2023-03-08

Whistleblowing the whistleblower - are head contact penalties a target for injury prevention in youth and university basketball?

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Whistleblowing the whistleblower- are head contact penalties a target for injury prevention in youth and university basketball?

by

Christy Fehr

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

GRADUATE PROGRAM IN KINESIOLOGY

CALGARY, ALBERTA

MARCH, 2023

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Abstract

This thesis contains two original data papers, both using video analysis to determine incidence of head contacts (HCs), suspected concussion and injury, and other important factors contributing to injury outcomes in basketball. The first study focuses on male and female university level basketball players competing in the 2019/2020 regular season. Video analysis was used to compare the incidence of suspected concussion, injury, and HCs (both direct, [HC1], and indirect [HC2]). Further, we assessed proportions of these outcomes that occurred by game event, as well as court location and penalization of HCs. Our main finding from this study was males sustained HC1s at a 1.55-fold greater rate than females. Despite illegality of HC in basketball competition, we revealed an astonishingly low proportion of HCs were assessed as a foul by referees. The second study assessed the same research question with the same objectives but was focused on a youth demographic. We divided games into divisions (Division 1 and Division 2) for a more like comparison concerning age and skill level. We found no statistically significant sex differences in our study outcomes in Division 1, however, Division 2 boys sustained HC1s at a 1.42-fold greater rate than females in Division 2. Although most of our rates were not statistically different between sexes, our point estimates do warrant concern regarding our injury outcomes for youth in both Divisions. Common to both studies, the ‘key’ was the most common court location for sustaining HCs. Game events varied by sex within each study, but commonly reported for sustaining HCs was the act of rebounding both offensively and defensively. Overall, these studies highlight potential sex differences that may exist when assessing HCs, suspected concussion and injury, and the need for targeting stricter penalization of HCs in competition.

Keywords: basketball, video-analysis, female, male, youth, university, concussion, injury
Preface

Information presented in this thesis is part of a larger study called Surveillance in High Schools and Community Sport to Reduce Concussions and its Consequences (SHRed Concussions), a large longitudinal cohort study covering multiple cities across Canada. Ethics approval for these studies was obtained through the University of Calgary Conjoint Health Research Ethics Board (CHREB) (Ethics ID: REB21-1249).


Chapter 4 of this thesis will be submitted in February of 2023, as Fehr, C., West, S., Hagel, B., Goulet, C., Emery, C.A., “Head contacts and suspected concussion rates in youth basketball: Time to target head contact penalties for prevention.” Clinical Journal of Sports Medicine.
Acknowledgements

I would like to acknowledge my supervisor, Dr. Carolyn Emery, for supporting my projects, and providing a clear direction and feedback throughout my master’s degree. Thank you for your time reading, editing, and providing feedback to me, even when I push timelines to their limits. Your commitment to the prevention of injury and concussion in youth through evidence-based approaches is inspiring and continues to fuel my desire to stay involved in sport.

I would like to thank both Dr. Brent Hagel and Dr. Claude Goulet for being on my supervisory committee and providing feedback that has been critical to the success of this thesis. Your time and dedication to not only your own work, but mine, has not gone unnoticed.

I would like to thank Dr. Stephen West for giving up hours of time to providing guidance throughout this degree through a series of weekly meetings. I would not be in the position I am now without your support and generosity of time. You have challenged me to be a better researcher and I am ceaselessly grateful for you as a member of this committee.

I would like to thank Dr. Tracey Covassin for being my external examiner during my thesis examination. I admire your work and dedication to the sport of basketball in your research, and I look forward to reading high-quality literature you continue to put together.

I would lastly like to acknowledge everyone who is a part of the SHRed study; research assistants, my fellow master’s students, PhD students/candidates, postdoctoral fellows, and the primary investigators, your dedication to preventing concussion will impact generations to come.
Dedication

I would like to primarily dedicate this thesis to my stepmom, Desiree, who we lost very suddenly last summer. A hole remains in my heart knowing that you will not get to witness my graduation this year, and words cannot express how much I miss you. I would like you to know how your words of encouragement play over and over in my head on my worst days. Your passion for seeing me succeed continues to be a driving force in my life. Thank you for always supporting my sisters and I both athletically and academically over the years. I wait with great anticipation for the day I see you again.

I would also like to dedicate this thesis to my parents, Rae, and Laura. For your endless support and encouragement throughout my academic and athletic career and providing a spark when I needed it most. Thank you for never questioning my goals, and meeting each conversation of past, present, and future with a smile.

I would like to dedicate this thesis as well to my sisters, Brianna, and Gracee. Your competitive natures have fueled me in every aspect of my life. I am so lucky to be surrounded by your love and empathy. Both of your desires to excel both in academics and athletics has pushed me to be where I am today. I am so lucky to be your sister. Thank you for all that you do for me.
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List of Symbols, Abbreviations and Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE</td>
<td>Athlete exposure</td>
</tr>
<tr>
<td>CHREB</td>
<td>University of Calgary Conjoint Health Research Ethics Board</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>CR</td>
<td>Concussion rate</td>
</tr>
<tr>
<td>Division 1</td>
<td>U18 and U17</td>
</tr>
<tr>
<td>Division 2</td>
<td>U16 and U17</td>
</tr>
<tr>
<td>HC</td>
<td>Head contact</td>
</tr>
<tr>
<td>HC1</td>
<td>Direct head contact</td>
</tr>
<tr>
<td>HC2</td>
<td>Indirect head contact</td>
</tr>
<tr>
<td>IPR</td>
<td>Injury proportion ratio</td>
</tr>
<tr>
<td>IR</td>
<td>Incidence rate</td>
</tr>
<tr>
<td>IRR</td>
<td>Incidence rate ratio</td>
</tr>
<tr>
<td>NCAA</td>
<td>National Collegiate Athletic Association</td>
</tr>
<tr>
<td>NBA</td>
<td>National Basketball Association</td>
</tr>
<tr>
<td>NFL</td>
<td>National Football League</td>
</tr>
<tr>
<td>NMT</td>
<td>Neuromuscular training program</td>
</tr>
<tr>
<td>PC</td>
<td>Physical contact</td>
</tr>
<tr>
<td>PR</td>
<td>Proportion ratio</td>
</tr>
<tr>
<td>RA</td>
<td>Research assistant</td>
</tr>
<tr>
<td>SD</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>SHRed Concussions</td>
<td>Surveillance in High Schools and Community Sports to Reduce Concussion and its Consequences</td>
</tr>
<tr>
<td>SRC</td>
<td>Sport-related concussion</td>
</tr>
<tr>
<td>TRIPP</td>
<td>Translating Research into Injury Prevention Practice</td>
</tr>
<tr>
<td>USport</td>
<td>Canadian University Sport</td>
</tr>
<tr>
<td>U16</td>
<td>Under-16 (ages 14-15)</td>
</tr>
<tr>
<td>U17</td>
<td>Under-17 (ages 15-16)</td>
</tr>
<tr>
<td>U18</td>
<td>Under-18 (ages 16-17)</td>
</tr>
<tr>
<td>WNBA</td>
<td>Women’s National Basketball Association</td>
</tr>
</tbody>
</table>

* Exceptions include players younger than their respective divisions and playing up, not determinable for analyses due to anonymity of video analysis.
Chapter 1: Introduction

1.1 Research Purpose

Physical activity is critical for maintaining optimal physical and mental health in addition to other psychosocial benefits. Basketball continues to be one of the most popular sports of choice amongst youth and adult populations, with 28.4% of junior high school students in Calgary, Alberta reporting basketball amongst their top 3 sports for participation. Further, basketball ranked first for sport participation in males, and was second to dance in females in a high school survey of 2,209 Alberta students. Further, an estimated 16,090 students participated in university basketball in the United States in 2021. High participation levels in sport conversely increase the opportunity for injury, with an estimated 14% of all sports-related injury in Canadian high schools occurring in basketball. There is limited research assessing incidence of head contacts (HCs) and concussion in Canadian basketball players, specifically at the youth level despite high participation levels. Basketball, played with the same rules for both males and females, provides the opportunity to assess potential sex differences that have been reported previously regarding concussion and injury outcomes. Sport-related concussion (SRC) in basketball has been identified as a common injury for both youth and university level players; and differences in SRC rates by sex have been reported. A greater understanding of concussion and injury rates in basketball is critical to informing the safety of basketball and lifelong sport participation for both youth and higher level players. Further, identifying key game events, court location of HCs, and penalization of HCs will develop a greater understanding of when and where players may be at higher risk for sustaining HCs and injury outcomes in competition.
1.2 Background

Injury prevention has been long informed by models that outline determinants and aetiology of sport injury. The van Mechelen injury prevention model, for example, continues to be used as the primary model for assessing injury in sport, outlining four steps to prevent sport injury, known as the ‘sequence of prevention.’ The first step in this model is to identify and describe the extent of the problem. Second is to identify factors and mechanisms that play a part in a sports injury. Third, is to introduce prevention measures that attempt to reduce future risk and or severity of the injury, and lastly, prevention strategies implemented need to be assessed by repeating the first step. Another model commonly used in injury prevention is the ‘Translating Research into Injury Prevention Practice’ (TRIPP) model. The TRIPP model emphasizes a similar injury prevention sequence with six proposed stages. The first step is to use injury surveillance to understand the extent of an injury. Second, to establish aetiology and mechanisms of injury. Third, to introduce a preventative measure. Fourth, to evaluate the measure in ideal conditions. Fifth, to describe the intervention context to inform implementation strategies, and lastly, to evaluate the effectiveness of the prevention strategy. Both van Mechelen’s model and the TRIPP model have similar objectives, which is to identify a sport injury problem and ultimately develop effective prevention strategies that can be accepted across all levels in all sports.

Basketball is a court-sport played with a total of 10 individuals on the court at one time, with 5 players per team. The game is played over a total time of 40 minutes of ball-in-play, often divided into 4, 10-minute quarters. Rules for male and female competition are the same.

Basketball literature has identified concussion as a common injury amongst higher level, or professional athletes, specifically males, (e.g., National Basketball Association or NBA, or the
National Collegiate Athletics Association or NCAA). Therefore, it is imperative that research assessing concussion in basketball broadens to the youth context with greater inclusion of females. The studies outlined in this thesis will highlight the first step of both the van Mechelen and TRIPP models, where a greater understanding of concussion, injury, and HCs is required at both the university and youth levels to determine effective injury prevention strategies. Although the TRIPP model emphasizes use of injury surveillance, we analysed our study outcomes using video analysis to establish the extent of concussion and HCs in basketball, along with identifying factors that may play a part in a player’s risk of concussion or for sustaining these outcomes, (specific game events, court location, and penalization of HCs by game referees). These studies should be used to inform future injury analysis using injury surveillance to verify suspected concussion and injury on film.

1.3 Research Questions and Objectives

This thesis is composed of two individual original data studies with focus on two different age groups. The first analysis was completed in university athletes (Project A) and was used to inform the second study, which answered identical research questions, in a youth demographic (Project B).

1.3.1 Project A: Video analysis in university level male and female basketball players

1.3.1.1 Primary objective

1) To compare the incidence of HCs and suspected concussion and injury rates in male and female university basketball players.

1.3.1.2 Secondary objectives

1) To assess HCs associated with a foul in competition.
2) To identify additional factors associated with suspected concussion, injury, and HCs, such as specific game events, court location, and the associated intensity of physical contact (PC).

1.3.2 Project B: Video analysis in youth level boys’ and girls’ basketball players

1.3.2.1 Primary objective

1) To compare the incidence of HCs and suspected concussion and injury rates in boys’ and girls’ youth basketball players.

1.3.1.2 Secondary objectives

1) To assess the penalization of HCs in competition.

2) To identify additional factors associated with suspected concussion, injury, and HCs, such as specific game events, court location, and the associated intensity of physical contact (PC).

1.4 Research Rationale

There is limited research assessing concussion, injury and HCs rates in Canadian university and youth basketball players, despite high participation and injury rates. A greater understanding of injury, specifically concussion, is needed in this demographic to inform safety in the sport to keep players healthy and participating for longer. Consequently, identifying factors that may increase an athlete’s likelihood of concussion and injury should inform future prevention strategies for safer play. Keeping athletes in sport for longer should be the goal of injury prevention research, to not only provide individuals with physical activity benefits, but to maintain these benefits over time. Kids who participate in sport in their youth are more likely to be physically active into adulthood, which highlights the importance of safe play and reducing injury and concussion in this age group to ensure lifelong health. Further, sex-tailored strategies to keeping athletes playing sports longer should be considered, as differences may exist when assessing injury and concussion outcomes.
Video analysis has been previously used to assess injury outcomes in sport\textsuperscript{13–18} often complementing injury surveillance or sensor data to validate outcomes. For the purposes of beginning to understand a sport injury problem, video analysis is a useful tool for identifying several factors that should be considered when using injury surveillance and considering game events potentially associated with injury.

\textbf{1.5 Summary of Thesis Format}

Chapter 1 of this thesis serves as an introduction to basketball as a popular, high participation sport amongst several age groups, specifically, university level players and youth in Canada. Basketball competition formatting is outlined, as well as study rationale with focus on preventing concussion and injury moving forward. Chapter 2 is a literature review, highlighting concussion and injury rates in basketball at both the university and youth levels and how this research fills current gaps in injury prevention literature. Chapter 3 introduces Project A: Video analysis to compare incidence of HCs, suspected concussion and injury in university male and female basketball players, a manuscript style paper used to inform the youth analysis covered in Chapter 4. Chapter 4 introduces the second original data paper of this thesis, video analysis comparing HCs, suspected concussion and injury in youth boys’ and girls’ basketball players, which is also a manuscript style paper. Both original data chapters also seek to compared additional factors that may contribute to a player’s risk of injury, including game events, court location, and penalization of HCs and injury outcomes. Chapter 5 is the conclusion chapter, with a summary of results from both Chapters 3 and 4, including strengths and limitations of these studies, and future directions for research in basketball injury.
Chapter 2: Literature Review

2.1 Introduction

Sport participation rates in Canadian youth are high, with an estimated 86.9% of 2,029 youth in Alberta reporting participation in a sport or recreational activity in the previous year. A similar study found that 43% of young adolescents (12-15 years) and 35% of older adolescents (16-21 years) participated in organized sports at least once per week. Participation in sport amongst youth provides numerous benefits such as improved physical fitness, social connectivity through team sport, as well as psychosocial and mental health improvements. Basketball continues to be one of the most popular sports for youth in Canada, with 28.4% of junior high school students reporting basketball amongst their top three sports for participation. Basketball ranked first for males in Alberta high school students and was second to dance for females. Basketball is a team game that requires the integration of both individual and team skill. It is played with 10 people on the floor at one time – 5 per team in a formal competition setting. With high rates of youth sport participation, specifically in basketball, the opportunity for injury is also high. In 2009-2010, nearly 66% of injuries among Canadian adolescents were sport-related. Specifically, basketball represented the sport with the greatest proportion of “most serious” injuries representing 14% of all reported sport-related injuries in Canadian junior high school participants. Sport-related concussion (SRC) in basketball has been identified as a common injury for both male and female youth players, with one study reporting a competition concussion rate of 0.74 per 1000 athlete exposures (AEs); (95% CI: 0.66-0.82) over 11 seasons in high school girls, and a competition rate of 0.33 per 1000 AEs; (95% CI: 0.28-0.37) in boys. This was the second highest reported injury rate behind ligament sprains for both sexes in competition. Further, rates of concussion and head impacts in youth basketball have been
compared to those in collision sports such as lacrosse and football,\textsuperscript{22-24} which highlights concern for safety of young athletes and the need for prevention strategies that reduce head impacts and concussion in basketball.

Considering consistently reported differences regarding concussion in boys and girls,\textsuperscript{5,6,9,10,25} further examining injury and concussion rates in basketball is critical to increasing the safety of the sport, as well as understanding the aetiology surrounding SRC and injury for keeping athletes healthy and playing their sport longer.

\textbf{2.1.1 Definitions}

\textit{2.1.1.1 Concussion}

Many sports organizations such as the National Basketball Association (NBA),\textsuperscript{26} National Collegiate Athletics Association (NCAA),\textsuperscript{27} and Canada’s USports\textsuperscript{28} have adopted the concussion definition from the most recently published 2016 Consensus Statement on Concussion in Sport, which defines SRC as, “a traumatic brain injury induced by biomechanical forces.”\textsuperscript{29} There are a number of sub-identifiers that have additionally been characterized in the consensus statement, such as, “a direct blow to the head, face, neck, or elsewhere on the body with an impulsive force transmitted to the head”, and potential “neuropathological changes, impairment of neurological function.”\textsuperscript{29} When identifying suspected concussion through video-analysis, 17 criteria previously used in professional sports settings and validated based on expert consensus were used.\textsuperscript{30} The criteria include motor incoordination, lying motionless, no protective action- floppy (ragdoll-like), no protective action- tonic (falling stiff), cervical hypotonia, impact seizure/convulsion, tonic posturing, blank or vacant look, uncontrolled/controlled fall to the ground (following indentified HC), dazed, slow to get up, clutching at the head, walking away/disengaged from the game, disorientation, confusion, and facial injury.\textsuperscript{30} Further, about
half of these criteria were identified as most shared amongst all sports; however, a more liberal approach was taken in our study due to lack of video analysis in basketball for identifying concussion, and therefore, a player needed to meet only one of the aforementioned criteria to be deemed a suspected concussion.

2.1.1.2 Injury

Injury is a common experience in sport that many athletes have come to understand. It has been agreed upon by experts that researchers match their choice of definition to the context in which it is relevant. For example, the consensus statement on injury definitions and data collection procedures defines injury as, “any physical complaint sustained by a player that results from training or matches, irrespective of the need for medical attention or time loss from activities.” This injury definition has previously been used for data collection procedures in soccer and football, and in the context of our study, sport-specific considerations regarding video analysis data are important. Therefore, validated criteria developed in professional and non-professional sports leagues to identify non-concussive injury were used. Suspected non-concussive injuries identified on film, as validated in soccer, were verified using 4 criteria including: referee interrupted play for injury, a player remained on the ground for 15 seconds or longer, the player appeared to be in pain, or the player received medical attention. If a player met at least one of the previous criteria, a non-concussive injury was coded. Criteria used for analysis are effective for identifying injury outcomes as all criteria can be observed on video.

2.1.1.3 Physical Contact (PC)

Physical contacts (PCs) in basketball on video have not been previously assessed, but have been assessed in Canadian ice hockey and ringette, which divided PCs into categories including; limb, trunk, and stick. Similar criteria were adapted and validated for use in these studies,
which included the use of limb and trunk categories as appropriate for a basketball context. Unlike for ice hockey and ringette studies, all PCs were rated on a scale from 1 to 3 with increasing intensity, rather than 1 to 5 in a collision sport where body checking was classified as level 4 and 5. This decision was made based on feedback from content validation by experts that determined distinguishing certain contact intensities may prove difficult, (e.g., distinguishing a ‘2’ contact versus a ‘3’). Consequently, 1 was defined as a “mild” contact, 2 as a “moderate” contact, and 3 as a “severe” contact. (Table 2.1).

Table 2.1 Description of trunk and limb contact intensities, as adapted from Williamson et al.\textsuperscript{14}

<table>
<thead>
<tr>
<th>Trunk/Limb physical contact (PC)</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1 (‘Mild’)</strong></td>
<td>Inconsequential contact. Contact is visible but did not affect a player’s ability to execute their skill.</td>
</tr>
<tr>
<td><strong>Level 2 (‘Moderate’)</strong></td>
<td>Contact apparent, and execution of skill is affected in a way that the player was visibly disrupted, with consequence (arms were slapped, legs were taken out, body was pushed off direct line course, as examples).</td>
</tr>
<tr>
<td><strong>Level 3 (‘Severe’)</strong></td>
<td>Contact is visible and overly aggressive. Player receiving/initiating contact is obviously unable to execute their skill, with evident consequence (injury, falling over, flagrant foul, as examples).</td>
</tr>
</tbody>
</table>

Notes. This rating scale was face-validated by basketball community partners, administrators, players, coaches, and one team Canada video analyst.

2.1.1.2 Injury Incidence Rates in Basketball

Injury incidence rates (IR) are often expressed in sport injury literature with consideration of exposure (athlete exposures or athlete participation hours) as the denominator.\textsuperscript{6,36} Basketball is played for a total of 40 minutes, split into four 10-minute quarters. Since the total time of ball in play (40 minutes) remains consistent across basketball literature, it is possible to report injury
IRs per player-minutes\textsuperscript{37} using presumptive knowledge of ball in play time via anonymous video analysis data.

