating injury are complex for stakeholders to ensure youth safety.

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Chapter VI: Conclusions

The overall purpose of this thesis was to understand how and why head contact occurs in minor competitive bodychecking hockey. With the composition of two articles (Chapters IV & V), discrete research questions guided the evaluation of contextual gameplay factors inherent to U15 and U18 AA/AAA hockey. Article one (Chapter IV) sought to identify if: 1) head contact events were the result of illegal or legal play based on the rules in place by Hockey Canada; and 2) if head contact events were the consequence of aggressive play, executed hockey tactics, or involuntary/unintentional play. Article two (Chapter V) employed an inductive analytical method to identify if head contact resulting from bodychecking events were potentially preventable as a result of technical execution, and/or player vulnerability. Collectively, these questions were addressed and constitute this thesis, which provides a nuanced analysis of head contact occurrence in minor hockey competitive bodychecking contexts. To provide closure, this final chapter will discuss: a) the gaps in previous hockey injury studies which were addressed, b) the justification for research across the specific levels explored, c) the "context" of the findings, d) future contributions, and e) limitations of the thesis.

Addressing the Gaps

The research methods and design of this thesis was used specifically to address certain limitations and gaps in previous minor hockey injury studies that were identified across the literature review. Notably, there were significant issues surrounding data collection and interpretation in previous research on youth hockey injury, related to retrospective and prospective designs. The research in this thesis offered a different direction and unique methodology by employing a descriptive observational video analysis. Rather than emphasizing rates of injury, particularly concussion injuries which are complex in diagnostics, assessment,

and reliability, head contact events were analyzed. By learning from previous research efforts, this thesis was able to contribute a nuanced understanding of how and why injury occurs.

As retrospective and prospective injury reporting systems have been explained, it is clear the purpose they serve in providing a vast audience with injury information specific to different sports. Across retrospective designs, large amounts of injury data can be amassed and assessed to understand local, regional and national injury trends that span multiple years and decades. Specific to youth hockey in Canada, retrospective research has identified the risk for injuries, notably concussion, in youth hockey, and the increased risk for injury from collisions or bodychecks (Cusimano et al., 2011; Macpherson et al., 2006; Kukaswadia et al., 2010). Although these large-scale datasets present trends which help point towards a direction of focus for injury in minor hockey, there are significant limitations that inhibit drawing clear conclusions. Due to how the injury data is submitted and collected, there is a lack of concise inclusion criteria and incomplete categories of injury mechanisms; further, only injuries of severity that require medical attention are included in retrospective designs which does not consider the full scope of injury and potential underreporting. To combat this, prospective designs have been increasingly used by researchers, placing emphasis on injury surveillance at the team and organizational levels. Although collection methods vary, prospective systems generally use smaller pools of primary data that are implemented prior to injury results being collected and interpreted, with researchers placing more emphasis on identifying specific injury details. In Canadian youth hockey, prospective designs have been used to identify the risk for concussion and head injury (Williamson & Goodman, 2006), which has helped corroborate injury trends that retrospective research has identified, specifically how bodychecking is a primary mechanism leading to injury (Darling et al., 2010; Emery & Meeuwisse, 2006; Willer et al., 2005). There are, however,

limitations with prospective designs. For example, studies are concerned with injury data for an entire league and/or provincial/regional branch, where designated team officials record injuries as opposed to researchers themselves due to the availability of resources. Additionally, researchers have indicated a likelihood for concussion underreporting at the team personnel and governing body levels (Emery et al., 2010; Williamson & Goodman, 2006). Therefore, although both retrospective and prospective designs have provided stakeholders with information surrounding the risk of concussion/head injury and bodychecking, there are certain gaps in identifying the true scope of head injuries in minor hockey.