\textbf{2.1.1.3 Head Contact in Basketball}

In basketball, player-to-player head contact is an illegal act and is to be called by a referee as a personal foul against whomever initiated the HC. These fouls are associated with an HC that has been initiated via a limb or trunk contact, which excludes contact that may occur as head-to-head. Exceptions include excessive swinging of the elbows, which referees are permitted to call a flagrant foul.\textsuperscript{38} Flagrant fouls in basketball result in the opposing team shooting foul shots and regaining possession of the ball, which is a significant consequence in competition. A player with two flagrant fouls in one game is to be ejected from that competition. Canada Basketball and USA Basketball have both adopted FIBA rules and regulations, with minor adjustments (such as quarter length and run-time) for groups below grade 9 (age 14).

The National Federation of State High School Basketball in the United States implemented criteria with respect to swinging of the elbows as a flagrant foul in 2013-2014 to reduce concussion IRs by way of HC reduction in competition.\textsuperscript{39} The goal of the rule change was to align with the NBA Concussion policy\textsuperscript{40} of 2011, which was subsequently implemented by the NCAA that same year. FIBA additionally implemented the ‘excessive swinging of the elbows’ rule which is, therefore, also applicable to Canadian basketball competition.\textsuperscript{38}

\textbf{2.2.1 Concussion and Injury Incidence Rates in Basketball}

Despite the lack of Canadian basketball literature, there has been research conducted over many years in the NBA and many other American sports leagues. With an increase in concussion awareness across professional sports leagues over the last 2 decades, the NBA implemented a league-wide concussion policy in 2011, and the same policy in the Women’s National Basketball
Association (WNBA) in 2012. The policy seeks to increase reporting and diagnosis of concussions amongst NBA and WNBA players, alongside structure for return to play protocols in alignment with current research and clinical evidence. The policy did exactly that, with a significantly greater total seasonal concussions reported in the NBA following implementation of the policy as of 2018 (16.7 reported concussions ± standard deviation [SD] 7.5 versus 5.7 reported concussions ± SD 2.8, \( P=0.007 \)). This equates to approximately 11 additional concussions reported per season following commencement of the policy. Padaki et al. found that athletes missed significantly more games (5 average games missed) following the policy compared with pre-policy (1.6 average games missed). Concussion IRs significantly increased following the policy in the WNBA (1.7 versus 5.0 per season, \( P=0.001 \)). Following trends in the NBA, WNBA players missed a mean of 6.7 games after commencement of the policy compared with before the policy, missing only 0.9 games per season (\( P=0.006 \)), and 31.6 days missed after the policy versus 5.8 days before the policy (\( P=0.006 \)). The most recent study from the NCAA database reports overall concussion IRs in competition of 3.2 per 10000 AEs and 1.2 per 10000 AEs in practice. Across a number of injury surveillance databases, current findings suggest that the concussion IR is currently underestimated due to underreporting amongst athletes in all sports and failure to seek medical treatment. There is evidence to suggest this is specifically true for males, who are overall less likely to report concussion symptoms compared with females. Basketball ranked first amongst athletes self-reported “most serious” injuries of all reported injuries at 13.4% (includes both competitive and recreational settings in high school aged athletes), with 14.3% of those described as injury to the head and/or face. Further, both high school and post-secondary injury surveillance databases consistently show higher rates of concussion in competition compared to practice. Concussion sustained in practices among
NCAA females still ranked in the top 10 amongst all injury types, but was top 3 in competitions.\textsuperscript{43} Further research should examine injury and concussion rates in practice and competition settings in Canadian basketball in the youth and collegiate levels.

The most frequently reported injury in the NCAA for both males and females were ankle sprains at 14.3\% of all reported injuries in females, and 22.2\% in males.\textsuperscript{52,53} Ankle sprains, alongside knee injuries, are consistently reported as common non-concussive injuries in the NCAA and at the high school level. Similar to the NCAA, Clifton et al.\textsuperscript{5} reports findings in high school male basketball players with 32.6\% of competition injury reported as ankle sprains, 21.5\% were head/face injuries, and 12.6\% as knee injuries. Competition injuries were similar for high school females, with 28.9\% reported as ankle sprains, 27.5\% as injuries to the head/face, and 19.2\% as knee injuries.\textsuperscript{7}

An important factor to consider when examining concussion and non-concussive injury IRs is sex. There is consistent evidence to support significant sex differences from reported IRs when assessing concussion in sport.\textsuperscript{10,25,50,54,55} Literature in basketball remains consistent with other sports, where concussion rates are reportedly higher in females. A recent systematic review found that basketball demonstrated significantly higher concussion IRs in females compared with males, (rate ratio [RR]= 1.99; 95\% CI, 1.56 – 2.54).\textsuperscript{10} The NCAA follows this trend with higher concussion IRs reported amongst female basketball players compared with male basketball players (RR= 1.53; 95\% CI, 1.16 – 2.03).\textsuperscript{51} Concussion was listed as a top three specific injury type in competition for females accounting for 7.5\% of all injuries over a 4-year period in NCAA athletes.\textsuperscript{53} However, a recent cohort study following high school athletes over the course of a season found males sustained higher head impact rates than their female counterparts while wearing a head impact sensor (RR= 3.5; 95\% CI, 2.6 – 4.6).\textsuperscript{23} At the
professional level, sex differences align with those reported at the post-secondary level, with the WNBA reporting a concussion IR that was 3 times greater than the NBA.\textsuperscript{56}

Injuries sustained by females and males follow similar trends in both the NCAA and high school level, however, differences do exist. The most frequently reported specific injury type for males in the NCAA was partial or complete lateral ligament complex tears (ankle sprains) at 16.2%, followed by concussions at 4.6% and quadriceps contusions (2.5%).\textsuperscript{52} Females also most frequently sustained partial or complete lateral ligament complex tears (ankle sprains) at 14.3%, followed by concussion (7.5%) and anterior cruciate ligament (ACL) tears (2.5%).\textsuperscript{53} Consistently, males and females at all levels sustain ankle sprains as the most common injury in competition. However, sex specific mechanisms are important to consider when assessing injuries, given the higher rates of ACL tears in female basketball players. Contact with another player was the most common mechanism of injury for both males and females with respect to ankle sprains, however, females experienced majority of injuries to the knee that was non-contact. Females in the NCAA also report an estimated 16.1% of injuries as ‘overuse’ injuries, opposed to males who report only 9.6% as overuse. When assessing game events that result in injury, females sustain majority of injuries while in ‘general play’ (31.3%) followed by rebounding (14.5%) and ‘other/unknown’ (14.1%).\textsuperscript{53} These differed slightly from males, where majority of injuries were sustained during ‘general play’ (30.4%), followed by defending (15.6%) and rebounding (15.4%).\textsuperscript{52}

Understanding sex as a risk factor for basketball players is crucial to developing effective concussion and injury prevention strategies. Knowing that females are consistently vulnerable to concussion allows for evidence-based, tailored strategies to prevent concussion dependent on sex. Rates of concussion in competition, although notably stable in more recent years in the
NCAA, are an important injury to continue assessing as concussion continues to be a top three reported injury in collegiate athletes.\textsuperscript{52,53}

\subsection*{2.2.2 Burden and risk factors of concussion and injury in basketball}

The van Mechlen injury prevention framework and the TRIPP model emphasize the importance of determining and establishing mechanism and aetiology to identify risk factors that contribute to injury.\textsuperscript{11,12} Understanding the burden and risk factors of sport injury is crucial in developing successful injury prevention strategies. There are a few ways in which burden can be defined in the context of sport injury. The International Olympic Committee consensus statement offers a number of definitions – one stating, “burden of injury and illness can be expressed using measures that combine their frequency and consequences.”\textsuperscript{57} Frequency describing the total number of injuries, often specifically reported as rates (considers exposure time), and consequences describing injury severity (time loss, as an example). The consensus statement on injury definitions defines injury severity as, “the number of days that have elapsed from the date of injury to the date of the players return to full participation in team training and availability for match selection.”\textsuperscript{32} Sports such as football and rugby have used this definition, where burden is reported as the number of days lost due to injury or illness per 1000 hours of player exposure.\textsuperscript{57} In a basketball context, there is evidence to support females experience greater time loss from concussion compared with males. Covassin et al.\textsuperscript{9} reports female basketball players in the NCAA took 7.40 ± SD 7.10 days to recover from concussion compared to their male counterparts (5.57 ± SD 3.39 days). For both males and females, time loss injuries accounted for a similar proportion of all injuries in the NCAA (40.7\% for females and 41.1\% for males).\textsuperscript{52,53}

Injury severity in sport may also be considered based on emergency department visits, where basketball was found to be associated with a high number of youth (under 18) sport-
related emergency department (ED) visits in the United States from 2010-2016, (ranked third following football and bicycling). The same database found that females participating in basketball contributed to 11.9% of all sport or recreation-related traumatic brain ED visits, and 9.8% of all males. Basketball-related injuries accounted for the most patient encounters at 32% in the ED, and made up approximately one third of all sport-related visits to the ED (31.6%).

Pertaining to severe injuries, Borowski et al. demonstrated that fractures to the head/face/neck were the second most fractured location for both boys and girls playing basketball at 13.6%, noting that boys are more likely to require surgery following a head/face/neck fracture compared with girls (injury proportion ratio (IPR) 4.43; 95% CI, 1.25-15.68; P <0.01). Confidence intervals should be noted as the sample of fractures to the head/face/neck are likely a small percentage of overall injuries. However, the implication of facial fractures and the long-term impact this may have on a young athlete is of concern. The study did not speak to the potential of concussion in conjunction with a head/face/neck fracture; however, concussion can be suspected based on the required force needed to fracture bone.

It is concerning that ACL (partial and complete) tears were amongst the most common specific competition injury type for NCAA females. Time loss following an ACL injury is significant, there is often a need for surgery to repair a complete tear, and the long-term consequences associated with this injury (e.g., osteoarthritis, decreased quality of life, neurocognitive changes).

Burden of injury is an important clinical consideration when assessing an athlete’s recovery from injury, specifically, if there is evidence to support that injury time loss may vary by sex. Literature seeking to understand primary prevention strategies amongst youth basketball players to keep them playing sport for longer and healthier is warranted.
Another important consideration when assessing injury in sport are risk factors. Risk factors can be broken down into modifiable and non-modifiable. Modifiable risk factors refer to factors (e.g., balance, strength) that can be altered using prevention strategies (e.g., neuromuscular training programs). Non-modifiable risk factors refer to anything that an athlete is predisposed to and cannot be changed (e.g., sex, age). Understanding different factors when assessing concussion and injury in basketball will assist in guiding literature pertaining to prevention and ensuring safe participation at both the organized and recreational levels for all ages.

2.2.3 Extrinsic risk factors

Extrinsic risk factors are environmental factors that play an independent role in an athlete’s risk of injury in their sport setting. Game conditions, officiating decisions, and player position are all examples of extrinsic risk factors that an athlete may experience. Player position in basketball has previously been investigated as a risk factor in competition. There is evidence to support that there is an association between player position and injury in collegiate basketball players, with guards (smaller players) sustaining the highest proportion of injuries in female NCAA players (51.4%). This was also found to be true for males, with guards experiencing 48.9% of all reported injuries. There is a paucity of literature supporting player position as a risk factor relating to injury in youth, which should be a focus for future research in basketball. Studies that have assessed this have been conducted at the high school level, where Vanderlei et al. reported injury prevalence in high school basketball players to be highest among shooting guards at 47.8%, centers at 34.8%, and point guards (often the smallest player) at 17.4%. A recent study in male professional basketball reported conflicting results, where point guards had the highest injury rate at 26%, shooting guards at 21%, power forwards at 21%,
centers at 19% and small forwards at 13%. It is important to consider that professional league data may not generalize to high school level basketball due to many factors (age, height, weight, player experience). Therefore, more research is required to confidently establish player position as a risk factor at both the collegiate and youth level.

Session type (practice versus competition) exposes athletes differently to injury risk through structure, length of session, or volume of sessions as examples. Across several sports, practice sessions are very different in structure compared with competition. Practice sessions are often controlled environments with stoppage in play and structured plans for technical and tactical work. Competition is much the opposite, with the addition of several uncontrollable factors, such as: referees, the opponent, fans, and a game clock, as examples. Literature consistently shows higher injury and concussion rates in competition compared with practices in basketball. The NCAA Injury Surveillance System reported competition injury rates that were two times higher than practice injury rates on the men’s side at 9.9 injuries versus 4.3 per 1000 AE’s (RR = 2.3; 95% CI, 2.2 – 2.4), and reported the same two-fold increase in injuries between games and practices on the women’s side at 7.68 injuries versus 3.99 per 1000 AE’s (RR = 1.9; 95% CI, 1.9 – 2.0). This trend remained true in the most recent NCAA injury reports, with a two-fold greater rate in competition compared to practice in males (IRR=2.07; 95% CI 1.93-2.22). This was similar to rates in female competition compared to practice (IRR=1.75; 95% CI 1.62-1.88).

Although most data pertaining to practice versus competition focuses on higher levels, there are studies that show similar trends at the high school level, where practice injury IRs are consistently reported at nearly half the rate of those in competition. Injuries sustained in basketball practices versus competition in male high school athletes were primarily ankle
(practices = 35.9%, competition = 32.6%), head and face (practice = 14.8%, competition = 21.5%), and knee (practice = 11.2%, competition = 12.6%). Notably, the high prevalence of injuries to the head and face warrant concern for competition behaviours that may be a result of players sustaining head and face injuries, and consequently, concussion.

2.2.4 Intrinsic risk factors

Intrinsic risk factors are biological or physiological characteristics that are a part of an individual’s make-up and may contribute to their overall risk of injury. Examples of intrinsic risk factors, relevant in video analysis, are sex and age. Sex comparisons are common in literature pertaining to basketball. This is likely because the sport adopts the same rules and regulations at the youth level for both males and females. This allows for an easier comparison without extraneous factors that may contribute to injury and concussion rates. Although studies have reported consistent sex differences at higher levels of play, sex differences at the youth level are not as clear. Concussion/head injury IRs in basketball athletes increased significantly from childhood to adolescents, with similar IRs in males and females at 4.9 injuries per 100,000 athletes-days (95% CI: 3.1 – 6.7) versus 5.9 injuries per 100,000 athlete-days (95% CI: 4.3 – 7.5), respectively.

Age has also been assessed in basketball literature as an intrinsic risk factor that may contribute to an athlete’s overall risk of injury. Both males and females have demonstrated higher injury rates in university (usually 18 years and up) compared with high school (typically 14-17 years), but evidence is conflicting, and results may not be generalizable between these age groups. Broken down further, significant increases in injury prevalence were present amongst adolescents (12-17 years old) when compared with children (7-11 years old). The higher concussion IR at the university level may be due to the increase in physicality that occurs
in the transition from high school to college athletics. It may also be due to the inevitable age gap that occurs when entering a university level team and the increase in strength that higher level athletes develop over time (e.g., due to increase in weight training).

### 2.2.5 Mechanisms of injury and concussion in basketball

Mechanism of injury in male high school basketball players was most commonly contact with another person (practices = 44.1%, competition = 51.5%), with rebounding as the most common game event resulting in injury (practice = 26.3%, competition = 29.0%). High school females most commonly injured the ankle (practice = 29.3%, competition = 28.9%), knee (practice = 16.6%, competition = 19.2%), and head and face (practices = 11.3%, competition = 27.5%). This was similar to high school males, with majority of injuries as ankle sprains (practices = 35.9% competitions = 32.6%), head and face (practices = 14.8% competitions = 21.5%) and knee injury (practices = 11.2% competitions = 12.6%).

Mechanism of injury in high school female basketball players was similar to males, with contact with another person as the most common (practices = 28.9%, competition = 47.0%). Females sustained injury more commonly while rebounding (22.6%) and defending (20.1%) in competition.

### 2.2.6 Concussion and injury prevention strategies in basketball

Sport-related injury is the leading reason why individuals discontinue participation in physical activity. Therefore, preventative measures are required to implement strategies that keep athletes safe in sport and playing longer. Frameworks and models exist that describe stepwise action to reducing injury in sport (van Mechlen and TRIPP) and such models have informed strategies across a variety of sports, including basketball. Prevention measures are best introduced and informed by aetiological factors (such as player position and court location)
and the different mechanisms involved.\textsuperscript{11} Emery and Pasanen (2019) identified three categories for primary injury prevention in sport, which are: training programs, rule modification and policy change, and equipment.\textsuperscript{74}

\textbf{2.2.6.1 Training Programs}

In the context of basketball, neuromuscular training (NMT) programs as a means of primary injury prevention have been identified as an effective strategy.\textsuperscript{71,72,74,75} A systematic review demonstrated the protective effect of NMT’s in reducing lower-extremity injuries (IRR= 0.64; 95% CI, 0.49 – 0.84), indicating a 36% reduction in lower-extremity injury risk for youth team sports, which included basketball.\textsuperscript{71} NMT programs are comprised of four exercise components including aerobic, agility, strength, and balance.\textsuperscript{75} NMT programs have been found to significantly reduce the risk of ankle sprain injuries in basketball by 32% (IRR= 0.68; 95% CI, 0.46 – 0.99).\textsuperscript{76} Females in sport are at risk of sustaining lower-extremity injuries, including anterior cruciate ligament (ACL) tears, with a number of studies finding females at a four-to six-fold higher knee injury IR compared with males.\textsuperscript{77,78,79} Further, a comparison of long versus short NMT programs for female athletes found the greatest ACL injury reduction in the high volume group (OR=0.32; 95% CI, 0.19 – 0.52), followed by moderate (OR=0.46; 95% CI, 0.21 – 1.03), and low volume (OR=0.66; 95% CI, 0.43 – 0.99).\textsuperscript{80} By analysing context of contacts in game settings and identifying suspected injury, training program research can aid coaches in providing training programs for their athletes using an evidence-based approach. Research pertaining to training strategies seeking to mitigate concussion in basketball is sparse; however, Howell et al.\textsuperscript{81} recently demonstrated that an 8-week NMT intervention following a concussion may reduce subsequent time loss injury for up to 1-year post-injury when compared with standard of care practices. They found that in the first year following a concussion in basketball,
those in the NMT intervention group saw a 75% reduction in time-loss injuries compared with the standard of care group at 36%. There is currently a gap in literature examining training programs in basketball related to injury prevention; however, in the last few years, the popularity of NMT programs and their effectiveness in sport is a promising research endeavour.

2.2.6.2 Rule modification and policy change

There is currently little research that examines the impact of rule modification and policy change on concussion and injury in basketball. Rule modification that was implemented in the 2010-2011 NBA season is the “no-charge circle,” which is a 3-foot-wide semi-circle that sits directly under the rim. The point of the semi-circle is to deter players from initiating excessive contact under the rim. If a defensive player is occupying space in the no-charge circle, the offensive player is allowed to initiate contact with the defense, who will be penalized. This semi-circle was implemented to prevent defensive players from excessively fouling a player attacking the rim.

Further, it has been determined that severe injuries in Canadian university basketball players are sustained in the “lane,” as coined by Meeuwisse et al. It has been speculated that due to the high volume of contact and injury occurring within this zone, a prevention strategy may involve increasing the size of the “lane,” otherwise known as the “key,” due to the difference in size of the key between the current NCAA regulations and the WNBA key size.

An increase in reporting of concussions was a result of the 2011 concussion policy implemented by the NBA, with the highest reported concussions occurring in the 2012 season (average of 20 concussions per season). Increasing awareness surrounding concussion identification and associated risk factors is critical in reducing unsafe return to play and overall enhancing concussion treatments during rehabilitation. Another example of rule implementation
in basketball to reduce concussion and head contact is the supplementary ‘excessive swinging of elbows’ rule, which has been a point of emphasis to referees by the NCAA Rules Committee following the concussion policy. There is no evidence that has assessed the effectiveness of this rule; however, effective policy change and rule modification should seek to prevent overall concussion recurrence due to the inevitable increase in physicality of the sport over time.

### 2.2.6.3 Equipment

Basketball does not require specific equipment to participate apart from court shoes. Low-to-mid cut basketball shoe is favoured for guards and small forwards due to high traction and support during acceleration and cutting. Mid-to-high cut shoes are favored amongst forwards and centers due to need for greater ankle stability and jumping performance. Lateral cutting in basketball is a common movement pattern amongst athletes, where it’s been suggested that court shoes with a stable shank prevent occurrence of metatarsal fracture, alongside high-collars to improve ankle stability during cutting and landing to reduce ankle supination and inversion. Technology such as the ‘Spraino’ shoe patch is a new area of discussion amongst researchers in the world of sport. Although exploratory, Spraino was found to be an effective method of preventing ankle sprains with a mean time loss of 1.8 weeks (95% CI: 1.3 - 2.3) in Spraino users, and 2.8 weeks (95% CI: 2.2 – 3.4) in those not using. The addition of Spraino is comparable to the effects of other prevention measures (e.g., training programs, taping, bracing).