Much of the emphasis in minor hockey injury research in Canada has evidently been placed on quantifying the risk(s) of injury, yet the question still remains whether or not these studies have actually yielded a comprehensive understanding of how injury occurs *in situ*. This query has led to an increased focus on descriptive observational and video analysis methods by researchers (Aguiar et al., 2020, 2023; Goulet et al., 2016; Hutchison et al., 2015; Mihalik et al., 2010a, 2010b; Williamson & Goodman, 2006), moving away from injury reporting and shifting towards understanding how and why injury occurs. Additionally, the literature review in this thesis highlighted the complexities of concussion diagnosis, assessment, and (under)reporting. This requires an alternative method for documenting a broader scope of head injury, analyzing head contact events rather than symptom-based reporting. Accordingly, researchers have been employing descriptive video analysis using verified head impacts as a measure representing injury risk (Aguiar et al., 2020, 2023; Mihalik et al., 2010a, 2010b), as any head contact event has the potential to result in short- or long-term brain injury. The use of game footage in video analysis also helps alleviate issues surrounding direct observation, as hockey is a fast-paced sport on a large ice surface with multiple players. By employing a descriptive observational video

analysis method of verified head impacts, the research presented in this thesis characterized contextual factors that led to head contact in gameplay. Although head contact is frequent in hockey, limited studies have attempted to describe how and why head contact occurs which identified a niche area for this study to address specific to bodychecking levels of minor hockey. Further, this research adds to previous studies using similar methods which have sought to identify if head contact was the result of penalties (Mihalik et al., 2010b), the intensity of physical contact being executed (Goulet et al., 2016), and player's anticipation for collisions (Aguiar et al., 2023; Mihalik et al., 2010a).

Narrowing the Scope

This thesis was concerned with analyzing the highest levels of minor competitive bodychecking hockey, which comprised both the U15 and U18 age groups. The purpose behind selecting these groups was largely due to bodychecking being the most common mechanism for injury, particularly concussions, in the sport (Cusimano et al., 2011; Emery & Meeuwisse, 2006; Goulet et al., 2015; Hagel et al., 2016; Kukaswadia et al., 2010; Toth et al., 2005). Further, players at these levels have acquired the fundamental athletic skills and are moving at higher speeds relative to younger age groups; this combined with bodychecking, higher stakes, and players attempting to progress their careers to the next level place U15 and U18 AA/AAA players at particular risk for injury. What is interesting, as explored through the two articles (Chapters IV & V), is how the game is characterized as aggressive and/or violent, especially at elite minor hockey levels that include bodychecking. Essentially, players at these levels learn how to play the sport in a specific way, often described as "Canadian hockey" (Robidoux & Trudel, 2006), which promotes their progress through competitive ranks with the anticipation of one day playing Junior, Collegiate, and/or Professional hockey. This has been countered by

efforts in promoting safety and reducing injury and debate about when bodychecking should be introduced, which was outlined in article two (Chapter V). This places the governing body at a crossroads for mitigating injury while also developing "elite" players to be the best they can be.

Across this thesis, this balancing act required by Hockey Canada to develop "elite" youth players while ensuring player safety has been identified. Based on the evidence of the research conducted across the two articles (Chapters IV/V) and what was highlighted in the thesis introduction, Hockey Canada, and other stakeholders have opportunities to help reduce head contact and injury from occurring. First, there should be increased emphasis on the protection of head contact via stricter enforcement of the head contact rule. This rule was introduced in the 2011/12 season in an effort to reduce head injuries in minor hockey, and although our analysis in article one (Chapter IV) revealed that this was the most common penalty, it clearly was not a deterrent for player behaviour as it continually occurred. There are multiple components at play here, as head contact between two opposing players can evidently happen by accident (e.g. errant high stick, skating into opponents), however, the analysis in this study was focused on an external verbatim interpretation of the rulebook and not the call on the ice by officials/referees. Although beyond the scope of the analysis, there were a variety of instances observed where plays that should have resulted in head contact penalties were not being assessed by the referee on the ice. The parameters of the study and use of frame-by-frame video analysis clearly was advantageous versus an on-ice official having to make a call in a fast-paced sport. If there was greater rule enforcement and adherence to the rules, it should lead to a reduction of head contact events. Officials would likely benefit from increased practice, instruction and video sessions from governing bodies and stakeholders to ensure this penalty is being called more frequently

and is being assessed the appropriate severity (e.g. minor, double minor, major and game misconduct).

A second opportunity for injury mitigation is to reduce and/or eliminate aggressive and dangerous play for the sake of competitive advantage. Hockey Canada recently revised their organizational purpose, mission, vision and values on "a journey towards a healthier hockey environment" (Hockey Canada, 2025). Although it is well known that physical domination can be a strategy for success, the two articles in this thesis (Chapters IV/V) reveal that aggressive play only constitutes a minor part of youth bodychecking hockey, and minor hockey overall should not be characterized as an aggressive and violent sport as often associated with the National Hockey League and other professional levels. While 'Excellence' and 'Ambition' are understandably core values in Hockey Canada's effort to maintain their top standards in performance on the global and professional stages, how the game is being coached and played at "elite" youth levels should fully embrace providing safe experiences for participants. While a physically dominant style of play may be difficult to remove from levels of the sport that include bodychecking, the primary focus of bodychecking instruction from coaches and other stakeholders should be puck separation and player safety. In doing so there will be increased attention to details that can provide safe and fun experiences for youth participants, reducing unnecessary and dangerous play, and holding players accountable for any intentional or unintentional contact to the head. That is to say, while skill development should continue to be a point of emphasis for Hockey Canada in pursuit of success, this should not take priority over the safety of youth participants.

Providing Context & Implications

The findings from this thesis underscore the importance of understanding how injuries occur within gameplay, which must take into consideration game tactics and styles of play. In article one (Chapter IV), I attempted to describe what is meant by aggression in hockey, specifically how it can be understood as a learned behaviour, and issues in establishing sport specific definitions. From this contextual base and previous research efforts, a novel methodology was undertaken to establish four contextual definitions of aggressive and non-aggressive gameplay behaviours. While this helped identify how the game is played at this level, the types of physical contact that may occur, and situations leading to head contact, it was also explained relative to the frequency of rule infractions based on the regulatory framework. It should also be underscored that the novel methods and analytical procedures established in this article is replicable, and further research using the third-reviewer process to assess head contact events, aggressive behaviour and rule transgressions would be important to provide more detailed and effective injury mitigation measures. This study identified that although the majority of head contacts were the result of non-aggressive and legal play, the rules in place do not help prevent head contact from occurring.

In article two (Chapter V), the nuances of bodychecking in minor hockey were explained, including seminal research studies that led to changes in when bodychecking is introduced at the U15 level. Further, the distinctions between bodychecking and non-bodychecking hockey were established, the discourse amongst when bodychecking is introduced was explained, and current injury prevention measures offered in minor hockey explained. While this article sought to understand why head contact occurred during bodychecking events, categories related to player vulnerability and technique identified that some head contact could be prevented in gameplay.

However, with having explained potential injury prevention measures, excluding the removal of bodychecking entirely, it was identified that not enough is being done to prepare youth players for the demands of bodychecking hockey and that if bodychecking is to be included at this level, head contact will continue to occur as a result of executed game tasks.

Contribution(s) for the Future

While the research across this thesis effectively described how head contact occurs in a minor competitive bodychecking hockey context, it certainly does not solve the main issue which is reducing head contact in the sport. Findings from both articles note that the majority of head contact occurs as a result of executed gameplay tasks, which are inherently frequent due to the inclusion bodychecking. Although head contact occurs across all levels of play in minor hockey (Karton et al., 2021), the risk for the U15 and U18 levels analyzed in this study were of ample severity to be studied for a myriad of factors. Despite finding out that head contact occurs frequently across these levels, and explanations as to how and why they occur, this accentuates the difficult task for stakeholders in the sport to balance competitive player development and player safety. While it is unlikely that bodychecking will be removed from minor hockey unless it is taken away from the professional game, both articles identified that future steps for stakeholders to reduce head contact must consider at least one of the following: the enforcement and uptake of introducing youth players to bodychecking fundamentals (tactics and technique), some degree of change in rules/enforcement, and/or changes in playing style and the culture of the sport.