Further examples of optional equipment used by basketball players are bracing, mouthguards, and padding. Ankle braces are a popular piece of additional equipment that basketball players choose to wear and have proven effective in preventing ankle injury in basketball players. McGuine et al. found that lace up ankle braces were effective in reducing the overall incidence of acute ankle injuries, with an incidence of 0.47 per 1000 AEs (95% CI:...
0.30 – 0.74) in the braced group, and 1.41 per 1000 AEs (95% CI: 1.05 – 1.89) in the un-braced group. Popularity of ankle bracing in basketball is likely due to the overall greater understanding of ankle injuries as a common and visible injury in the sport. A systematic review by Andreoli and colleagues determined that ankle and foot injuries, when analyzed by age and skill level, were the most common injury in adolescents at 37.7%.

Basketball has notably high rates of orofacial injuries sustained from contact between players (e.g., elbow to face) and between ball and player (e.g., ball to face). High force contacts, such as an elbow to the mouth or jaw, puts athletes at risk of sustaining concussion. There is little research that supports the effectiveness of mouthguards in basketball as a means to prevent concussion despite the high rates of contact to the mouth and face in basketball. One study found no significant difference in concussion rates between athletes who did wear a mouthguard and those who did not in male college basketball players. This study did not assess effectiveness in female players, which has since been determined as an at-risk demographic for dental injury, determined by Huffman et al., where girls’ basketball was second to baseball assessing dental injury. A more recent study revealed that basketball was the second most common sport after rugby for the highest prevalence of dentofacial injury (27.6%). Acuity of mouthguard use in basketball players has been evaluated by Collins et al. where males and females reported not using a mouthguard primarily because they “didn’t have to” (65.3%), and that it ‘hindered breathing and talking’ (61.5%). Interestingly, they found that most players did not wear one because either their coaches (87.3%) or parents (64.5%) never spoke to them about mouthguard use. This study highlights the need for greater awareness surrounding risk of concussion and dental injuries in basketball, importantly, the need for more research around protective equipment use to prevent these injuries.
2.2.7 Limitations of Previous Research

A large portion of current literature assessing concussion and injury IRs comes from collegiate or professional basketball leagues, specifically male professional leagues. Findings from higher-level leagues (professionals) are not generalizable to younger age groups, such as youth, who participate competitively and recreationally in basketball. Although rules and regulations are relatively consistent amongst all basketball leagues, the generalizability of injury and concussion rates in elite-level players to youth context is unknown. Similarly, results from professional leagues may not be generalizable to those in collegiate basketball, and vice versa.

Current research is scarce when assessing concussion rates at the high school level, with majority of research in youth focused on high school basketball athletes in the United States. Injury surveillance systems, such as the National High School Sports Injury Surveillance System in America (developed for purpose of the National High School Sport-Related Injury Surveillance Study) has provided a strong foundation for research in this age group, which is a limiting factor for collecting large cohort data in Canadian basketball players. The Canadian Intercollegiate Sport Injury Registry (CISIR) was created in 1997, but subsequent validation and studies implementing the CISIR are limited. Therefore, most data collected in Canadian players (youth and collegiate) is based on data collected over smaller time periods and smaller sample sizes. Limited research assessing concussion in basketball may be due to a significant focus on concussion research in collision sports such as football, rugby, and ice hockey and less focus on high contact sports such as basketball and soccer.

There are several additional factors that may contribute to concussion rates in basketball players. These include, but are not limited to, confounders or effect modifiers such as height and weight, previous injury history, surface type, equipment use, or player experience. Current
literature that assesses concussion rates in youth basketball players generally does not involve individual level descriptors assessing an athlete’s exposure to injury or concussion. For example, a potentially important confounder to consider in examining concussion rates is an athlete’s history of concussion. When not addressed, overall concussion IRs reported may be biased when concussion history is not considered.

Further, there is currently no Canadian literature that examines suspected concussion and head contact IRs using video analysis. Many studies have used video analysis to assess basketball related injury such as ACL tears or Achilles’ ruptures; however, none have a focus on head contacts or suspected concussion.

Studies that examine the impact of rule modification and policy change are often seeking to understand how changes impact performance, but not from an injury prevention perspective. Similarly, evidence of primary prevention strategies that are investigated in literature often assesses only professional players, particularly players in the NBA.

2.2.8 Summary

Participation in basketball continues to grow. Concussion and injury rates at both the university and high school (adolescent) are amongst some of the highest when analyzing contact sports. There is also evidence to support sex differences in concussion rates at both university and youth levels. When assessing concussion and injury in sport, it is important to consider risk factors that may play a part in a player’s susceptibility to injury, as well as the burden of concussion and injury in these athletes.

More research is needed to confirm extrinsic risk factors (referees, game conditions, player position, as examples), for concussion and injury in basketball, specifically, in youth players. Further, despite illegality of HCs in competition, there are alarmingly high rates of
competition head impacts amongst youth players verified via sensor data, where girls’ basketball players had an HC rate similar to that in lacrosse.23

Another limitation to previous research is lack of generalizability amongst player groups, with majority of concussion and injury data reported in the NCAA, the NBA, or professional contexts, and little research in high school or youth basketball players. It may be challenging to generalize concussion or injury trends in higher level players to youth due to several factors, such as age, skill level, physicality, and player experience, as examples. Future research should focus on analyzing incidence of concussion and injury in youth basketball players using a variety of approaches such as video analysis in conjunction with injury surveillance or sensor data for verification.
Chapter 3: Head contact and suspected concussion rates in university basketball: Are head contact penalties a target for prevention?

3.1 Introduction

Basketball is a popular sport at the university level for both male and female players, with an estimated 16,090 athletes participating at the university level in the United States last year. University level basketball is a fast-paced game, and although considered a ‘partial-contact sport,’ rates of concussion are amongst some of the highest reported in collegiate sports. Previous research has found that in university basketball, contact with another player is the primary mechanism of concussion for both males and females (77.4% and 68.1%, respectively). It has also been demonstrated that females reported a greater number of concussions sustained in competition compared with males. Notably, female basketball players, alongside female soccer players, had a 1.4-fold greater incidence of concussion compared with their male counterparts. Assessing contacts in competition that may increase a player’s risk of concussion is critical to increasing the safety of the sport for both males and females along with preventing potential long-term effects of concussion.

Basketball provides opportunity to examine potential differences that may exist between sexes regarding injury and concussion, as rules are comparable between males and females. Injury surveillance data is scarce amongst Canadian university basketball players; however, leagues such as the National Collegiate Athletics Association (NCAA) and the National Basketball Association (NBA) have collected data over the years. A systematic review and meta-analysis demonstrated that basketball has significantly higher concussion rates (CRs) for females compared with males in players older than 10, (RR=1.99; 95% confidence interval (CI), 1.56 – 2.54; P < 0.01). The NCAA follows this trend, with higher CRs reported amongst female basketball players compared
to males (RR = 1.53; 95% CI, 1.16 – 2.03).\textsuperscript{51} Similar trends are reported in the Women’s National Basketball Association, (WNBA), reporting a CR that was 3 times greater than the NBA.\textsuperscript{56} The NCAA reported female CRs in competition of 5.8 per 10,000 AEs in 2016-2017, which remained relatively stable into 2018-2019 with an injury rate of 5.4 per 10,000 AEs.\textsuperscript{53} Male CRs in the NCAA were reported at 4.6 per 10,000 AEs in 2016-2017, which slightly declined into 2018-2019 with rate of 3.2 per 10,000 AEs.\textsuperscript{52} Additionally, female basketball players report greater time loss (7.40 ± SD 7.10 days) compared with males (5.57 ± SD 3.39 days) at the collegiate level.\textsuperscript{9} Differences in time loss have been attributed to physiological sex differences,\textsuperscript{47,103} as well as increased likelihood of reporting amongst females compared to males.\textsuperscript{47,49} These findings affirm the need for investigation into sex differences among basketball players, particularly in youth where research is limited compared to higher level leagues.

Game events in which athletes appear to sustain concussion is an important factor to consider and how these may differ between males and females. Male professional league video analysis determined that 91.7% of injuries to the head were a result of player-to-player contact.\textsuperscript{16} Specifically, males were more likely to sustain player-to-player contact when rebounding (31%,) and females were most likely to sustain player-to-player contact when defending (22%). Contact while ball handling was also more prominent in women’s basketball (19%) compared with men’s (10%).\textsuperscript{50,100} Boys were found to sustain a greater proportion of concussions while chasing loose balls, (26.0% proportion ratio, (PR)= 2.46; 95% CI, 2.28 – 2.64), and rebounding, (30.5% PR= 1.83; 95% CI, 1.72 – 1.95), when compared with females.\textsuperscript{50} Interestingly, in the WNBA, players with multiple concussions compared with a single concussion reported as forwards (57.1%) and were notably younger, (24.8 years vs. 27.0 years), heavier (81.1kg vs.74.9kg), and taller (1.88m vs. 1.81 m).\textsuperscript{104} Although our study did not assess player position, it is typical in basketball for
larger players to function mainly within the key, which is found to be a high contact area during competition with high risk of injury. Game events and court location with higher contact rates contribute to a greater understanding of competition outcomes that put athletes at risk for injury or concussion.

Research examining the incidence of concussion or injury due to foul play has not been previously examined in the context of Canadian basketball. Achenbach et al. examined injury due to foul play using video analysis in men’s professional basketball. They revealed that injuries to the head (92%), ankles (76%), shoulders (70%), knees (47%) and thighs (32%) were a result of direct contact with another player. They note that 19% of all moderate and severe injuries analyzed were due to foul play (denoted by a referee making a call) and rule modification and enforcement should be examined in Canadian basketball.

Despite an abundance of research assessing injury and concussion at higher levels, (NCAA, NBA), literature is scarce amongst Canadian university basketball players. Therefore, the aim of this study is to identify if sex differences are evident regarding HCs, suspected concussion, and injury in Canadian university basketball players. Further, we assessed the percentage of HCs that were penalized by a referee, alongside assessing court location and game event as additional factors surrounding these outcomes.

3.2 Methods

3.2.1 Design and Participants

This is a cross-sectional video analysis study assessing 10 (five male and five female) Western Canadian university basketball games, (40-minute total game length). Participants were male and female university basketball players participating in the 2019-2020 regular season (n=10
team-games; N=5 games). Ethical approval was obtained from the University of Calgary Conjoint Health Research Ethics Board (CHREB) (Ethics ID: REB21-1249; Appendices A-G).

3.2.2 Video Footage Collection

Video footage was originally collected for the purpose of performance analysis by team analysts, coaches, and players. All video was obtained for secondary analysis in this study and was analyzed anonymously by approval from the University of Calgary’s director of Dino’s athletics (Appendix G) with additional approval from the University of Calgary basketball team head coaches. Ethics was approved by the University of Calgary Conjoint Research Ethics Board (Ethics ID: REB21-1249). Video was transferred from team-based viewing platforms to a secure server (SharePoint) and imported and analyzed in Dartfish video analysis software. Games were randomly selected from a total of 20 regular season games. All footage quality and angles were deemed acceptable for analysis.

3.2.3 Outcome Measures

All games were analyzed using Dartfish 10.0 video analysis software\textsuperscript{105} based on criteria that was face-validated by community partners, coaches, administrators, and a former Team Canada video analyst. Video coders consisted of individuals with elite level player experience in basketball (n=3). Each coder was trained to use the program and the criteria being measured in the same manner before undertaking interrater reliability with percentage agreement of $\geq 90\%$ prior to beginning analysis. All coders were compared to a gold standard coder across categories including court location of contact, contact type (limb, trunk, none) head contacts, (HC1 or direct head contact [player-to-player] and HC2 or indirect head contact [player-to-environment]) and contact event type. The gold standard assessor had experience in the sport of basketball with approximately 15+ years of player experience, with 6 years at the university level, approximately
1 year of elite level coaching, and was responsible for the creation of the coding template used in analysis.

HCs (direct and indirect) were tagged. HCs were classified as both HC1 (direct) and HC2 (indirect), where HC1s are any head contact occurring player-to-player, (elbow to head, head-to-head, arm/hand-to-head, as examples), and HC2s are any head contact with the external environment (floor, ball, as examples). Head contact descriptors were defined based on studies with similar objectives done in ringette and ice hockey.\textsuperscript{14,34} Descriptors such as court location, defensive and offensive perspectives of each contact, game event, and whether a foul was called because of the contact by the referee were assessed. A foul was tagged by coders if a referee stopped the game to call a foul, therefore, fouls were not a subjective measure. Further, direct head contacts assessed on film were coded with a respective limb and/or trunk contact intensity, if applicable (Table 3.1). Head-to-head contacts were not associated with an intensity. Suspected concussion was assessed using 17 criteria developed for professional sport based on video signs common to all sports.\textsuperscript{30} These included: motor incoordination, lying motionless, no protective action- floppy (ragdoll-like), no protective action- tonic (falling stiff), cervical hypotonia, impact seizure/convulsion, tonic posturing, blank/vacant look, uncontrolled fall to the ground (following an evident head contact), controlled fall (following an evident head contact), dazed, slow to get up, clutching at the head, walking away/disengaged from the game, disorientation, confusion, and facial injury. We identified non-concussive injury using validated criteria in soccer video analysis studies. These included: a player remains on the court for longer than 15 seconds, the player appeared to be in pain, the player required medical attention, or the play was interrupted by the referee due to the injury.\textsuperscript{33} To ensure that appearance of pain was related to injury, coders were instructed to only code a suspected injury is an inciting event occurred to result in ‘pain.’\textsuperscript{13} To
Suspected concussion and injury was included in the analysis if one or more of the criteria was met.\textsuperscript{13}

Table 3.1. Description of trunk and limb contact intensities, as adapted from Williamson et al.\textsuperscript{14}

<table>
<thead>
<tr>
<th>Trunk/Limb physical contact (PC)</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1 (‘Mild’)</strong></td>
<td>Inconsequential contact. Contact is visible but did not affect a player’s ability to execute their skill.</td>
</tr>
<tr>
<td><strong>Level 2 (‘Moderate’)</strong></td>
<td>Contact is visible, and execution of skill is affected in a way that the player was visibly disrupted, with consequence (arms were slapped, legs were taken out, body was pushed off direct line course, as examples).</td>
</tr>
<tr>
<td><strong>Level 3 (‘Severe’)</strong></td>
<td>Contact is visible and overly aggressive. Player receiving/initiating contact is obviously unable to execute their skill, with evident consequence (injury, foul, as examples).</td>
</tr>
</tbody>
</table>

*Notes.* This rating scale was face-validated by basketball community partners, administrators, players, coaches, and one team Canada video analyst.

**3.2.4 Data Analysis**

All data analyses were performed using STATA version 15.1 statistical analysis software.\textsuperscript{106} Incidence rates (IRs) were used to assess HC1 and HC2 and expressed as the number of HCs per 10 player-minutes. For all statistical tests, an alpha level of 0.05 was used. Incidence rate ratios (IRRs) were used to compare male and female HCs and suspected concussion rate via univariate Poisson regression analyses and offset by game length in minutes. Game events and court location of HC were reported as a proportion of total number of HCs assessed.
3.3 Results

3.3.1 Head Contact Incidence Rates

Across 5 games, males experienced 138 HCs, and females experienced 92 HCs, with 11 HCs occurring because of contact between players of the same team. 230 HCs were observed (88.7% HC1s and 11.3% HC2s), where 51.7% were received by the offensive player, and 48.3% by the defensive player. Any head-to-head contacts were coded as two individual head contacts, (one to the offensive player, and one to the defensive player). All games assessed were a standard 40 minutes of ball-in-play, with no games running into overtime. Overall, the HC1 IR was 1.55-fold higher in males (IR= 0.62/10-player-minutes; 95% CI, 0.52 – 0.74) than in females, (IR=0.40/10-player-minutes; 95% CI, 0.32 - 0.50) (IRR=1.55; 95% CI, 1.16-2.06) (Figure 3.1). Regarding contact intensity, the greatest proportion of offensive HC1s for females were associated with a limb and/or trunk contact intensity of ‘moderate’ (55.0%), followed by ‘mild’ (40.0%) and lastly, ‘severe,’ (5.0%). Men on offense experience the greatest proportion of HC1’s associated with a ‘moderate’ limb and/or trunk contact intensity (57.0%), followed by ‘mild’ intensity (37.7%), and lastly, ‘severe’ (6.6%).
Figure 3.1. Incidence rates and incidence rate ratios (IRRs) per 10-player minutes with 95% CIs of total head contacts (HCs), direct head contacts, (HC1) and indirect head contacts, (HC2) by male and female, offset by game-minutes.

*Represents a significant p-value, *P* <0.05.

*Head Contact*

**3.3.2 Game Events, and Court Location**

The primary game event for offense receiving HCs was shooting for both males (24.6% of all HC1s) and females (20.0% of all HC1s). Defensively, the primary game event for receiving HCs for males was guarding an attacker, (40.6% of all HC1s), and rebounding for females, (31.0%). Majority of HCs occurred within the key (males 73.2%, females 59.8%), inside the 3-point line, excluding the key, (males 18.1%, females 26.1%), and outside the 3-point line (excluding areas inside the 3-point line), (males 8.7%, females 14.1%) (Figure 3.2).
3.3.3 Suspected Concussion

Suspected concussion rates did not significantly differ for males (IR=0.02/10-player-minutes; 95% CI:0.005-0.05) and females (IR=0.01/10-player-minutes; 95% CI:0.001-0.04) (IRR=2.00; 95% CI:0.20-19.8) (Table 3.2). Of the 6 total suspected concussions coded (4 male concussions, 2 female concussions), only 2 were associated with a foul call, 1 of which was received to a male player and 1 to a female player. Further, 1 suspected concussion assessed as a foul was attributed to a limb and/or trunk contact intensity coded ‘severe,’ and 1 was coded as ‘moderate.’
Table 3.2. Competition injury and concussion incidence rates (IRs) and incidence rate ratios (IRRs) by sex, reported per 10 player-minutes.

<table>
<thead>
<tr>
<th># of Injuries</th>
<th>Male IR (95% CI)</th>
<th>Female IR (95% CI)</th>
<th>IRR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-concussive</td>
<td>21</td>
<td>0.07 (0.03-0.11)</td>
<td>0.04 (0.02-0.08)</td>
</tr>
<tr>
<td>Concussion</td>
<td>6</td>
<td>0.02 (0.005-0.05)</td>
<td>0.01 (0.001-0.04)</td>
</tr>
</tbody>
</table>

3.3.4 Penalization of Head Contacts

Our study revealed that only 11.2% of HC1s to defenders and 25.7% of HC1s to offensive players were assessed as a foul by a referee in game, despite the illegality of contact to the head in basketball. Females on offense sustained 38 HC1s, (2 HC1s were recorded between players on the same team), of which 2 were assessed as a foul by the offense (5.3%). Further, 10 HC1s by a player on defense were assessed as a foul, (33.3%). Males on offense sustained 63 HC1s, of which 2 were assessed as a foul by the offense (3.2%), and 16 HC1s were assessed as a foul on a defender, (25.8%). Defensively, females sustained 40 HC1’s, with 3 fouls assessed to the offensive player, (7.5%), and only 3 fouls were assessed to players on defense, (7.5%). Males sustained 61 HC1’s on defense, of which 8 were assessed as a foul to the defense, (13.1%), and 8 to players on offense, (13.1%). In total, 26 of 101 (25.7%) HC1’s that were sustained by offensive players were assessed as a foul by a referee, 3 (7.7%) of which were coded as ‘mild’ intensity, 19 (33.9%) were coded as ‘moderate’ intensity, and 4 (66.7%) were coded as ‘severe.’ Of 98 total HC1’s sustained by players on defense, 11 were assessed as a foul by a referee. 1 was coded as ‘mild,’ 4 were coded as ‘moderate,’ and 6 were coded as ‘severe.’ (Table 3.3).
Table 3.3. Percentage of direct head contact fouls assessed in game by a referee by offense and defense and the associated limb/trunk contact intensity.

<table>
<thead>
<tr>
<th>Intensity of Contact</th>
<th>Foul Assessed by Referee (HC1s to players on offense) (n=101)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Mild</td>
<td>7.7% (n=3)</td>
<td>92.3% (n=36)</td>
</tr>
<tr>
<td>Moderate</td>
<td>33.9% (n=19)</td>
<td>66.1% (n=37)</td>
</tr>
<tr>
<td>Severe</td>
<td>66.7% (n=4)</td>
<td>33.3% (n=2)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>25.7% (n=26)</td>
<td>74.3% (n=75)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intensity of Contact</th>
<th>Foul Assessed by Referee (HC1s to players on defense) (n=98)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Mild</td>
<td>2.5% (n=1)</td>
<td>97.5% (n=39)</td>
</tr>
<tr>
<td>Moderate</td>
<td>8.3% (n=4)</td>
<td>91.7% (n=44)</td>
</tr>
<tr>
<td>Severe</td>
<td>60.0% (n=6)</td>
<td>30.0% (n=4)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>11.2% (n=11)</td>
<td>88.8% (n=87)</td>
</tr>
</tbody>
</table>

* Does not include head-to-head contacts.