Limitations

The research in this thesis was focused on providing a rich contextual understanding of how and why head contact occurs in gameplay. Due to this, there are evident limitations in the

volume of games and head contacts observed that have guided our results and interpretations. Although further research using similar methods could support the findings of this research, it should be noted that the studies (Chapters IV & V) only depict minor competitive bodychecking hockey in Eastern Ontario and should not be considered representative of all minor hockey across Canada. This research was also reliant on video capture of verified head impacts collected by NISL, with which there are some limitations. Across our game film only one camera was used which attempted to hold a broad view of the play sequence while following the puck and maintaining view of players directly involved in the play. Although all of the head impacts analyzed in this study occurred within the sight lines of camera and central to the focus of gameplay, multiple cameras may have yielded more head impacts occurring away from the puck to other players on the ice. This thesis supports further studies to evaluate aggression, penalties, player vulnerability, preparedness, and technique in relation to head contact across different levels and regions to help identify if steps can be taken by stakeholders for injury prevention.

Summary

As increased scientific and public attention has recognized the risk for paediatric head injury in youth sports such as hockey, pressures on key stakeholders to help mitigate these types of injures have been intensified, while maintaining a focus on developing youth talent. For Canadian minor hockey, this has only intensified discourse surrounding a tradition of the sport, bodychecking. While the inclusion of bodychecking certainly increases the risk of injury, researchers have increasingly called for it to be delayed further (Goulet & Beno, 2023; Tator et al., 2022), or to be removed from youth levels entirely in order to reduce injuries, particularly concussion. This has led to increased academic attention across youth levels of hockey where bodychecking is permitted. This thesis provides insight and analysis across these contexts, by

analyzing head contact events in minor competitive bodychecking hockey at the U15 and U18 levels of play. Across this thesis, contextual gameplay factors which led to head contact were addressed in order to provide a better understanding of how and why these types of injury occur. This has helped shift emphasis away from the rates and frequency of injury in order to assist and provide decision makers with understandings of the gameplay factors that influence injuries occurring *in situ*. While this research does not claim to solve the issue of reducing head contact frequency, it does make important contributions about how and why head contact happens in gameplay which can be utilized for future injury prevention efforts.

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Appendix A

Trauma profile event description spreadsh

Start Game Time: 0:00:00:00
End Game Time:

NISL Researcher:
Level of Play:
Total Game Time:

Estimated velocity:
very low = 0 - 2 m/s
Low = 2 - 4m/s
Medium = 4 - 6m/s
high = 6 - 8m/s
Very High = 8 m/s +

Head impact definitions
(only answer one of these when filling out chart)

Impact confirmed = can see head contact + Event mechanism creating the impact
Impact suspected = cannot see head contact necessarily but are pretty sure it occurred given the