3.4 Discussion

This study is the first of its kind to assess incidence of head contacts in Canadian university basketball using video analysis. HC1 IRs in males were 1.55-fold greater than their female counterparts. This finding is comparable to a recent study in high school basketball athletes reporting head impact IRs (via sensor data) that were greater in males at 0.9 impacts per AE compared with females at 0.25 impacts per AE (RR=3.60; 95% CI, 2.60-4.60), where 1 AE is a player entering competition wearing the sensor.23 They determined that 88% of head impacts reported were HC1s, which is also comparable to findings of this study. Although we could not validate suspected concussion or degree of HCs with sensors, this should be a focus of future research pertaining to video analysis.
Dick et al.\textsuperscript{44} reports a trend in male NCAA basketball athletes over a 16-year period, where incidence of head and facial injuries substantially increased, (65% increase over last 3 seasons of data collection compared with the first 3 seasons). More recently, the NCAA reports a female concussion rate of 5.4 per 10,000 AEs from the 2019-2019 season.\textsuperscript{53} Males report a concussion rate of 3.2 per 10,000 AEs for that same year.\textsuperscript{52} Further, it has been demonstrated that over 6 years in the NCAA, a linear trend exists ($P=0.05$) regarding SRC in men’s basketball.\textsuperscript{84} When considering competition and practice, this same study demonstrates overall concussion rates of 3.89 per 10,000 AEs (95% CI: 3.06-4.72) for males and 5.95 per 10,000 AEs (95% CI: 4.87-7.04). These rates are higher than overall injury rates in men’s lacrosse. It should be noted that men’s basketball was third amongst 17 NCAA sports for recurrent concussions at 13.1%.\textsuperscript{84} Although head contacts, or dental/facial trauma are not always associated with concussion diagnosis, it is critical to make note of impacts that may result in injury such as concussion, and develop a greater understanding of the potential for sub-concussive hits in basketball.

Alternatively, a number of studies have noted the increase in size, physicality, and strength of both male and female basketball players over time as another possible explanation for increases in concussions and facial trauma reported in the NCAA.\textsuperscript{23,44} Although we did not find a significant difference in suspected concussion rates between males and females, evidence from previous literature\textsuperscript{8,9,43,84} supports the need for further investigation into potential sex differences that may exist in Canadian basketball players with respect to concussion. Interestingly, regarding direct head contacts, we saw higher IRs in males when compared with females. These differences in findings compared to current literature may be attributed to a small sample size; however, the significant finding of direct head contacts between sexes warrants further examination.
Regarding the illegality of contact to the head in basketball, this study demonstrates a very small percentage of HC1s that were assessed by referees as a foul. Our percentages align with a study assessing high-school sport injuries and illegal activity during play,\textsuperscript{107} where injuries to the head and face accounted for 32.3\% of all sport-related injuries caused by illegal activity. Girls’ basketball saw the highest proportion of injuries sustained due to illegal activity at 14.0\%, and boys at 10.0\%. This was reported as an injury rate of 0.32 per 1000 game AEs for boys, and 0.36 per 1000 game AEs for girls.\textsuperscript{107} Further, concussion had the highest IPR due to illegal activity when compared with legal play, (25.4\% vs. 10.9\% IPR= 2.35; 95\% CI, 1.71-3.22). It was also determined that a greater proportion of injuries related to illegal play was attributed to contact with another player, (80.1\%) compared with injuries not related to illegal play, (56.2\%; IPR= 1.43; 95\% CI, 1.31-1.56). Similar findings regarding illegal behaviour and concussion have been demonstrated in high school rugby players, where two-thirds of injuries related to illegal activity were concussions.\textsuperscript{108} Williams et al.\textsuperscript{14} examined the “Zero Tolerance for Head Contacts” policy change made at the youth level in ice hockey, which highlights the low proportion of HCs assessed in ice hockey as a result of illegal play. The study calls for further examination of practical on-ice training for referees, which could be an area for further examination in basketball considering similarities in the low proportions of foul calls from HCs.

It is important to note that non-concussive injuries, such as ankle and knee sprains, are also reported to be commonly related to illegal activity in competition. Collins et al.\textsuperscript{107} reports injuries to the ankle and knee were second and third, respectively, behind head and face injuries related to illegal activity. Although this study did not provide sport specific estimates, we can speculate that due to the high prevalence of ankle and knee injury in basketball, these estimates
are relevant for high school basketball athletes and should be a focus for injury prevention with respect to game rules and policies.

These findings provoke the need for further research examining policy implementation, specifically how referees implement such changes and their accountability to upholding policy. King and Coughlan\textsuperscript{109} examined concussion knowledge amongst youth referees in rugby, soccer, hockey, and football. They revealed that 85% of referees in response to their survey felt that they play an important role in concussion recognition in youth, but only 41% felt adequately equipped with skills to recognize concussion. Therefore, formal education sessions amongst both new and returning referees is an important first step in reducing concussion in youth sport. Little research examines effective implementation strategies regarding policy in youth sport; however, multimodal approaches with sport-specific content targeting referees has been suggested as an effective strategy to reducing concussion.\textsuperscript{109} Achenbach et al\textsuperscript{16} reported through video analysis that in professional male basketball players, 19% of all injuries coded (33 total) were due to foul play, (denoted as referee assessing a foul). Of the 11 injuries coded where contact was sustained to the head, 2 of 11 injuries were the result of foul play.\textsuperscript{16} Although number of injuries caused by foul play was low, lack of fouls called pertaining to head contact does raise concern and aligns with findings of this study. Due to the limitation of video analysis, this study could not verify suspected concussion or injury, and therefore cannot be directly compared. However, the proportion of player-to-player contact aligns with findings of this study, and therefore warrants concern regarding concussion and injuries sustained due to illegal activity and player-to-player contact. This should be a considered direction for future studies seeking to understand concussion and injury in basketball and illegal play.
3.4.1 Limitations

Limitations to this study stem from quality of video, specifically obstruction of view (by either spectators or external equipment, as examples). Due to obstructed view, there may have been difficulty in determining whether a contact occurred and the nature of the contact. Specifically, game footage may have been subjected to obstructed view for only small increments of time due to movement of camera, players, and referees, therefore, this limitation likely did not lead to any significant systematic differences in the study. Additionally, concussion criteria used in this study, as adapted from other professional sports, are designed to assess the injury using numerous camera angles and high-quality image. A single camera angle may have limited identification of suspected concussion or injury during analysis. However, 100% of games were filmed from an ideal location which was from centre court with elevation. Therefore, this limitation likely did not lead to systematic differences between games. Further, rates of suspected concussion may have been limited by a low sample size. Since only one university level team was used for this analysis, lack generalizability should be a consideration. Therefore, these results should be interpreted with caution when generalizing to other university level basketball teams, and to younger age groups. Further, although we used previously validated criteria for assessing suspected concussion and injury, the nature of such definitions is subjective to the coders, and therefore may result in an overestimation of our results. Additionally, due to anonymity of video analysis, the identified suspected concussions cannot be verified via injury surveillance.

3.5 Conclusion

Canadian male varsity basketball players sustained HC1s at a rate that is 1.55-fold greater than females. Despite the illegality of contact to the head in basketball, we revealed a very small percentage of HC1s identified on film were assessed by referees as a foul. These findings can be
used to further assess fouls associated with HCs in game, and better understand potential sex
differences that may exist when identifying contact to the head in Canadian university basketball.
Further, knowledge of high-risk areas regarding head contacts in competition can be pertinent for
referees and warrants future research on referee behaviours. This study can help inform prevention
strategies targeting head contacts in the game of basketball, however further research should
include a greater sample size to confirm these results.
Chapter 4: Head contact and suspected concussion rates in youth basketball: Time to target head contact penalties for prevention

4.1 Introduction

The sport participation rate in Alberta youth (ages 14-19) is estimated at 86.9% from 2,029 youth reporting participation in a sport or recreational activity in the previous year. Further, 43% of adolescents (12-15 years) and 35% of 16-21 year old’s report participating in organized sports at least once per week. Basketball continues to be one of the most popular sports for youth in Canada, with 28.4% of junior high school students in Calgary and area reporting basketball amongst their top three sports for participation. Basketball ranked first for high school males and was second to dance for high school females in Alberta. High rates of participation in basketball presents opportunity for injury, with 14% of all sport-related injuries in Alberta junior high school students reported in basketball. This was the greatest proportion of sport-injuries from this study. Further, basketball is a high risk sport for injury recurrence in youth. Sport-related concussion (SRC) in basketball has been identified as a common injury for both male and female youth players, with one study reporting a concussion rate of 0.74 per 1000 AEs (95% CI: 0.66-0.82) over 11 seasons in girls, and a rate of 0.33 per 1000 AEs in boys (95% CI: 0.28-0.37). This was the second highest reported injury rate behind ligament sprains for both sexes in competition. Despite differences reported in boys and girls, SRC rates by sex in youth athletes has been less established when compared elite levels. A greater understanding of concussion rates in basketball is critical to informing the safety of basketball and lifelong sport participation for youth.

Video analysis is often used across a variety of sports as a learning tool for measuring player performance retrospectively and has additionally been validated as a tool to analyze injury
Video analysis has been used to document injury in basketball previously, specifically ligamentous injury, but has not been used to assess concussion or head contact (HC)s. The use of video analysis in collision sports has proven effective for assessing concussion and injury in competition in other sports, but remains relatively novel in high contact, non-collision sports such as basketball. Video analysis provides opportunity to assess incidence of suspected concussion and injury, including several additional factors, (court location of HCs, game events and mechanisms, as examples). Therefore, video analysis should be considered as a complimentary tool for future research, in conjunction with injury surveillance, to verify and assess incidence of concussion or injury in competition.

Most studies assessing concussion in basketball stem from collegiate or elite leagues where injury surveillance systems exist. Subsequently, literature pertaining to youth athletes, particularly Canadian youth, is limited. Concussion injury rates in elite and non-elite players have been consistently reported as differing by sex. A study assessing injury in high school basketball players found that girls sustained concussion more frequently than boys over the course of two seasons (IPR= 2.41; 95% CI, 1.49-3.91; P <0.01). Head/face/neck was the third most common injury site for boys and girls when combined (13.6%), and was the second most common site for fractures (23.9%).

It is important to note that head contacts do not always equate to a concussion diagnosis. However, head contacts are an important variable when considering contact sports and the injury potential of sub-concussive hits. Huber et al. quantified HC differences by boys and girls using headband-mounted impact sensors measuring linear and angular velocity accelerations. They demonstrated that boys sustained higher head impact rates compared to girls in basketball during one season [rate ratio (RR)=3.6; 95% CI, 2.6-4.6]. Boys’ and girls’ basketball sustained the
highest rate of head impacts ahead of lacrosse, field hockey, and soccer (when headers were removed from analysis). Buzas et al.\textsuperscript{22} reports basketball with the second highest overall frequency of concussions across 11 years in youth (ages 4-13) reporting to emergency departments (ED) in the United States. These results align with an 8-year Centre for Disease Control ED report estimating basketball as a top five sport leading to non-fatal traumatic brain injury in those under 19 years of age.\textsuperscript{113} Literature pertaining to burden of concussion in Canadian youth basketball players is limited and should be an area of focus considering high participation levels. Literature should identify primary prevention strategies amongst youth basketball players to keep them playing sport for longer, and healthier. Differences in concussion and injury rates between youth boys and girls warrants more research and effective strategies to mitigate concussion in this demographic.

Game events and mechanisms of concussion and injury for youth basketball players are underreported. However, Clifton et al.\textsuperscript{6} demonstrated girls sustained all reported competition injuries most commonly while rebounding in competition with an IR of 0.72 per 1000 AEs (95% CI: 0.65-0.80). Similarly, males also sustained the most competition injuries while rebounding with an IR of 0.71 per 1000 AEs (95% CI: 0.65-0.78).\textsuperscript{5} Further, there is limited research on concussion and injury due to illegal activity. One study reported 12.5\% of all injuries were a result of illegal activity, resulting in 34.4\% as injuries to the head/face/neck.\textsuperscript{60} Understanding illegal play with respect to head contact is imperative to improving the safety of the game. Currently, there are rules in place to mitigate contact to the head at both the youth and collegiate level, but more research is needed to understand the effectiveness of these rules.

The aim of our study was to examine the differences in head contacts (HC1 and HC2, where HC1s are direct, or player-to-player, and HC2s as indirect, or player-to-environment)
between boys and girls by division (Division 1 and Division 2). Operational definitions were adapted from ice hockey and ringette\textsuperscript{14,34} and were modified using face validation via community partners to accurately describe HCs in basketball. We wish to compare specifically the incidence of suspected concussion and injury, court location of HCs, game events in which HCs occur, and the penalization of HCs in youth club basketball players (U16-U18) during 2 tournaments in the 2022 season.

4.2 Methods

4.2.1 Design and Participation

This is a cross-sectional video analysis study in which 48 youth basketball games were examined (24 boys and 24 girls) in Calgary, Canada during the 2022 club basketball season (40-minute total game length). Participants (ages 15-18) were boys and girls registered in 2 tournaments from the 2022 club season. Boys’ and girls’ teams competed in ‘division 1’ (U17/U18) and ‘division 2’ (U17/U16). Teams were analyzed based on seeding for their respective tournaments. Ethical approval was obtained from the University of Calgary Conjoint Health Research Ethics Board (CHREB) (Ethics ID: REB21-1249; Appendices A-F).

4.2.2 Video Footage Collection

Games were recorded during two club tournaments. All video was obtained anonymously with ethical approval by the University of Calgary Conjoint Health Research Ethics Board (Ethics ID: REB21-1249), with additional approval from tournament directors prior to filming. Video was then offloaded from secure digital (SD) cards to a secure server (SharePoint), imported, and analyzed in Dartfish video analysis software.\textsuperscript{105} Games were randomly selected for analysis using a random number generator from a total of 70 filmed games.
4.2.3 Sample Size and Game Selection

There is conflicting evidence with respect to concussion rates in youth compared to university athletes, specifically in Canadian basketball. However, it is consistently reported that at both the high school and university level, females sustain higher concussion rates compared to males. Therefore, we used the male HC1 rate from the university level analysis to obtain a conservative sample size (HC1 IR of 0.62 per 10 player-minutes). Assuming similar rates at the youth level and to detect a clinically relevant difference of 30% between groups, a total of 423 player-minutes was required, (where $\alpha=0.05$, $1-\beta=0.80$). When divided by sex and Division (4 categories), a total of 105.8 player-minutes per division was required. This translates to a total of 11 (rounded) games per category. We analyzed 12 games per division to remain conservative, for a total of 48 games analyzed. All games filmed occurred over 2 tournaments during the 2022 club season. We filmed a total of 70 tournament games including both boys and girls, which we then randomly selected 48 games for analysis using a random number generator, (all games were numbered).

4.2.4 Outcome Measures

All games were analyzed using Dartfish version 10.0 video analysis software based on criteria face-validated by community partners, coaches, administrators, and a former Team Canada video analyst. Individuals tagging video had elite level experience in basketball (n=2). Each coder was trained on the system and the criteria before undertaking interrater reliability with percentage agreement of $\geq 90\%$. Interrater reliability was completed prior to the university analysis. Youth analysis began immediately following this analysis with the same tagging procedure. Therefore, interrater reliability occurred only once. The additional rater was compared with a gold standard rater across all measures. The gold standard assessor had experience in basketball with
approximately 15+ years of player experience, 6 at the university level, approximately 1 year of elite level coaching, and was responsible for the creation of the coding template used in analysis.

HCs were operationally defined as both HC1 (direct) and HC2 (indirect), where HC1s included any HC occurring player-to-player (e.g., elbow to head, head-to-head), and HC2s included any HC with the environment (e.g., head to floor, ball, as examples). We simultaneously assessed court location of HCs, defensive and offensive perspectives (intensity) of each contact, game events of HCs, and whether a penalty was assessed by the referee. HCs were coded with a respective limb and/or trunk contact intensity rated on a scale from 1-3 (mild, moderate, severe: Table 4.1). Mild contacts were defined as inconsequential, where a player was not visibly impacted by the contact. Moderate contacts were defined as a player being visibly disrupted by the contact but was able to complete their executed skill with only subtle consequence. Severe contacts were defined as a player being visibly impacted, resulting in non-execution of their skill, and appeared overly aggressive. Any direct head-to-head contacts were not assessed using the intensity scale. Suspected concussion was assessed using 17 criteria developed for professional sport based on video signs common to all sports. These included: motor incoordination, lying motionless, no protective action- floppy (ragdoll-like), no protective action- tonic (falling stiff), cervical hypotonia, impact seizure/convulsion, tonic posturing, blank/vacant look, uncontrolled fall to the ground (following an observed head contact), controlled fall (following an observed head contact), dazed, slow to get up, clutching at the head, walking away/disengaged from the game, disorientation, confusion, and facial injury. We identified non-concussive injury using validated criteria in soccer video analysis studies. These included: a player remains on the court for longer than 15 seconds, the player appeared to be in pain, the player required medical attention, or the
play was interrupted by the referee due to the injury. Suspected concussion and injury was included in the analysis if one or more of the criteria was met.

**Table 4.1. Description of trunk and limb contact intensities, as adapted from Williamson et al.**

<table>
<thead>
<tr>
<th>Trunk/Limb physical contact (PC)</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1 (‘Mild’)</strong></td>
<td>Inconsequential contact. Contact is visible but did not affect a player’s ability to execute their skill.</td>
</tr>
<tr>
<td><strong>Level 2 (‘Moderate’)</strong></td>
<td>Contact is visible, and execution of skill is affected in a way that the player was visibly disrupted, with consequence (arms were slapped, legs were taken out, body was pushed off direct line course, as examples).</td>
</tr>
<tr>
<td><strong>Level 3 (‘Severe’)</strong></td>
<td>Contact is visible and overly aggressive. Player receiving/initiating contact is obviously unable to execute their skill, with evident consequence (injury, foul, as examples).</td>
</tr>
</tbody>
</table>

*Notes.* This rating scale was face-validated by basketball community partners, administrators, players, coaches, and one team Canada video analyst.

**4.2.5 Data Analyses**

All data analyses were performed using STATA version 15.1 statistical analysis software. Incidence rates (IRs) were used to assess HCs (HC1s and HC2s) and expressed as the number of HCs per 10 player-minutes. Incidence rate ratios (IRR) were used to compare HC and suspected concussion and injury IRs via univariate Poisson regression analyses, adjusted for cluster by team and offset by game length in minutes. For all statistical tests, an alpha level of 0.05 was used. Game events and court location of head contacts were reported as a proportion of total number of head contacts assessed.
4.3 Results

4.3.1 Head Contact Incidence Rates

Division 1. All games analyzed were a standard 40 minutes of ball-in-play, with no games running into overtime. Across 12 games, a total of 238 HCs were sustained by boys, where 89.9% were HC1s and 10.1% were HC2s. Girls sustained a total of 220 HCs in 12 games, where 90.0% were HC1s and 10.0% were HC2s. We revealed an HC1 IR of 0.45 per 10 player-minutes (95% CI: 0.39-0.51) for boys, which was compared with girls with an HC1 IR of 0.41 per 10 player-minutes (95% CI: 0.36-0.47) (IRR=1.08; 95% CI, 0.83-1.41). Further, HC2 IRs for boys and girls did not statistically differ, with a boys IR of 0.05 per 10 player-minutes (95% CI: 0.03-0.07) and girls with an IR of 0.05 per 10 player-minutes (95% CI: 0.03-0.07) (Figure 4.1 and Table 4.2). Boys experienced 100% of HC2s as ball-to-face or head, and girls experienced 95.0% that were ball-to-face or head, and 5.0% that were head-to-floor. Further, majority of HC1s experienced by boys were associated with a limb/trunk contact intensity that was rated ‘moderate’ followed by ‘mild’ and lastly, ‘severe’, (55.5%, 37.4% and 7.1%, respectively). Similarly, girls experienced HC1s most associated with limb/trunk contact intensities of ‘moderate’, followed by ‘mild’ and lastly, ‘severe,’ (53.5%, 37.4%, and 9.1%, respectively).

Table 4.2. Incidence rates for direct (HC1) and indirect (HC2) head contacts for Division 1 boys and girls.

<table>
<thead>
<tr>
<th></th>
<th>HC1 IR (95% CI)</th>
<th>HC2 IR (95% CI)</th>
<th>Total HCs (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Division 1 Boys</strong></td>
<td>0.45 (0.39-0.51)</td>
<td>0.05 (0.03-0.07)</td>
<td>0.50 (0.43-0.56)</td>
</tr>
<tr>
<td><strong>Division 1 Girls</strong></td>
<td>0.41 (0.36-0.47)</td>
<td>0.05 (0.03-0.07)</td>
<td>0.46 (0.40-0.52)</td>
</tr>
</tbody>
</table>
Division 2. Across 12 games, boys incurred a total of 252 HCs, of which 90.5% were HC1s and 9.5% were HC2s. Girls incurred a total of 192 HCs, of which 83.9% were HC1s and 16.2% were HC2s. We revealed a boys HC1 IR of 0.48 per 10 player-minutes (95% CI: 0.42-0.54), which was significantly higher than girls with an HC1 IR of 0.34 per 10 player-minutes (95% CI: 0.29-0.39) (IRR= 1.42; 95% CI, 1.01-1.98). Boys revealed an HC2 IR of 0.05 per 10 player-minutes (95% CI: 0.03-0.07), that was not significantly different than girls with an IR of 0.06 per 10 player-minutes (95% CI: 0.04-0.09) (IRR=0.77; 95% CI, 0.44-1.36) (Figure 4.1 and Table 4.3). Majority of HC2s sustained by boys were ball-to-face or head at 92.3%, and 7.7% were head-to-floor. Girls experienced majority of HC2s that were ball-to-face/head at 83.3%, and 16.7% were head-to-floor. When assessing the associated limb/contact intensity of HC1s, we revealed that most HC1s sustained by boys were a limb/trunk intensity of ‘mild,’ followed by ‘moderate’ and lastly, ‘severe,’ (49.6%, 44.6% and 5.9%, respectively). Girls experienced most HC1s associated with limb/trunk intensities of ‘moderate,’ followed by ‘mild’ and lastly, ‘severe,’ (58.7%, 32.9% and 8.4%, respectively). HC intensities do not include HCs that were head-to-head, (n=6).

Table 4.3. Incidence rates of direct (HC1) and indirect (HC2) head contacts in Division 2 boys and girls.

<table>
<thead>
<tr>
<th>Division</th>
<th>HC1 IR (95% CI)</th>
<th>HC2 IR (95% CI)</th>
<th>Total HCs (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boys</td>
<td>0.48 (0.42-0.54)</td>
<td>0.05 (0.03-0.07)</td>
<td>0.48 (0.42-0.54)</td>
</tr>
<tr>
<td>Girls</td>
<td>0.34 (0.29-0.39)</td>
<td>0.06 (0.04-0.09)</td>
<td>0.40 (0.35-0.46)</td>
</tr>
</tbody>
</table>

Differences in HC rates when comparing sex and division (Figure 4.1), show point estimates that are slightly higher in boys compared to girls, apart from Division 1 and 2 HC2s. Although only 1 comparison was significantly different between sexes, (Division 2 HC1s), it should be noted that
all reported rates suggest point estimates that highlight potential sex differences which should be examined in future research.
Figure 4.1. Incidence rates and incidence rate ratios (IRRs) per 10-player minutes with 95% CIs of total head contacts (HCs), direct head contacts, (HC1) and indirect head contacts, (HC2) by boys and girls of division 1 and division 2, offset by game-minutes.

*Represents a significant p-value < 0.05
4.3.2 Game Events and Court Location

Division 1 boys sustained the majority of HC1s while offensively rebounding (28.9%). Boxing out/rebounding was the most common defensive event for HC1s for boys (36.8%) and girls (47.3%) on defense. Division 1 girls sustained HC1s commonly on driving/attacking offensively (25.0%). Division 2 boys and girls sustained HC1s while driving/attacking offensively (40.8% for boys and 30.0% for girls) and while rebounding defensively (40.8% for boys and 43.7% for girls).

During division 1 games, 67.6% of HCs for boys occurred in the key (144 HC1s, 17 HC2s), 19.3% inside the 3-point line (excluding the key) (44 HC1s, 2 HC2s), and 13.0% outside the 3-point line (26 HC1s, 5 HC2s). Girls experienced 67.7% within the key (134 HC1s, 15 HC2s), 20.5% inside the 3-point line (39 HC1s, 6 HC2s), and 11.8% outside the 3-point line (25 HC1s, 1 HC2). During division 2 games, most HCs occurred in the key for boys (66.3%; 153 HC1s, 14 HC2s) and girls (72.9%; 117 HC1s, 23 HC2s). Inside the 3 point-line was the second most common HC location for both boys (19.4%; 44 HC1s, 5 HC2s) and girls (15.7%; 28 HC1s, 2 HC2s). Outside the 3-point line resulted in 14.3% of HCs for boys (31 HC1s, 5 HC2s) and 10.9% of HCs for girls (16 HC1s, 5 HC2s: Figure 4.2).
4.3.3 Suspected Concussions

Division 1 boys revealed a suspected concussion IR (0.02/10 player-minutes; 95% CI, 0.007-0.03) that was not significantly different than girls (IR=0.008/10 player-minutes; 95% CI, 0.002-0.02) (IRR=2.00; 95% CI, 0.53-7.53). A total of 12 suspected concussions were reported, of which 8 were boys and 4 were girls (Table 4.4). Division 2 boys had a suspected concussion IR (0.02/10 player-minutes; 95% CI, 0.01-0.04) that was not significantly different than girls (IR=0.01/10 player-minutes; 95% CI, 0.005-0.03) (IRR=1.83; 95% CI, 0.71-4.74). A total of 17 suspected concussions were reported, of which boys sustained 11 and girls sustained 6 (Table 4.5.)
Table 4.4. Competition injury and concussion rates for division 1 by sex, reported per 10 player-minutes.

<table>
<thead>
<tr>
<th></th>
<th># of Injuries</th>
<th>Male IR (95% CI)</th>
<th>Female IR (95% CI)</th>
<th>IRR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-concussive</td>
<td>18</td>
<td>0.02 (0.07-0.03)</td>
<td>0.02 (0.01-0.04)</td>
<td>0.80 (0.29-2.18)</td>
</tr>
<tr>
<td>Concussion</td>
<td>12</td>
<td>0.02 (0.007-0.03)</td>
<td>0.008 (0.002-0.02)</td>
<td>2.00 (0.53-7.53)</td>
</tr>
</tbody>
</table>

Table 4.5. Competition injury and concussion rates for division 2 by sex, reported per 10-player minutes.

<table>
<thead>
<tr>
<th></th>
<th># of Injuries</th>
<th>Male IR (95% CI)</th>
<th>Female IR (95% CI)</th>
<th>IRR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-concussive</td>
<td>20</td>
<td>0.02 (0.01-0.50)</td>
<td>0.02 (0.01-0.50)</td>
<td>1.00 (0.34-2.87)</td>
</tr>
<tr>
<td>Concussion</td>
<td>17</td>
<td>0.02 (0.01-0.04)</td>
<td>0.01 (0.005-0.03)</td>
<td>1.83 (0.61-4.83)</td>
</tr>
</tbody>
</table>

4.3.4 Head Contact Penalties

**Division 1.** Boys offensively sustained 127 HC1s and only 19.7% were assessed as a foul. Boys defensively sustained 86 HC1s for which 4.7% were assessed as a foul. Girls offensively sustained 123 HC1s, with only 19.5% assessed as a foul. Girls defensively sustained 74 HC1s, with only 4.1% assessed as a foul. Of all offensive HC1s, 4.8% were assessed as a foul with an associated ‘mild’ limb and/or trunk contact, 22.2% rated ‘moderate’ and 65.0% rated ‘severe.’ HC1s sustained by defenders, none were assessed as a foul with an associated ‘mild’ limb and/or trunk contact, 5.1% of ‘moderate’ contacts, and 23.1% of contacts rated ‘severe.’ (Table 4.6).

**Division 2.** Only 8.8% of HC1s to boys on offense were assessed as a foul, while defensively, of 103 HC1s 3.9% were assessed as a foul. Of 90 total HC1s to girls, 12.2% were assessed as a foul. Of 70 HC1s to girl defenders, 1.5% were assessed as a foul. Of all offensive HC1s, referees assessed 4.0% of limb and/or trunk contacts rated ‘mild’ as a foul, 12.4% of those rated ‘moderate,’ and 26.3% of ‘severe’ contacts. Of all HC1s sustained on defense, 1.2% of limb
and/or trunk contacts rated ‘mild’ were assessed as a foul, 3.9% of ‘moderate’ contacts, and 14.3% of ‘severe.’ (Table 4.6).

**Table 4.6. Percentage of head contacts assessed as a foul by referees by Division.**

<table>
<thead>
<tr>
<th>Intensity of Contact</th>
<th>Foul Assessed by Referee in Division 1 associated with an HC1</th>
<th>Foul Assessed by Referee in Division 2 Associated with an HC1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes (n)</td>
<td>No (n)</td>
</tr>
<tr>
<td>Mild</td>
<td>2.6% (n=4)</td>
<td>97.4% (n=147)</td>
</tr>
<tr>
<td>Moderate</td>
<td>16.1% (n=36)</td>
<td>83.9% (n=187)</td>
</tr>
<tr>
<td>Severe</td>
<td>48.5% (n=16)</td>
<td>51.5% (n=17)</td>
</tr>
</tbody>
</table>

4.4 Discussion

This study is the first to assess suspected concussion, suspected injury, and head contact IRs in Canadian youth basketball players using video analysis. Although the difference in HC1 and HC2 IRs did not differ by sex, these rates in youth do warrant concern. These findings contrast those of Huber et al.\textsuperscript{23} where boys high school basketball players had a significantly higher head impact rate wearing sensors when compared with girls. These findings trend in a direction that conflicts concussion IRs as greater in females than in males.\textsuperscript{24,102,114} Specifically, the Healthy Sport Index of 2018,\textsuperscript{114} reports concussion rates in girls basketball that were nearly twice those reported in males (4.2 concussions per 10,000 AEs versus 2.2 concussions per 10,000 AEs, respectively), as did Lincoln et al.\textsuperscript{24} who revealed an RR of 1.70 (95% CI: 1.30-2.20) comparing girls’ and boys’ high school basketball over 11 years. Similarly, a systematic review by Cheng et al.\textsuperscript{102} reported females had a significantly higher concussion incidence compared to males (relative risk [RR]= 1.99; 95% CI, 1.56-2.54, \(P<0.01\)). Comparatively, our rates (although not significantly different)
reveal point estimates for suspected concussion rates that trend higher for Division 1 boys compared to girls (IRR=2.00; 95% CI, 0.53-7.53), and Division 2 boys (IRR=1.83; 95% CI, 0.71-4.74), although neither were statistically significant. Our differences (notably not statistically significant) in suspected concussions may be attributed to an overestimation of concussion due to criteria used in video analysis versus reported injuries via injury surveillance. The degree to which concussions were seen on film that were reported following competition may not reflect our suspected concussions based on our criteria. We can speculate that concussion rates may have been underestimated, specifically in females, as evidence suggests that females are more likely to report concussion symptoms.\textsuperscript{47,49,103} Therefore, video-based suspected concussion incidence compared with injury surveillance data reported in literature for youth is difficult to compare and may not represent the true incidence of concussion. More literature is required in youth using both video analysis and injury surveillance to accurately compare.

Regarding penalization of HCs in both divisions for boys and girls, it should be noted that the majority occurred because of a limb and/or trunk contact that was rated either ‘mild,’ or ‘moderate.’ ‘Mild,’ as determined by individuals tagging games and by experts involved in face-validation, was a ‘contact in which the player receiving was minimally impacted and deemed inconsequential.’ Therefore, it is likely that referees were not able to see a mild intensity HC without playback of footage which is not possible during games. However, ‘moderate’ and ‘severe’ were defined as contacts in which a player was ‘noticeably impacted’. Therefore, the small proportion of fouls called is concerning for ‘moderate’ and severe’ contacts. A video analysis study by Achenback et al.\textsuperscript{16} analyzed illegal play over 4 seasons in a male professional league, where a reported 91.7% of all injuries to the head were a result of player-to-player collision, and only 2 of 11 (18%) moderate/severe contacts to the head were assessed as a foul by a referee. Contact to the
head in basketball is illegal, which suggests a deeper look into referee behaviours and training regarding their assessment of HCs in competition. As noted by Achenback and colleagues, stricter enforcement of rules regarding contact to the head in basketball may decrease head injuries due to foul play, but may not prove as effective as football and soccer due to characteristics of match play and injury patterns. At the university level, only 25.8% of HC1s to males on offense were assessed as a foul to defenders, and 33.3% of HC1s to females on offense were assessed as a foul to defenders (Fehr et al., unpublished). Our percentage of penalization for HCs in youth are much lower than those reported at the university level. It can be speculated that percentages of HCs assessed as a foul in youth may be lower than referees at the university level due to the lack of experience in referees at the youth level. University level referees in Canada must have refereed in the community, competitively (club or high school), and/or provincially with a minimum year requirement at each level before refereeing university. Therefore, youth level referees likely have a variety of experience, which is minimal compared to requirements of university level referees in Canada.

4.4.1 Limitations

This study should be interpreted within the context of its limitations. These include reduced quality of video. For example, ideal camera angle (high elevation with all players in view) was not always achieved depending on the gym layout. Specifically, 25.0% of Division 1 girls games were filmed without elevation, but all games captured all 10 players on court. Only 33.3% of Division 2 girls games were filmed with elevation. Filmer’s were instructed to film all games from a secondary location if centre court from elevation was not accessible, which was from corner court on the baseline. 100% of video not filmed from centre court with elevation was filmed from this location, effectively capturing all players on court. All film from Division 1 and 2 boys’ games
were filmed at court level, but all players were captured on film from centre court. Another limitation with video analysis is obstruction of view (by spectators, other players, or referees, as examples). Obstruction only occurred for brief moments during footage, as this was often a result of a referee standing in view, or other players in view. This limitation likely did not lead to any significant systematic differences in the study, as it was common to all games assessed, and would only occur in small increments of time. Additionally, suspected concussion criteria used in this study, as adapted from other professional sports, are designed to assess an injury using numerous camera angles and high-quality image. Due to a single camera angle, suspected concussion and injury may have limited identification during analysis and has only been validated for youth in a rugby setting.\textsuperscript{13} Although suspected concussion and injury criteria were previously validated, the nature of the criteria is subject to the final opinion of coders. Despite the high basketball knowledge of each coder, rates of concussion and injury outcomes may be overestimated using such criteria. Lastly, due to anonymity of video analysis, the identified suspected concussions could not be verified via injury surveillance. The results of this study should be interpreted with caution when generalizing to populations of ages that we did not include in our analysis.

4.5 Conclusion

Across 24 games, the absolute number of head contacts for both boys and girls warrants concern given contact to the head in basketball is illegal. A small percentage of HCs incurred by boys and girls in both divisions were penalized, which highlights the need for stricter HC policies and effective implementation strategies targeting prevention of HCs and concussion in competition. We revealed significantly higher rates of HC1s in Division 2 boys compared to girls, however, point estimates for HCs across both divisions highlights the need for further examination into HCs sustained in youth basketball. We examined most HCs occurred in the ‘key’ for both
boys and girls across both divisions. Common game events for sustaining HCs in Division 1 boys were offensively and defensively rebounding, while girls experienced most HCs while offensively attacking the rim, and defensively rebounding. Division 2 boys and girls sustained most HCs while attacking the rim, and defensively while rebounding. Although we did not demonstrate significantly different suspected concussion or injury rates, further research is needed to address concussion and injury in youth basketball via video analysis in conjunction with injury surveillance to confirm these outcomes.
Chapter 5: Conclusion

5.1 Summary of Findings

This thesis is the first to investigate the incidence of HCs, suspected concussion and injury rates, game events in which these outcomes occur, and court location where they occur in both a university and youth demographic. Both studies included in this thesis answer the same research questions regarding the measures listed above. The first study assessed the potential differences in HCs (both direct and indirect) and suspected concussion and injury rates between male and female university basketball players partaking in the 2019/2020 regular season. We found across 10 games at the university level, males experienced an overall HC1 rate that was 1.55-fold greater than that of females. We did not find significant differences in the rate of HC2s or suspected concussions between males and females. Both males and females sustained the most HCs while playing in the ‘key,’ (males 73% females 60%), and while in the act of offensively shooting the ball (males 25% females 20% of all HC1s). Defensively, the primary game events for sustaining HC1s for males was guarding an attacker (41%) and rebounding for females (31%). Further, only 10% of all HC1s to defenders and 24% of HC1s to offense were assessed as a foul by the referee, despite the illegality of HC in basketball. It should be considered that we had a small sample size and results should be interpreted with this in mind.

Our second study investigated similar research questions with a comparison between sexes in a youth demographic (U16-U18). However, we divided youth by division (Division 1 [24 games] and Division 2 [24 games]) for a more like comparison. Division 1 included U18 and U17 teams, and Division 2 included U16 and U17 teams. U17s were included in each division but were analyzed respective to which division they were seeded in during the tournaments we filmed. We found no significant difference between Division 1 boys and girls when comparing
incidence of HC1 and HC2, as well as no difference in suspected concussion or injury. We found that Division 2 boys sustained 1.42-fold greater HC1 incidence compared with girls, but no significant difference in HC2s between sexes in this division. Suspected concussion and injury rates did not differ. Although most rates were not statistically significant comparing boys and girls, the differences in our point estimates do warrant concern for sex differences that may exist when addressing these injury outcomes. More research is required to validate differences between sexes in this age group. Comparable to our university analysis we found that both Divisions, male and female, sustained majority of HCs in the ‘key,’ (Division 1 boys= 67.6%, Division 1 girls= 67.3%, Division 2 boys= 66.3%, Division 2 girls= 72.9%). Division 1 boys sustained majority of HC1s rebounding on offense (29.1%), and defensively while boxing out/rebounding (47.3%). Division 1 girls sustained majority of HCs offensively driving/attacking the rim (25.0%), and defensively while boxing out/rebounding (43.7%). Both Division 2 boys and girls sustained the most HCs while offensively while driving/attacking the rim (40.8% and 30.0%, respectively), and defensively while rebounding (40.8% and 43.7%, respectively). We found an alarmingly low number of HCs called as a foul by referees, despite illegality of HCs in both age categories. This identifies a potential prevention strategy regarding referee’s and penalization of HCs in both youth and university level competitions. A summary of variables assessed across both studies can be found in Table 5.1.
Table 5.1. Summary of non-concussive injury and concussion incidence rates reported per 10 player-minutes, for both university and youth level analysis.

<table>
<thead>
<tr>
<th>Category</th>
<th># of Non-Concussive Injuries</th>
<th># of Concussions</th>
<th>Non-concussive IR (95% CI)</th>
<th>Concussion IR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>University Males</td>
<td>13</td>
<td>4</td>
<td>0.07 (0.03-0.11)</td>
<td>0.02 (0.005-0.05)</td>
</tr>
<tr>
<td>University Females</td>
<td>8</td>
<td>2</td>
<td>0.04 (0.02-0.08)</td>
<td>0.01 (0.001-0.04)</td>
</tr>
<tr>
<td>Division 1 Boys</td>
<td>8</td>
<td>8</td>
<td>0.02 (0.007-0.33)</td>
<td>0.02 (0.007-0.33)</td>
</tr>
<tr>
<td>Division 1 Girls</td>
<td>10</td>
<td>4</td>
<td>0.02 (0.01-0.04)</td>
<td>0.008 (0.002-0.02)</td>
</tr>
<tr>
<td>Division 2 Boys</td>
<td>10</td>
<td>11</td>
<td>0.02 (0.01-0.04)</td>
<td>0.02 (0.01-0.04)</td>
</tr>
<tr>
<td>Division 2 Girls</td>
<td>10</td>
<td>6</td>
<td>0.02 (0.01-0.04)</td>
<td>0.01 (0.005-0.03)</td>
</tr>
</tbody>
</table>

5.2 Strengths

Our studies analyzed incidence rates of HCs, suspected concussion, injury, and several other factors by means of video analysis. Watching video retrospectively allows for a detailed analysis of our research questions, as we could rewind, rewatch, slow down, speed up, or zoom in on portions of film in which an HC, suspected concussion or injury was suspected. Therefore, there is a high degree of certainty when determining our study outcomes. Similarly, both the university and youth studies were analyzed with a group of individuals with an impressive knowledge of basketball, (n=3 for university analysis and n=2 for youth analysis). For both studies, raters involved (n=3 for university analysis, n=2 for youth analysis) were to achieve interrater reliability with percentage agreement of greater than or equal to 90% overall between all categories before beginning analysis. 90% as a conservative agreement level was used to ensure all raters were reliable when assessing video used once analysis began. All raters were
provided with definitions and criteria regarding all outcomes, which was in the form of a ‘cheat sheet,’ to be used by raters each time they analysed video. This sheet was created by all raters through a series of meetings by using real time examples (Appendix J). Further, divisions were created in our youth analysis (Division 1=U18/U17 and Division 2=U17/U16) to allow for more like-comparisons regarding potential player experience, skill, and age.