Video Name	Time of Impact Game	Time of Impact Clip	Clip code: Division-Level-Category-Game#-Initials-Reviewer#-Clip#	Team Colour	Jersey Number	Player Position	Event Type	Location of Impact	Estimated Closing Velocity	Placement	Boards Anvil	Confirmed or Suspected	Situational Factor
U18-AAA-Y-GAME	0:56:35:7	0:00:03:13	U18-AAA-Y-GAME1-SL-1-3	White	39	Forward	head to shoulder	Side	Very Low	center		Confirmed	body collision
	1:05:52:2	0:00:03:37	U18-AAA-Y-GAME1-SL-1-6	White	50	Center	other	Side	Very Low	center		Confirmed	body collision
	1:16:09:8	0:00:02:98	U18-AAA-Y-GAME1-SL-1-9	Black		Goalie	puck	Front	High	center		Confirmed	hit by puck
	1:54:37:3	0:00:03:41	U18-AAA-Y-GAME1-SL-1-14	Black	14	Defenseman	head to ice	Rear	Very Low	center		Confirmed	unaided fall to ice
	2:03:26:6	0.189583	U18-AAA-Y-GAME 1-PD-2-29	bLACK	16	Forward	head to ice	Rear	Low	center		Confirmed	unaided fall to ice
U18-AAA-Y-GAME	0:47:41:0	0:00:02:29	U18-AAA-Y-GAME2-SL-1-3	White	7	Forward	head to shoulder	Side	Low	below		Confirmed	body collision
	0:47:57:4	0:00:02:97	U18-AAA-Y-GAME2-SL-1-4	White	12	Forward	head to shoulder	Side	Very Low	center		Confirmed	body collision
	0:47:57:4	0:00:03:09	U18-AAA-Y-GAME2-SL-1-4	Red	52	Forward	head to head	Front	Very Low	below		Confirmed	body collision
	0:47:57:4	0:00:03:09	U18-AAA-Y-GAME2-SL-1-4	White	12	Forward	head to head	Side	Very Low	above		Confirmed	body collision
	1:15:16:4	0:00:03:80	U18-AAA-Y-GAME2-SL-1-10	White	21	Forward	head to boards	Crown	Low		flat	Confirmed	body collision to boards/glass
U18-AAA-Y-GAME	0:10:20:4	0:00:02:68	U18-AAA-Y-GAME3-SL-1-2	Red	18	Forward	other	Side	Low	above		Confirmed	hit by stick
	0:32:27:0	0:00:03:15	U18-AAA-Y-GAME3-SL-1-4	Red	55	Defenseman	other	Side	Low	center		Confirmed	body collision
	1:09:32:0	0:00:02:60	U18-AAA-Y-GAME3-SL-1-8	Red	21	Forward	other	Front Boss	Low	below		Confirmed	hit by stick
	1:10:19:0	0:00:08:21	U18-AAA-Y-GAME3-SL-1-9	Red	89	Forward	head to ice	Rear Boss	Low	center		Confirmed	body collision to ice
U18-AAA-Y-GAME	1:09:21:0	0:00:02:27	U18-AAA-Y-GAME4-SL-1-6	Black	27	Center	head to elbow	Side	Very Low	below		Confirmed	body collision
	1:56:19:1	0:00:04:07	U18-AAA-Y-GAME4-SL-1-10	Black	9	Forward	head to shoulder	Front	Low	center		Confirmed	body collision
U18-AAA-Y-GAME	1:06:41:1	0:00:03:05	U18-AAA-Y-GAME5-SL-1-2	Blue	22	Forward	other	Side	Very Low	above		Confirmed	body collision
	1:18:58:1	0:00:03:17	U18-AAA-Y-GAME5-SL-1-3	White	46	Defenseman	other	Front	Low	below		Confirmed	hit by stick
	1:23:22:5	0:00:04:33	U18-AAA-Y-GAME5-SL-1-4	White	44	Forward	head to ice	Front	Low	below		Confirmed	body collision to ice
	1:31:30:3	0:00:03:52	U18-AAA-Y-GAME5-SL-1-6	White	44	Forward	head to glass	Rear	Very Low	center		Confirmed	body collision to boards/glass
	1:37:05:0	0:00:04:53	U18-AAA-Y-GAME5-SL-1-7	Blue	89	Forward	head to glass	Side	Very Low	center		Confirmed	body collision to boards/glass
	2:10:32:8	0:00:03:61	U18-AAA-Y-GAME5-SL-1-9	Blue	64	Forward	head to glove	Front Boss	Very Low	below		Confirmed	punch/fight

Example of Head Impact Criteria Coded in a NISL Spreadsheet