Overall, video analysis to determine our study outcomes was a strength in our studies in conjunction with several factors (such as the cheat sheet, conservative interrater reliability) contributing to the success of raters during analysis phases and consequently, confidence in our study results.

5.3 Limitations

Use of video analysis to capture incidence of HC and suspected concussion without verification via injury surveillance is a limitation of these studies. Anonymity of video analysis limits the ability to verify suspected concussion and injury seen on film, which can potentially over or underestimate rates. Injury surveillance would ensure verification of identified suspected concussion opposed to using video analysis criteria and would further validate our findings. Injury verification would also allow us to account for potential confounders or effect modifiers that are important to consider when assessing injury or concussion, (height, weight, player experience, history of injury or concussion, as examples).

Further, assessment of our study outcomes relies upon the quality of film, angles, and unobstructed view of play. This limitation was particularly evident in the youth analysis, since games were filmed by a team of research assistants (RAs) using tripods and video cameras, and not acquired retrospectively via high-quality filming equipment which was used for the university analysis. Although RAs were instructed in detail about where each game should be
filmed (centre court, with as much elevation as possible) this was not always feasible given layout of the gym, full stands, no elevation, or referees standing in the way, as examples. RAs were also instructed to capture all players in their camera view; however, this was not always possible due to the nature of fast-paced play. Therefore, quality of video was not always ideal with respect to best angles or no obstruction, which may have resulted in an overall underestimation of our study outcomes. Although footage acquired for the university analysis was of greater quality and used a high angle view, the cameras still follow the ball which may leave some players unaccounted for. Limitations regarding video quality with respect to angles and obstruction were common to all footage analysed in their respective studies, and therefore, is non-differential in each study.

Although we captured a variety of age groups (U16-U18) and skill levels (Divisions 1 and 2), we did not assess study outcomes in youth under U16. Therefore, results from our youth analysis may not be generalizable to players beyond the age groups or divisions assessed. This is a similar limitation to our university analysis, where we did not determine mean age of each team. Further, university level basketball may not be generalizable team-to-team due to significant age gaps that may exist between players. There is no age cap for players in Canadian university basketball, which highlights player experience as a potential confounder or modifier when assessing concussion and injury rates in university athletes.

Our first study in university teams was limited by a small number of games analysed overall. This was due in part to the nature of time required to analyse a single game (approximately 4-5 hours at onset per 40-minute game), not considering time to achieve interrater reliability. Although time to analyse did decrease as study duration went on, this was a limitation in our pilot analysis in university teams.
5.4 Future Directions

Research assessing incidence of concussion, injury, and HCs in Canadian youth and university basketball players has not previously been investigated. These studies should serve as a foundation for defining future research questions analyzing concussion and injury in basketball, specifically in a Canadian context, where concussion literature primarily focuses on collision sport, (football, ice hockey, rugby). Despite being the first to assess our study outcomes, it should be noted that future studies will greatly benefit from injury validation via injury surveillance or impact sensors to further quantify HCs, suspected concussion, or injury seen on film. Further, concussion and injury validation via injury surveillance would allow control of potential confounders or modifiers that cannot be accounted for using video analysis alone.

This study should inform future research endeavours that seek to prevent incidence of concussion in youth and university level basketball players. Although studies have assessed the effectiveness of NMT programming in basketball players to prevent musculoskeletal injury, there has not been research assessing training programs designed to prevent concussion in basketball. These studies have highlighted considerable HC rates at both the youth and university levels, and although we did not reveal a statistically significant sex difference in suspected concussion, our point estimates warrant concern for athletes at both levels and should be a consideration for future research. Further, literature moving forward should adopt a multi-faceted approach for concussion and injury prevention in basketball assessing equipment use, policy and rule modification, and implementation of training programs. Specifically in a youth demographic where concussion literature across all sports is limited compared with studies done in elite level or professional leagues. Equipment use for concussion prevention in basketball may include
mouthguards, which has not been effectively tested in youth basketball players despite basketball (specifically girls), amongst some of the highest rates for dental injuries in sport. Further, the evaluation and implementation of a head-neck component in a basketball-specific NMT program may be of benefit for players at all levels given high HC rates. There has been little research done assessing referee behaviour regarding HCs in basketball, despite its illegality and the low penalization rate of HCs in our studies. Although the NBA, WNBA, NCAA, and Canada Basketball have a concussion policy in place, there has been little to no emphasis regarding adherence to this policy in Canadian youth and university level referees or players. With astonishingly low penalization rates, a direction for future research should assess referee behaviour and adherence to policy, specifically at the youth level where concussion policy varies team to team.
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Appendix A: TCPS Certification Christy Fehr

Successfully completed the Course on Research Ethics based on the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2: CORE 2022)
Appendix B: SHRed Concussions Ethics Certificate of Approval

CERTIFICATION OF INSTITUTIONAL ETHICS APPROVAL

The Conjoint Health Research Ethics Board (CHREB), University of Calgary has reviewed and approved the requested modification to the following research protocol:

Ethics ID: REB18-2107.MOD20
Principal Investigator: Carolyn Emery
Co-Investigator(s): Catherine Lebel
Kati Pasanen
Darren Stefanyshyn
Sarah Kenny
Bradley Gordon Goodyear
Luz Palacios-Derflingher
Chantel Debert
Brent Hagel
Alberto Nettel-Aguirre
Keith Yeates
Jonathan Smirl
Jeffrey Dunn
William Bridel
Tyler Cluff
Sean Dukelow
Amanda Black
Ashley Harris
Kathryn Schneider

Student Co-Investigator(s): Courtney Kennedy
Heidi Morrison
Stephen West
Destiny Lutz
Christy Fehr
Robert Graham
Devon Stuart
Srijal Gupta
Kenzie Friesen
Olivia Galea
Lan Tran
Emily Heming
Alexandra Sobry  
Kirsten Holte  
Paul Eliason  
Carlyn Stilling  
Jocelyn McCallum  
Clodagh Toomey  
Mark Pankow  
Lauren Miutz  
Berlyn Seselja  
Jason Tabor  
Nik Josafatow  
Alexis Cairo  
Ishaan Cheema  
Andrew Lapointe  
Ashley Kolstad  
Justin Tan  
Mackenzie Vaandering  
Sagar Grewal  
Reid Syrydiuk  
Jacalyn Moore  
Delowar Hossain  
Isla Shill  
Heather Shepherd  
Meghan Critchley  
Rylen Williamson  
Linden Penner  
Taylor Price

Study Title: Surveillance in High School to Reduce Concussions and Consequences of Concussions in Canadian Youth

Sponsor: National Football League’s Scientific Advisory Board

Effective: 26-Feb-2022    Expires: 26-Feb-2023

The following documents have been approved:

- MG and FNIRS Poster, 1, January 3, 2023
- NFL Protocol Ethics_V16_Clean_Jan_3_2023, 16, January 3, 2023

The CHREB is constituted and operates in accordance with the current version of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS); International Conference on Harmonization E6: Good Clinical Practice Guidelines (ICH-GCP); Part C, Division 5 of the Food and Drug regulations, Part 4 of the Natural Health Product Regulations and the Medical Device Regulations of Health Canada; Alberta’s Health Information Act, RSA 2000 cH-5; and US Federal Regulations 45 CFR part 46, 21 CFR part
50 and 56.

**Restrictions:**

This Certification is subject to the following conditions:

1. Approval is granted only for the research and purposes described in the application.
2. Any modification to the approved research must be submitted to the CHREB for approval.
3. An annual application for renewal of ethics certification must be submitted and approved by the above expiry date.
4. A closure request must be sent to the CHREB when the research is complete or terminated.

**Approved By:**

Stacey A. Page, PhD, Chair, CHREB

**Date:**

6-Jan-2023 3:18 PM

*Note: This correspondence includes an electronic signature (validation and approval via an online system).*
Appendix C: SHRed Concussions Parent/Guardian Consent Form

Consent Form for Parents/Guardians

TITLE: Surveillance in High Schools to Reduce Concussions and Consequences of Concussions in Canadian Youth – SHRed Concussions

FUNDING: National Football League’s Scientific Advisory Board

INVESTIGATORS:

Principal Investigator: Dr. Carolyn Emery

This consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your child’s participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Take the time to read this carefully and to understand any accompanying information. A copy of this form can be downloaded for your records.

BACKGROUND

Sport is good for youth, but there is always a chance of getting injured. One of the injuries that can happen is a concussion. There has been research on concussion in some Canadian youth sports, such as hockey. This research has looked at why some youth may be more likely to get a concussion, what affects the amount of time it takes to recover from concussion, and ways to prevent concussions in sports. This helps researchers and health professionals develop strategies that can be used to educate teachers, coaches, parents, and students in schools about concussions.

WHAT IS THE PURPOSE OF THE STUDY?

This study has six major goals:

(1) Collect information on injuries and concussions in high school students
(2) Determine why some high school students may have a higher risk of concussion than others
(3) Examine recovery following a concussion
(4) Evaluate what high school students, teachers, coaches, and parents know about concussion, and how they manage it
(5) Create a concussion education program for high school teachers, coaches, and students, and evaluate if it works
(6) Create sport-related concussion prevention programs and evaluate if these programs work

To accomplish these goals, we will be comparing children who sustain a concussion to those who do not through their high school years. These comparisons include a number of measures that look at how the child feels about sport, concentration, physical measures such as flexibility, vision, coordination and balance. Biological measures including MRI and blood tests will also be done. Testing may occur at school, at the University or in a clinic.
WHAT WOULD MY CHILD HAVE TO DO?

We will be asking 6000 high school students participating in at least one high-risk concussion sport (e.g. ice hockey, rugby, football, soccer, basketball, volleyball, wrestling, ringette, cheerleading, lacrosse) across Canada to be in the study.

We will follow these participants through their years at high school. All participating youth will be asked to attend a baseline testing session at the time of study recruitment during which they will be asked to complete a variety of measurements. This will take approximately 3 hours to complete and will occur in a combination of your school location, University of Calgary, Faculty of Kinesiology (Sport Medicine Centre and Sport Injury Prevention Research Centre), and/or community sport medicine clinic setting. The baseline tests/questionnaires will be repeated once per year over 3 years.

Measurements for all participants will include:

1. Completion of the following questionnaires online
   a. Baseline Questionnaire (e.g., demographics, medical history, sport participation). Completed by your child.
   b. Weekly self-report of participation hours in sport and any physical complaints and injuries that they sustain.
   c. Connor-Davidson Resilience Scale (this measures the “ability to “thrive in the face of adversity.”). Completed by your child only.
   d. The Strength and Difficulties Questionnaire is a brief emotional and behavioral screening questionnaire for children and young people.
   e. The Pediatric Quality of Life Inventory, (this measures health related quality of life in youth and adolescent and is completed by you and your child)
   f. Cambridge Brain Sciences (CBS), (this is a computerized test of attention and is completed by your child alone)
   g. 8-item PROMIS sleep-disturbance and sleep-related impairment short-forms completed by your child.
   h. Concussion Knowledge, Beliefs and Behaviour Questionnaire (completed by you and your child)

2. The following tests and physical assessments of your child administered by qualified research staff. The location of testing will be at the school, university or clinic
   a. Sport Concussion Assessment Tool 5 (SCAT5) (school or university or clinic)
   b. Cervical spine evaluation including measures of range of motion, strength, endurance, head and neck position sense and neuromotor control
   c. Vision assessment including tests of smooth pursuit, saccadic eye movement, convergence, optokinetic nystagmus, and stereo visual acuity test
   d. Vestibular, balance and strength measures will include the head thrust test, dynamic visual acuity, the Functional Gait Assessment, vertical jump height and grip strength
e. Walking While Talking Test, which involves walking at a normal pace, walking and
reciting the alphabet, and walking and reciting every other letter of the alphabet

f. 20-metre shuttle run, which involves travelling 20m distances within a set time.
The set time decreases as the test progresses. Your child will initially be walking to
complete the 20m distance, and eventually progress to jogging/running. The test
ends when they can no longer complete the distance in the set time. Your child will
be asked to wear a heart rate monitor during the whole 20-metre shuttle run to
identify their maximum heart rate as well as their heart rate 5 minutes after they
have completed the test.

g. KINARM Robot assessment, which involves performing arm movements, including
reaching and target hitting tasks

h. Blood test to help identify presence of biomarkers (chemicals) associated with
concussion. Blood will be taken by a trained phlebotomist or nurse with experience
in pediatric phlebotomy, who can help answer any questions, concerns or anxiety
your child may have about the blood test. A maximum of two attempts will be made
at each session. If your child is uncomfortable or anxious about the blood test, or if
they want to stop for any reason, they may do so. Your permission is being asked to
store blood specimens in a biobank for future studies, which may include sharing
the specimen, stripped of all identifying information, with other investigators for
research purposes. We will also be asking your child to have their blood taken in
the mid-season of their sport year.

Some measurements and assessments will only be undertaken on specific athlete groups:

i. Football, ice hockey, ringette or lacrosse athletes will be asked to have their helmet
fit assessed

j. Rugby and/or football athletes may be asked to participate in a study where they
will be asked to wear a mouthguard including wearable technology to measure
body and head impacts

A study therapist (Certified Athletic Therapist and/or physiotherapist) will be visiting your
child’s school on a weekly basis. If your child suffers any injury during the school year, they will
be able to have their injury assessed by the study therapist. If the study therapist suspects that
your child may have a concussion, they will refer your child to a study physician with expertise in
youth sport-related concussion.

3. For those children who have sustained a suspected concussion, the following examinations
and assessments will occur:

If you, your child, the coach, or other team personnel suspects that your child has sustained a
concussion, your child will have the opportunity to follow-up with a SHRed aligned physician
specializing in concussion within 72-hours. The SHRed aligned physician will assess and
diagnose your child’s injury and recommend what your child should do to recover from it fully
before returning to sports. Your child can continue seeing the physician until cleared to return to
playing sports.
Your child will be asked to repeat the baseline measurements described above (except the 20m shuttle run). The following additional assessments will be conducted:

a. Illness Perception Questionnaire,
b. Behavioral Avoidance Scale,
c. Behavioral Response to Illness Questionnaire
d. Graded Aerobic Treadmill Test, a standardized incremental treadmill test.
e. Actigraph which is a wearable technology monitor of physical activity to be worn around the waist following initial appointment (within 72 hours) with physician following concussion to monitor sleep and levels of physical activity (light-moderate-intensive). They may be asked to wear the Actigraph 30 days after the concussion and 6 months after the concussion.
f. Blood tests following concussion (acutely within 72 hours, 1 week, and every 2 weeks until physician clearance to return to sport). Your permission is being asked to store blood specimens in a biobank for future studies, which may include sharing the specimen, stripped of all identifying information, with other investigators for research purposes.
g. MRI – as soon as possible after the injury and 30 days following concussion, your child will be asked to undergo an MRI.
h. Finally, your child may be invited to participate in interviews or small group discussions about their knowledge, beliefs, and behaviours towards concussion. Information from interviews and groups discussions will be used to help develop a concussion education program.
i. Your child’s school sport team may be selected to participate in the evaluation an injury prevention strategy. In this case, additional information will be provided to you and specific consent for participation in the program will be sought at that time.

4. Uninjured/healthy comparison group

We are trying to learn about the differences between children who experience a concussion and those who do not. At the time any study participant sustains a concussion, a student participating in the study who has not had a concussion will also be asked to undergo an MRI assessment and/or wear an Actigraph. This student will be selected to be similar to the student with a concussion regarding age, sex, and sport participation. This approach will help us to determine if MRI can help diagnose concussion. Wearing the Actigraph will help us determine the difference in activity and sleep levels between individuals who have or have not sustained a concussion.
WHAT ARE THE RISKS FOR MY CHILD?

Physical Assessments – All physical assessments will be done under close supervision and every effort will be made to ensure the safety of your child. As with any physical activity, there is the possibility of a muscle strain for tests, such as running. Some testing may result in dizziness or muscle fatigue for a short time following the tests. The risk of injury will be reduced by careful supervision by trained research team members during testing procedures. The neck, balance, vestibular, eye movement and other tests are ones that are typically used in clinical practice. These tests will all be done by clinicians who have training in the tests. If an increase in discomfort occurs above what is typically expected during testing or if your child wishes to stop testing, your child should let the tester know. If your child does have any symptoms at any time during testing, they should let the tester know and the test will be stopped.

Blood tests - The blood tests will be done following standardized laboratory procedures. The person taking your child’s blood will be a trained technician. Although very rare, there is a possibility of local infection within days of having blood taken. There is also a remote possibility of fainting. There is a possibility of a slight bruise at the needle site.

Magnetic resonance imaging (MRI) is a technique that uses magnets and radio waves, not radiation, to take pictures of the body. MRI has no known harmful effects as long as your child has none of the risk factors that will be screened for by the MRI technologist. Specifically, your child should not have an MRI if they have a pacemaker or certain other metal objects inside their body (including dental braces), because the strong magnets in the MR scanner might cause these to heat up or move, causing harm. Your child will also need to remove all metal from their clothing and pockets; otherwise these objects could be pulled into the magnet and cause harm. No metal can be brought into the magnet room at any time, since the magnet is always “on”. During the MRI session, your child will lie on a padded table and be asked to hold as still as possible while pictures are being taken. The MRI technologist will be carefully monitoring the session and will answer any questions or concerns that you or your child may have during the session. When the scan begins, your child will hear a loud knocking noise (like a drum beat) that can change at times during the scan. If your child cannot lie still enough to complete a high-quality scan, is uncomfortable or anxious, or wants to stop for any reason, they can be removed from the scanner immediately. Further, MRI will not be performed if your child feels too claustrophobic to enter the scanner.

ARE THERE ANY BENEFITS FOR MY CHILD?

There are some direct benefits to you or your child. The information we get from this study will give researchers a better understanding of high school students’ injuries. This information will help develop strategies that can be used to prevent sport and recreational injuries in the future. The schools of students participating in the study will have access to a study therapist (athletic therapist or physiotherapist) one day per week to facilitate concussion educational opportunities in your child’s school. The study therapist will assess any injury sustained by a study participant in the previous week and make recommendations for follow-up. All study participants will have access to follow-up with a study physician with expertise in youth sport-related concussion within 72 hours of sustaining a suspected concussion.
It is possible that you and/or your child may learn more about injuries and concussions. If your child gets injured during the study, they will be assessed by a study therapist. If the study therapist suspects that your child may have a concussion, they will refer your child to a study physician.

**Incidental findings**

In the unlikely scenario that a researcher observes a suspected abnormality in your child's results (i.e. images, blood tests), a study physician will be consulted and provided with you and your child's information. He or she will make a determination of its potential significance to your child's health and welfare. If considered to be a finding of potential clinical significance, you will be informed and the physician will make recommendations for follow-up.

**DOES MY CHILD HAVE TO PARTICIPATE?**

Your child does not have to be in the study. Participation in the study is voluntary and your child may withdraw from the study at any time by contacting the study coordinator. If your child withdraws from the study, you and your child may request to withdraw their data from the study, as well. You may request to have any stored blood specimens destroyed if your child decides to withdraw from the study. Your child's involvement in their team or school will not be affected if they choose not to consent to take part in the study. You will be informed if there is new information available through this study.

Your child may be contacted in the future and be invited to take part in other aligned research studies in which separate consent will be sought. Data collected during this study may be combined and reported with data from other future studies conducted by this research team. We will not share your/your child's identifying information with anyone outside the research team.

**WILL THERE BE FINANCIAL COMPENSATION, OR WILL THERE BE COSTS FOR MY CHILD?**

There will be no financial compensation or costs to you or your child as a participant in this study. At the time of study related visits at a university or clinic, parking will be paid for you. In addition, juice and snacks will be available to your child at the time of blood draw.

**WILL MY CHILD'S RECORDS BE KEPT PRIVATE?**

All information collected throughout the study period will be de-identified and will remain strictly confidential. Only the investigators responsible for this study, the research team members directly supervised by a study investigator, and the team statistician who will analyze the data, the University of Calgary, and the Conjoint Health Research Ethics Board will have access to this information. Data will be collected primarily through an online web-based customized surveillance platform with authentication for users, encryption, and password protection in accordance with Personal Health Information Protection and Privacy Act (HIPPA) guidelines and in accordance with University of Calgary information Security Control Requirements approval and stored on an OVH Canada dedicated server in compliance with University of Calgary requirements.
Confidentiality will be protected by using only study identification numbers in the database. Any results of the study, which are reported, will in no way identify study participants. Online surveys may ask for personal identifiers or information that may be used to identify your child. However, no direct link is made between their information and their data. De-identified data may be used in future studies in alignment with this project. No medical data outside of study data collection will be accessed by the research team.

**IF MY CHILD SUFFERS A RESEARCH RELATED INJURY, WILL WE BE COMPENSATED?**

In the unlikely event that your child suffers an injury because of participating in this research, the University of Calgary, or the researchers will provide no compensation. You still have all your legal rights. Nothing said here will alter your right to seek damages.
SIGNATURES

Your signature on this form indicates that you have understood the information regarding your child’s participation in the research project and agree to allow them to participate. In no way does this waive your legal rights nor release the investigators or involved institutions from their legal and professional responsibilities. You and/or your child are free to withdraw from the study at any time without jeopardizing health care and/or education. If you have further questions related to this research, please contact:

Study Research Coordinator at SHRedConcussions@ucalgary.ca or Carolyn Emery 403-220-4608

If you have any questions concerning your child’s rights as a possible research participant, or research in general, or if you feel your child is being mistreated, please contact the Chair of the Conjoint Health Research Ethics Board, University of Calgary, at 403-220-7990.

_________________________________________  _______________________________  _______________________________
Parent/Guardian’s Name  Signature  Date

Parent Email address: __________________________________________________________

Parent Phone Number: _________________________________________________________

Please check this box if you are willing for your child to be contacted for future studies  □

*Required Fields

_________________________________________  _______________________________  _______________________________
Child’s Name  Email  Birthdate

_________________________________________  _______________________________  _______________________________
Investigator/Delegate’s Name  Signature  Date

_________________________________________  _______________________________  _______________________________
Witness’ Name  Signature  Date

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

SHRED Injuries (REB18-2107)
Dr. Carolyn Emery

Page 8 of 8
v.6 – Feb. 06, 2020
Appendix D: SHRed Concussions Child Assent Form

Assent Form

TITe: Surveillance in High Schools to Reduce Concussions and Consequences of Concussions in Canadian Youth – SHRed Concussions

FUNDING: National Football League Scientific Advisory Board

PRIMARY INVESTIGATOR: Dr. Carolyn Emery

What is a research study?

A research study is a way to learn new information about something. Individuals do not need to be in a research study if they don’t want to.

Why are you being asked to be part of this research study?

You are being asked to take part in this research study because we are trying to learn more about why some youth may be more likely to get a concussion, what affects the amount of time it takes to recover from concussion, and ways to prevent concussions is sports.

You are being asked to take part in this research study because you are a high school student participating in at least one high-risk concussion sport (e.g. ice hockey, rugby, American football, soccer, basketball, volleyball, wrestling, ringette, cheerleading, lacrosse). Approximately 6000 high school students across the country will be recruited for this study. The hope is to follow participants for 3 years.

If you join the study, what will happen to you?

- You will be asked to complete a variety of tests when you enter the study. These will take approximately 3 hours. Some tests will ask you questions about sport participation, injury history, and different aspects of your life. Some tests will be on the computer or tablet and some will require you to work with a physiotherapist to evaluate your balance and neck. Some tests will involve physical activity, such as running and jumping.
- You will be asked to complete a blood test and a robotic assessment.
- You may be asked to undergo a one-hour MRI session to help us determine if MRI can help diagnose concussion
- You will be asked to have your helmet fit assessed if participating in football, ice hockey, ringette, or lacrosse
- If playing rugby, you may be asked to participate in a study where you will be asked to wear a mouthguard including wearable technology to measure body and head impacts.
- You will be asked to keep track of your participation in sports, and you will be asked to report any injuries or concussions you get during your participation in the study.
- If you, your parent/guardian or coach thinks you might have a concussion, you will be able to see a SHRed aligned doctor who will decide if you have a concussion and what you should do to recover from it fully before going back to playing sports. You
will also repeat the tests you completed at the beginning of the study, along with questionnaires used for concussion injuries and a treadmill test. Some participants will receive an Actigraph (wearable technology monitor of physical activity) to be worn around the waist (Calgary only) following initial appointment (within 72 hours) with physician following concussion to monitor sleep and levels of physical activity (light-moderate- intense). These tests will allow us to see any changes that happen after a concussion and during recovery. You will keep seeing the doctor until you return to playing sports.

- You will be asked to complete blood tests within 72-hours following concussion, at 1 week following concussion and then every 2 weeks until you have returned to sport.
- You will be asked to undergo an MRI session within 72-hours following a concussion and 30 days following concussion.
- You may be involved in small group study that would involve interviews in a group setting.
- You may be asked to help us test an injury prevention program during the study. This program could be a special training program, warm-up or type of equipment.
- You may be in the study for 3 years, if you choose.

Will any part of the study hurt?

The testing done at the start of the season will not hurt. The measurements described above will be done under close supervision and every effort will be made to ensure your safety. If you have any painful areas in your body, please let the testing staff know at the start of testing and some of the tests may be modified or left out. As with any physical activity, there is the possibility of a muscle pull or strain for tests, such as running. Some of the testing may result in dizziness or fatigue in your neck muscles for a short time following the tests. If you do have any symptoms at any time during testing, please let the tester know and it will be stopped.

The blood tests will be done following standard laboratory procedures. The person taking your blood will be a trained technician. You should let the person taking your blood know if you have any allergies. Although very rarely, there is a possibility of local infection within days of having blood taken. You would need to see a physician for this and be treated with antibiotics. There is also a remote possibility of fainting, which would be related to having a needle. This is unpredictable and is resolved by lying down for a short period during or after the blood test. You would recover completely from this. There is a possibility of a slight bruise at the needle site.

Magnetic resonance (MR) is a technique that uses magnets and radio waves, not radiation, to take pictures of the body. MRI has no known harmful effects as long as you have none of the risk factors, that you will be screened for by the MRI technologist. Specifically, you should not have an MRI if you have a pacemaker or certain other metal objects inside your body, especially around the eyes because the strong magnets in the MR scanner might cause these to heat up or move, causing harm. You will also need to remove all metal from
your clothing and pockets; otherwise these objects could be pulled into the magnet and cause harm. No metal can be brought into the magnet room at any time, since the magnet is always “on”.

Will the study help you or others?

- If you do get a concussion during the study, you will be able to see a SHRed aligned doctor within 72-hours, while other athletes not in the study would have to wait much longer before they could be seen by a doctor.
- The information we get from this study may help us to provide better ways of preventing injuries and concussions in youth.

Do your parents/guardians know about this study?

Yes, your parents/guardians will receive information about this study. You can talk this over with them before you decide.

Who will know what you did in the study?

The information collected about you during this study will be kept safe. Nobody will know what you did in the study except the people doing the research. The information about you will not be given to your parents/guardians, except for the concussion test results. The researchers will not tell your friends or anyone else. The information collected about you may be combined and reported with data from other studies conducted by this research team. You may be contacted in the future and invited to take part in other research studies that are like this study, or which look at any injuries you may have. We will not share your contact information with anyone outside of the research team.

Incidental findings

In the unlikely scenario that a researcher observes a suspected abnormality in your results (i.e. images, blood tests), an appropriate study physician will be consulted and provided with your and your parents/guardians information. He or she will make a determination of its potential significance to your health and welfare. If considered to be a finding of potential clinical significance, your parents/guardians will be informed.

What do you get for being in the study?

You do not get any money or gifts for being in this research study. At the time of study related visits at the university or clinic, parking will be paid for you. In addition, juice and snacks will be available to you at the time of blood draw.

Do you have to be in the study?

You don’t have to be in the study. No one will be upset if you don’t want to do this study. If you don’t want to be in the study, you just have to tell us. It’s up to you. You can also take
more time to think about being in the study and also talk some more with your parents/guardians about being in the study. If you start the study and then change your mind, you can decide not to take part anymore, just tell your parents/guardians and the researchers.

What if you have any questions?

If you have any questions about the study, please contact or have your parents/guardians contact the people organizing the study at SHREDInjuries@ucalgary.ca. If you feel you are being mistreated, you can also contact the Chair of the Conjoint Health Research Ethics Board, University of Calgary at 403-220-7990.

Assent:

Do you want to be in this study?

Please put a mark sign (✓) next to your choice, then please write your name below.

☐ Yes, I will be in this research study ☐ No, I don’t want to be in this research study

_________________________ ___________________________ ___________________________
Child's Name (Print) Signature of Child Date

_________________________ ___________________________ ___________________________
Person who received assent Signature Date

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.
Appendix E: SHRed Concussions Mature Minor Consent Form

Consent Form for Participants

TITLE: Surveillance in High Schools to Reduce Concussions and Consequences of Concussions in Canadian Youth – SHRed Concussions

FUNDING: National Football League’s Scientific Advisory Board

INVESTIGATORS:

Principal Investigator: Dr. Carolyn Emery

This consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Take the time to read this carefully and to understand any accompanying information. A copy of this form can be downloaded for your records.

BACKGROUND

Sport is good for youth, but there is always a chance of getting injured. One of the injuries that can happen is a concussion. There has been research on concussion in some Canadian youth sports, such as hockey. This research has looked at why some youth may be more likely to get a concussion, what affects the amount of time it takes to recover from concussion, and ways to prevent concussions in sports. This helps researchers and health professionals develop strategies that can be used to educate teachers, coaches, parents, and students in schools about concussions.

WHAT IS THE PURPOSE OF THE STUDY?

This study has six major goals:

1. Collect information on injuries and concussions in high school students
2. Determine why some high school students may have a higher risk of concussion than others
3. Examine recovery following a concussion
4. Evaluate what high school students, teachers, coaches, and parents know about concussion, and how they manage concussion
5. Create a concussion education program for high school teachers, coaches, and students, and evaluate if it works
6. Create sport-related concussion prevention programs and evaluate if these programs work

To accomplish these goals, we will be comparing children who sustain a concussion to those who do not through their high school years. These comparisons include a number of measures that look at how you feel about sport, concentration, physical measures such as flexibility, vision, coordination and balance. Biological measures including MRI and blood tests will also be done. Testing may occur at school, at the University or in a clinic.

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Dr. Carolyn Emery
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WHAT WOULD I HAVE TO DO?

We will be asking 6000 high school students participating in at least one high-risk concussion sport (e.g. ice hockey, rugby, football, soccer, basketball, volleyball, wrestling, ringette, cheerleading, lacrosse) across Canada to be in the study.

We will follow these participants through their years at high school. All participating youth will be asked to attend a baseline testing session at the time of study recruitment during which they will be asked to complete a variety of measurements. This will take approximately 3 hours to complete and will occur in a combination of your school location, University of Calgary, Faculty of Kinesiology (Sport Medicine Centre and Sport Injury Prevention Research Centre), and/or community sport medicine clinic setting. Most of the baseline tests/questionnaires will be repeated once per year over 3 years. Some of the Psychosocial and sleep questionnaires (items 1c, 1d, 1e, and 1g below) may be repeated every 3 months to determine changes in these measures during the COVID-19 pandemic.

Measurements for all participants will include:

1. Completion of the following questionnaires online
   a. Baseline Questionnaire (e.g., demographics, medical history, sport participation). Completed by you.
   b. Weekly self-report of participation hours in sport and any physical complaints and injuries that you sustain.
   c. Connor-Davidson Resilience Scale (this measures the "ability to "thrive in the face of adversity."). Completed by you only.
   d. The Strength and Difficulties Questionnaire is a brief emotional and behavioral screening questionnaires for children and young people.
   e. The Pediatric Quality of Life Inventory, (this measures health related quality of life in youth and adolescent and is completed by you and your parent)
   f. Cambridge Brain Sciences (CBS), (this is a computerized test of attention and is completed by you)
   g. 8-item PROMIS sleep-disturbance and sleep-related impairment short-forms completed by you.
   h. Concussion Knowledge, Beliefs and Behaviour Questionnaire (completed by you and your parent)

2. The following tests and physical assessments of you administered by qualified research staff. The location of testing will be at the school, university or clinic
   a. Sport Concussion Assessment Tool 5 (SCAT5) (school or university or clinic)
   b. Cervical spine evaluation including measures of range of motion, strength, endurance, head and neck position sense and neuromotor control
   c. Vision assessment including tests of smooth pursuit, saccadic eye movement, convergence, optokinetic nystagmus, and stereo visual acuity test
   d. Vestibular, balance and strength measures will include the head thrust test, dynamic visual acuity, the Functional Gait Assessment, vertical jump height and grip strength
e. Walking While Talking Test, which involves walking at a normal pace, walking and reciting the alphabet, and walking and reciting every other letter of the alphabet.

f. 20-metre shuttle run, which involves travelling 20m distances within a set time. The set time decreases as the test progresses. You will initially be walking to complete the 20m distance, and eventually progress to jogging/running. The test ends when you can no longer complete the distance in the set time. You will be asked to wear a heart rate monitor during the whole 20-metre shuttle run to identify their maximum heart rate as well as their heart rate 5 minutes after they have completed the test.

g. KINARM Robot assessment, which involves performing arm movements, including reaching and target hitting tasks.

h. Blood test to help identify presence of biomarkers (chemicals) associated with concussion. Blood will be taken by a trained phlebotomist or nurse with experience in pediatric phlebotomy, who can help answer any questions, concerns or anxiety you may have about the blood test. A maximum of two attempts will be made at each session. If you are uncomfortable or anxious about the blood test, or if you want to stop for any reason, they may do so. Your permission is being asked to store blood specimens in a biobank for future studies, which may include sharing the specimen, stripped of all identifying information, with other investigators for research purposes. We will also be asking you to have your blood taken in the mid-season of their sport year.

Some measurements and assessments will only be undertaken on specific athlete groups:

i. Football, ice hockey, ringette or lacrosse athletes will be asked to have their helmet fit assessed.

j. Rugby and/or football athletes may be asked to participate in a study where they will be asked to wear a mouthguard including wearable technology to measure body and head impacts.

A study therapist (Certified Athletic Therapist and/or physiotherapist) will be visiting your school or practice on a weekly basis. If you suffer any injury during the year, you will be able to have your injury assessed by the study therapist. If the study therapist suspects that you may have a concussion, they will refer you to a study physician with expertise in youth sport-related concussion.

3. For those participants who have sustained a suspected concussion, the following examinations and assessments will occur:

If you, your parent, the coach, or other team personnel suspects that you have sustained a concussion, you will have the opportunity to follow-up with a SHRed aligned physician specializing in concussion within 72-hours. The SHRed aligned physician will assess and diagnose your injury and recommend what you should do to recover from it fully before returning to sports. You can continue seeing the physician until cleared to return to playing sports.

You will be asked to repeat the baseline measurements described above (except the 20m shuttle run). The following additional assessments will be conducted:
a. Illness Perception Questionnaire,
b. Behavioral Avoidance Scale,
c. Behavioral Response to Illness Questionnaire
d. Graded Aerobic Treadmill Test, a standardized incremental treadmill test.
e. Actigraph which is a wearable technology monitor of physical activity to be worn around the waist following initial appointment (within 72 hours) with physician following concussion to monitor sleep and levels of physical activity (light-moderate-intense). You may be asked to wear the Actigraph 30 days after the concussion and 6 months after the concussion.
f. Blood tests following concussion (acutely within 72 hours, 1 week, and every 2 weeks until physician clearance to return to sport). Your permission is being asked to store blood specimens in a biobank for future studies, which may include sharing the specimen, stripped of all identifying information, with other investigators for research purposes.
g. MRI – as soon as possible after the injury and 30 days following concussion, you will be asked to undergo an MRI. If you are ineligible to undergo an MRI scan (braces or claustrophobic for example), they will be offered the ability to have an fNIRS and EEG analysis.
h. Finally, you may be invited to participate in interviews or small group discussions about their knowledge, beliefs, and behaviours towards concussion. Information from interviews and groups discussions will be used to help develop a concussion education program.
i. Your sport team may be selected to participate in the evaluation an injury prevention strategy. In this case, additional information will be provided to you and specific consent for participation in the program will be sought at that time.

4. Uninjured/healthy comparison group

We are trying to learn about the differences between children who experience a concussion and those who do not. At the time any study participant sustains a concussion, an athlete participating in the study who has not had a concussion will also be asked to undergo an MRI assessment and/or wear an Actigraph and/or be asked to participate in the KINARM assessment. This athlete will be selected to be similar to the student with a concussion regarding age, sex, and sport participation. This approach will help us to determine if MRI can help diagnose concussion. Wearing the Actigraph will help us determine the difference in activity and sleep levels between individuals who have or have not sustained a concussion. The KINARM assessment is a measure of neuro-motor control and will allow us to measure any differences between concussed individuals and those who did not suffer a concussion.
WHAT ARE THE RISKS TO ME?

Physical Assessments – All physical assessments will be done under close supervision and every effort will be made to ensure your safety. As with any physical activity, there is the possibility of a muscle strain for tests, such as running. Some testing may result in dizziness or muscle fatigue for a short time following the tests. The risk of injury will be reduced by careful supervision by trained research team members during testing procedures. The neck, balance, vestibular, eye movement and other tests are ones that are typically used in clinical practice. These tests will all be done by clinicians who have training in the tests. If an increase in discomfort occurs above what is typically expected during testing or if you wish to stop testing, you should let the tester know. If you do have any symptoms at any time during testing, you should let the tester know and the test will be stopped.

Blood tests - The blood tests will be done following standardized laboratory procedures. The person taking your blood will be a trained technician. Although very rare, there is a possibility of local infection within days of having blood taken. There is also a remote possibility of fainting. There is a possibility of a slight bruise at the needle site.

Magnetic resonance imaging (MRI) is a technique that uses magnets and radio waves, not radiation, to take pictures of the body. MRI has no known harmful effects as long as you have none of the risk factors that will be screened for by the MRI technologist. Specifically, you should not have an MRI if they have a pacemaker or certain other metal objects inside their body (including dental braces), because the strong magnets in the MR scanner might cause these to heat up or move, causing harm. You will also need to remove all metal from their clothing and pockets; otherwise these objects could be pulled into the magnet and cause harm. No metal can be brought into the magnet room at any time, since the magnet is always “on”. During the MRI session, you will lie on a padded table and be asked to hold as still as possible while pictures are being taken. The MRI technologist will be carefully monitoring the session and will answer any questions or concerns that you or your parent may have during the session. When the scan begins, you will hear a loud knocking noise (like a drum beat) that can change at times during the scan. If you cannot lie still enough to complete a high-quality scan, are uncomfortable or anxious, or want to stop for any reason, you can be removed from the scanner immediately. Further, MRI will not be performed if you feel too claustrophobic to enter the scanner.

Near-Infrared (NIR) light can be used to measure blood flow responses in the brain. Near-infrared spectroscopy (NIRS) systems offer a non-invasive and safe way to measure oxygen content in the brain. This is done by shining light into the tissue. Different light is absorbed differently by blood. The light is measured using fiber optics. These fiber optics will be placed on the head using a head cap.

Electroencephalography (EEG) can be used to measure neuronal activity in the brain. EEG offers a non-invasive and safe way to measure brain activity. This is done by attaching electrodes to the scalp. These electrodes are sensitive to electric signals and thereby record electrical signals in their vicinity. The electrodes will be placed on the head using a head cap. An electrocardiogram (ECG) monitors heart function by measuring electrical activity of the heart. This is achieved through the placement of electrodes on three positions on the chest.
If you consent to be part of this study, we will use fNIRS/EEG/ECG to examine brain activity, cardiac rhythm, and oxygen levels. Furthermore, we will examine these measures in relation to questionnaires relating to chronic and acute stress, pain, fatigue, and concussion history.

The EEG, fNIRS, and ECG techniques are very safe and there are no risks to them.

**WILL I BENEFIT IF I TAKE PART?**

There are some direct benefits to you. The information we get from this study will give researchers a better understanding of high school students’ injuries. This information will help develop strategies that can be used to prevent sport and recreational injuries in the future. The schools or clubs of athletes participating in the study will have access to a study therapist (athletic therapist or physiotherapist) one day per week to facilitate concussion educational opportunities. The study therapist will assess any injury sustained by a study participant in the previous week and make recommendations for follow-up. All study participants will have access to follow-up with a study physician with expertise in youth sport-related concussion within 72 hours of sustaining a suspected concussion.

It is possible that you and/or your parent may learn more about injuries and concussions. If you get injured during the study, you will be assessed by a study therapist. If the study therapist suspects that you may have a concussion, they will refer you to a study physician.

**Incidental findings**

In the unlikely scenario that a researcher observes a suspected abnormality in your results (i.e. images, blood tests), a study physician will be consulted and provided with you and your parent’s information. He or she will make a determination of its potential significance to your health and welfare. If considered to be a finding of potential clinical significance, you will be informed and the physician will make recommendations for follow-up.

**DOES I HAVE TO PARTICIPATE?**

No, you do not have to be in the study. Participation in the study is voluntary and you may withdraw from the study at any time by contacting the study coordinator. If you leave the study, you may also request to withdraw your data. You may request to have any stored blood specimens destroyed if you decide to withdraw from the study. Your involvement in your team or school will not be affected if you choose not to consent to take part in the study. You will be informed if there is new information available through this study.

You may be contacted in the future and be invited to take part in other aligned research studies in which separate consent will be sought. Data collected during this study may be combined and reported with data from other future studies conducted by this research team. We will not share your identifying information with anyone outside the research team.
WILL THERE BE FINANCIAL COMPENSATION, OR WILL THERE BE COSTS FOR ME?

There will be no financial compensation or costs to you or your parent as a participant in this study. At the time of study related visits at a university or clinic, parking will be paid for you. In addition, juice and snacks will be available to you at the time of blood draw.

We will be offering pizza parties, as well as having random draws for participants for U of Calgary Dinos, Calgary Hitmen, or other games.

WILL MY RECORDS BE KEPT PRIVATE?

All information collected throughout the study period will be de-identified and will remain strictly confidential. Only the investigators responsible for this study, the research team members directly supervised by a study investigator, and the team statistician who will analyze the data, the University of Calgary, and the Conjoint Health Research Ethics Board will have access to this information. Data will be collected primarily through an online web-based customized surveillance platform (athlete monitoring) with authentication for users, encryption, and password protection in accordance with Personal Health Information Protection and Privacy Act (HIPPA) guidelines and in accordance with University of Calgary information Security Control Requirements approval and stored on an OVH Canada dedicated server in compliance with University of Calgary requirements.

Confidentiality will be protected by using only study identification numbers in the database. Any results of the study, which are reported, will in no way identify study participants. Online surveys may ask for personal identifiers or information that may be used to identify you. However, no direct link is made between their information and their data. De-identified data may be used in future studies in alignment with this project. No medical data outside of study data collection will be accessed by the research team.

IF I SUFFER A RESEARCH RELATED INJURY, WILL WE BE COMPENSATED?

In the unlikely event that you suffer an injury because participating in this research, the University of Calgary, or the researchers will provide no compensation. You still have all your legal rights. Nothing said here will alter your right to seek damages.
SIGNATURES

Your signature on this form indicates that you have understood to your satisfaction the information regarding you participation in the research project. In no way does this waive your legal rights nor release the investigators or involved institutions from their legal and professional responsibilities. You and/or your parent are free to withdraw from the study at any time without jeopardizing health care and/or education. If you have further questions related to this research, please contact:

Study Research Coordinator at SHRedConcussions@ucalgary.ca or Carolyn Emery 403-220-4608
If you have any questions concerning your rights as a possible research participant, or research in general, or if you feel you are being mistreated, please contact the Chair of the Conjoint Health Research Ethics Board, University of Calgary, at 403-220-7990.

__________________________________________________________________________
Participant’s Name                       Signature & Date
__________________________________________________________________________
Birthdate                                Email Address
__________________________________________________________________________
Investigator/Delegate’s Name             Signature and Date
__________________________________________________________________________
Witness’ Name                            Signature and Date
__________________________________________________________________________
Parent/Guardian’s Name                   Parent Email Address

__________________________________________________________________________
Parent Phone Number

Please check this box if you are willing to be contacted for future studies  ☐

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.
Appendix F: SIPRC Confidentiality Agreement

CONFIDENTIALITY AGREEMENT

WITHIN OR IN RESPONSE TO INFORMATION FROM THE
SPORT INJURY PREVENTION RESEARCH (SIPRC) CENTRE DATABASE

Please complete and present this form to your immediate supervisor. Your supervisor will authorize this form and send it to the SIPRC Manager.

NAME OF APPLICANT: ________________________________

DEPARTMENT/FACULTY: Sport Injury Prevention Research Centre, Faculty of Kinesiology

APPLICANT CATEGORY: □ employee □ volunteer □ contractor
□ student □ trust employee

I understand that:

1. The University of Calgary Sport Injury Prevention Research Centre uses and discloses personal information in accordance with the provisions of the Health Information Act (HIA) and Alberta’s Freedom of Information and Protection of Privacy Act (FOIP).

2. As an employee/volunteer/contractor/student of the University of Calgary Sport Injury Prevention Research Centre I may be given access to confidential information, which relates to the Sport Injury Prevention Research Centre, its patients, volunteers, business and prospective patients and volunteers.

3. For all purposes, “confidential information” shall mean information and documentation relating to or embodying all patients, volunteers and staff database information; all information received via telephone, fax, email, internet communication or mail communication; computer systems; results of survey, solicitation, or research; training programs; and all materials and methodologies relating to any of the foregoing but not including such information or documentation which I can conclusively establish:
   a) was within my knowledge prior to commencement of my initial service with the University of Calgary Sport Injury Prevention Research Centre, and/or
   b) was or became general public knowledge without any act on my part.
I agree that:

1. I will not, during or after my service with the University of Calgary Sport Injury Prevention Research Centre, discuss with or disclose to others confidential information that I have become aware of unless the disclosure is necessary for the performance of the requesting officer's duties. The information disclosed will only be as deemed necessary and only to the extent pertinent to the request.

2. All materials prepared for me, and by me, for the University of Calgary Sport Injury Prevention Research Centre shall be and remain the property of the University of Calgary Sport Injury Prevention Research Centre and, apart from my duties as a volunteer/employee, I will not make or permit anyone else to make any copy, abstract, or summary of this material in any form; printed, electronic, digital, or otherwise or of any other material disclosed to me in the course of my volunteer service/employment.

3. For the duration of my volunteer service/employment with the University of Calgary Sport Injury Prevention Research Centre, I agree to conduct myself professionally and ethically, in accordance with Health Information Act and in accordance with the Freedom of Information and Protection of Privacy Act.

4. I will adhere to all policies and practices of the University of Calgary Sport Injury Prevention Research Centre as outlined in the Privacy Impact Assessment protocol and policies manual for the University of Calgary Sport Injury Prevention Research Centre and I understand that it is my responsibility to be familiar with the requirements outlined in these policies and procedures.

5. I understand that a breach of this agreement may be just cause for termination of my employment or affiliation with the Sport Injury Prevention Research Centre.

6. I understand that I can refer to the Sport Injury Prevention Research Centre Privacy Officer for the details of these policies.

7. The obligations set out above survive the termination of my volunteer service/employment with the University.

Applicant's signature: __________________________ Date: ________________

Supervisor's authorization: ________________________ Date: ________________

FOR SPORT INJURY PREVENTION RESEARCH CENTRE USE:
User ID:
Security Level:
Appendix G: University of Calgary Athletic Director Letter of Support

To whom it may concern,

I, Ben Matchett, the interim Director of Dinos Athletics, support the acquisition of videos for anonymous video analysis related to the following objectives:

**Primary objectives:**
1. To examine the rates of primary (HC1) and secondary (HC2) head contacts in female ice hockey,
2. to evaluate player-to-player contact behaviors in varsity ice hockey, and
3. to examine mechanisms associated with suspected injuries in varsity ice hockey.

These videos are of game videos (regular season and tournament) from 2019-20 University season and can be accessed and downloaded through the online video platform, available currently to players and coaches. Throughout the entire video analysis process, all players will remain anonymous and there will be no linking of player identity to the video.

Danielle Goyette (outgoing University of Calgary Dinos Women’s Ice Hockey Head Coach) and Bonnie Sutter (University of Calgary Dinos Athletics Head Athletic Therapist) support the usage of the video for these purposes to better understand and quantify the varsity women’s ice hockey game. Information surrounding the objectives will come back to the Dinos and Canada West to help inform future injury prevention and performance strategies.

Sincerely,

Ben Matchett
Interim Director
University of Calgary Dinos Athletics
Appendix H: Dartfish Tagging Panel
Appendix I: Validation Form for Community Partners

Thank you for agreeing to participate in this important study for varsity men’s and women’s basketball in Canada. We would like to validate some things before moving forward, starting with defining contact in the sport. Please provide an honest review, as this will inform decisions around what we as a team will define as a contact.

Below are some examples of what the quality of film may look like, as this may impact whether it is possible to assess the contacts easily.

Name:

Position:

Years working in/around/playing basketball:

Below are a few common basketball scenarios, and follow-up questions about whether you would define these scenarios as contact.
1. An offensive player is running hip to hip with his/her defense while attacking the rim in the half court. The offensive player is bumped off course but finishes the play.
   a) Is this a valid scenario in which true contact was received by the offensive player?
   b) If so, why do you think this is a valid contact? If not, why not?
   c) On a scale from 1-5, (1 being hardly any, and 5 being severe), how would you rate this type of contact? Use this scale to determine your rating:
      1. No contact/very little contact
      2. Contact is made, player mildly impacted
      3. Contact is made, player evidently impacted (skill/execution disrupted)
      4. Aggressive contact/ stoppage in play likely as a result
      5. Severe contact/ appears to be intentional/ injury result

2. A player without the ball cuts to the rim on offense, and slightly bumps into his/her defense.

https://tenor.com/view/counter-attack-nba-basketball-gif-10047053

   a) Is this a valid scenario in which true contact was received by the offensive player?
   b) If so, why do you think this is a valid contact? If not, why not?
   c) On a scale from 1-5, (1 being hardly any, and 5 being severe), how would you rate this type of contact?
      1. No contact/very little contact
      2. Contact is made, player mildly impacted
      3. Contact is made, player evidently impacted (skill/execution disrupted)
      4. Aggressive contact/ stoppage in play likely as a result
      5. Severe contact/ appears to be intentional/ injury result

3. A shot is taken, and both offensive and defensive players go in for the rebound. The defense boxes out the offense.
   a) Is this a valid scenario in which true contact was received by the offensive player?
b) If so, why do you think this is a valid contact? If not, why not?

c) On a scale from 1-5, (1 being hardly any, and 5 being severe), how would you rate this type of contact?
   1. No contact/very little contact
   2. Contact is made, player mildly impacted
   3. Contact is made, player evidently impacted (skill/execution disrupted)
   4. Aggressive contact/ stoppage in play likely as a result
   5. Severe contact/ appears to be intentional/ injury result

4. An offensive charge

   ![Image of a basketball game](https://giphy.com/explore/take-a-charge)

   a) Is this a valid scenario in which true contact was received by the offensive player? How about the defensive player?

   b) If so, why do you think this is a valid contact? If not, why not?

   c) On a scale from 1-5, (1 being hardly any, and 5 being severe), how would you rate this type of contact that the offense received?
      1. No contact/very little contact
      2. Contact is made, player mildly impacted
      3. Contact is made, player evidently impacted (skill/execution disrupted)
      4. Aggressive contact/ stoppage in play likely as a result
      5. Severe contact/ appears to be intentional/ injury result

   d) On a scale from 1-5, (1 being hardly any, and 5 being severe), how would you rate this type of contact that the defense received?
      1. No contact/very little contact
2. Contact is made, player mildly impacted
3. Contact is made, player evidently impacted (skill/execution disrupted)
4. Aggressive contact/ stoppage in play likely as a result
5. Severe contact/ appears to be intentional/ injury result

5. An offensive player attacks the rim, and the defensive players hands touch the offenses’ hip on the drive but are quickly removed.
   a) Is this a valid scenario in which true contact was received by the offensive player?
   b) If so, why do you think this is a valid contact? If not, why not?
   c) On a scale from 1-5, (1 being hardly any, and 5 being severe), how would you rate this type of contact?
      1. No contact/very little contact
      2. Contact is made, player mildly impacted
      3. Contact is made, player evidently impacted (skill/execution disrupted)
      4. Aggressive contact/ stoppage in play likely as a result
      5. Severe contact/ appears to be intentional/ injury result

The following is a link to the decision tree that was designed to assist raters in identifying the proper rating for contacts during a game clip. Please note that this is just an example of a player RECEIVING the contact. The same process would be followed for the same contact, but for the player GIVING the contact. (This means there are 2 separate tags for 1 contact).
https://miro.com/app/board/uXjVOZIqesw=

Please answer the following questions about the decision tree/tagging scheme.

Do you feel that a scale from 1-5 (1 being hardly any, and 5 being severe), is an appropriate way to determine severity of a contact in basketball? Why, or why not?

If you disagree with the 1-5 scale, how would you rate contacts in the game of basketball?
Below is a screenshot of the tagging panel that will be used to tag contacts in a game. As you can see, there are several additional headings that will provide context to each contact being tagged. Additional comments, concerns on this tagging panel?

<table>
<thead>
<tr>
<th>Game Information</th>
<th>Game Action</th>
<th>Teams</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contact</strong></td>
<td><strong>Quarter</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Team 1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Team 2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 - Key</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 - inside</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 - outside</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Initiator Team</strong></td>
<td><strong>Defender</strong></td>
<td><strong>Offensive</strong></td>
</tr>
<tr>
<td>Team 1</td>
<td>Team 2</td>
<td></td>
</tr>
<tr>
<td><strong>Contact Type</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk Contact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limb Contact</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Trunk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limbs</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Receiver Team</strong></td>
<td><strong>Defender</strong></td>
<td><strong>Offensive</strong></td>
</tr>
<tr>
<td>Team 1</td>
<td>Team 2</td>
<td></td>
</tr>
</tbody>
</table>
Appendix J: Tagger ‘Cheat Sheet’

**Basketball Video Analysis Cheat Sheet**

**Tagging Location:**
- Note that tagging of location is irrespective of offensive/defensive player.
- For example, an offensive player sustains contact immediately after his/her team inbounds the ball at the spot of the red circle, this should be tagged as inside the 3-point line.
- Another instance, if a player is setting a screen with his/her leg straddling the 3-point line (blue line), try to distinguish where ‘majority’ of the contact occurred. If this is not super clear, (looks equal on each side of the 3-point line), **tag the spot closest to the rim**, (in this case, it would be inside the 3-point line).

![Diagram of basketball court with points of contact marked]

**Defense**

**Defensive Play Types:**
1. **On-ball defense:** Defense receives contact by the offensive player while he/she is defending the player in possession of the ball.
2. **Boxing out/Rebounding:** Defense receives contact by the offensive player who is looking to secure an offensive rebound.
3. **Hit by a Screen:** Defensive player pathway is impeded by the offensive player setting a screen, defense comes into full contact with the offensive screen, and can occur on the ball, or off the ball.
   - If defense is hit by a screen while defending on the ball, tag the defensive contact type as ‘hit by a screen,’ **NOT** ‘on ball defense.’
4. **Stopping a Cutter:** A defensive player contacts offense who is not in possession of the ball but is making a cut towards or away from the rim.
   - Differs from battling for position in that:
     a) Offensive player is running away or to the rim opposed to a static contact- the goal of the defense is to slow the offense, not move them from a static position.
5. **Battling for Position:** A defensive player receives contact by the offense who is attempting to move the offensive player out of their ‘space.’ Occurs in a more static situation, such as an attempted ‘post-up’ battle.
   - Differs from rebounding/boxing out in that:
a) Battling for position should only be tagged while the offense is in motion and would change to boxing out/rebounding once an offensive shot is taken.

7. **Other:** Use this tag only if a contact does not meet any of the descriptors mentioned above. If you use the ‘other’ button, please provide a comment on what occurred.

**CONTACT TYPE:**
- If a contact appears to include both a trunk and limb contact, tag only the contact that appears the most severe.
- Only tag 2 separate body contacts if there is CLEAR separation between contact 1 and contact 2, or if an additional contact occurs with a different player than the initial contact.

**OFFENSIVE PLAY TYPES:**
1. Driving/Attacking the rim: The offensive player is in possession of the ball and is attempting to dribble his/herself to the rim.
2. Rebounding: the offensive player is attempting to complete an offensive rebound and may be watching the trajectory of the ball as it approaches the rim.
3. Setting a screen: The offensive player has his/her arms crossed to bump a defensive player off their course. These can happen either on ball or off ball.
4. Cutting/Running: An offensive player is not in possession of the ball, and he/she is moving as a cutter anywhere on the court.
5. Battling for Position: An offensive player is fighting with her/her defense to gain an offensive advantage. This is typically a post-up/duck-in and can happen at any point in the offensive possession if a shot is not taken- **if a shot is taken, this is now rebounding.**
6. Probing: An offensive player is not looking to attack the rim but is dribbling and/or stationary with the ball. It is apparent that the player is not looking to score, but rather assist as a passer while in possession of the ball.
7. Passing: An offensive player is in possession of the ball and is in the action of completing a pass to another teammate.
8. Other: Anything that does not match the description of the play types described above. If other is selected, make a comment as to what occurred.

**HEAD CONTACTS:**
- Head contacts differ from physical contacts (trunk and limb) in that we are tagging head contacts from the perspective of the player RECEIVING the head contact, not initiating. This is the opposite to how we are tagging other contacts like trunk/limb.

**HC1:** Any apparent contact where the player RECEIVING the head contact is hit in the head by another player, (elbow to head, head-to-head).
**HC2:** Any apparent contact where the player RECEIVING the head contact has hit his/her head on something other than another player, (head hits floor, head hits backboard).

Select TRUNK if the following condition is met:
a) Defensive player received a contact by the offense that impacted his/her mid-section, including his/her torso, back, chest, and shoulders.

**TRUNK INTENSITY:**

**HOW TO DECIDE:** Note to only tag contacts that you are 100% confident occurred- otherwise it is deemed inconclusive and should not be tagged.

**Example of inconclusive contact:**

- It is difficult to determine simply from the camera angle if a contact occurred, therefore taggers should not tag anything as it is not clear.

**Trunk Rating 1 (Mild):**

Tag a trunk contact as 1 if the following conditions are met:
- A player is typically barely impacted by the contact; however, it is apparent that a contact did occur.
- A player is slightly bumped off course while playing but does not typically affect them in gameplay.
- The contact is a part of the game and can be expected by the player initiating and receiving the contact.

**Trunk Rating 3 (Severe):**

Tag a trunk contact as 3 if the following conditions are met:
- The contact is overly aggressive and seems excessive
- The player receiving the contact is 100% impacted by the contact, and was unable to execute the skill/movement as a result
- The player receiving the contact may have sustained a suspected injury
- The contact appears overly aggressive, not a part of gameplay, and typically results in a foul call

**Trunk Rating 2 (Moderate):**

- Literally anything else! If the contact does not align with the conditions of intensity 1 or 3, tag the contact as a 2.
Examples (from the perspective of the player receiving the contact):  
Trunk Rating 1 (Mild):

Trunk Rating 2 (Moderate):
Select LIMB if the following condition is met:

*Note: document images are .gif, and therefore may appear as poor quality.*
a) Defensive player used his/her arms to initiate or avoid a contact (E.g., defense gets underneath a screen by using his/her arms as leverage opposed to getting hit.)

**Limb Intensity**

Note to only tag contacts that you are 100% confident occurred- otherwise it is deemed inconclusive and should not be tagged.

**Limb Rating 1 (mild):**
Tag a limb contact as a 1 if the following conditions are met:
- A player is minimally or not at all impacted by the limb contact while playing
- A player is only touched with the hands/arms while playing
- Typically, a part of the game, and both initiator and receiver of the contact appear aware that this contact occurs in play.

**Limb Rating 3 (severe):**
- The limb contact seems overly aggressive and not typically apart of gameplay
- The player receiving the contact is typically completely impacted by the limbs and may result in a foul call
- The limb contact may result in injury to the player receiving

**Limb Rating 2 (moderate):**
- Again, anything else that doesn’t fall under limb intensities 1 or 3.

Tag a suspected **CONCUSSION** if the following conditions are met:
- lying motionless,
- motor incoordination,
- no protective action – floppy,
- no protective action – tonic, cervical hypotonia,
- impact seizure/convulsion,
- tonic posturing,
- blank/vacant look,
- uncontrolled fall to the ground,
- controlled fall,
- dazed,
- slow to get up,
- clutching at head,
- walking away from ice disengaged with the game,
- disorientation,
- confusion,
- facial injury

Tag a suspected **INJURY** if the following conditions are met:
- A player is on the ground for 15 seconds or longer after apparent contact or non-contact.
- A player APPEARS to be in pain (wincing expression, rolling around, grabbing body part, etc).
- A referee stops the game for suspected injury.
- A player receives medical attention on the court or once they were removed from play.

NOTES:
- At the end of the day, use your judgement. We may not all agree on certain contacts, but to the best of your ability, rate all contacts the way that makes the most sense to you, using this sheet as a guide.
- You should be tagging the same number of contacts as before and tagging details about contacts of all intensities.
- Details include the offensive/defensive play type.
- Quarter, location, contact type, suspected injury should all be tagged following each contact, no matter the intensity rating.
- Recall that head contacts are tagged from a different perspective than the body contacts! If a player is hit in the head with an elbow, the player whose head was hit is the one who is to be tagged as ‘HC1.’