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# Effect of Previous Concussion on Sport-Specific Skills in Youth Ice Hockey Players

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UNIVERSITY OF CALGARY

Effect of Previous Concussion on Sport-Specific Skills in Youth Ice Hockey Players

by

Paul Hamilton Eliason

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES  
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DEGREE OF MASTER OF SCIENCE

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## **Abstract**

**Objective:** To investigate the effect of previous concussion on sport-specific skill performance in youth ice hockey players.

**Methods:** In total, 596 participants [525 males and 71 females, ages 11-17, representing elite (upper 30% by division of play) and non-elite (lower 70% by division of play)] were recruited from minor ice hockey teams in Calgary, Alberta over three seasons of play (2012-2015).

**Primary Outcome Measure:** On-ice skill performance was based on the Hockey Canada Skills Test (HCST) battery which included forward agility weave, forward and backward speed skate, forward to backward transition agility, and a 6-repeat endurance skate.

**Results:** There were no significant differences in the adjusted odds ratios or the mean scores between those with and without a history of concussion for all HCST components.

**Conclusions:** Youth ice hockey players with a history of concussion have similar HCST performance scores to those that do not.

## **Acknowledgements**

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## **Dedication**

This thesis is dedicated to those who I hold dearest in my heart, my wonderful family. I dedicate this to my parents, Ardis and Marshall, for their unconditional love and support. Thank you for instilling the values of hard work, perseverance, and the importance of education. To my siblings, Jordana, Graeme, and Adam, thank you for putting up and taking care of me along the way. Finally, loving thanks to my Aunt Janice and Uncle Leo who have been like second parents to me during my post-secondary journey.

This is yours as much as it is mine.

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## List of Symbols, Abbreviations and Nomenclature

Symbol	Definition
ACL	Anterior cruciate ligament
AFL	Australian Football League
AHL	American Hockey League
ANOVA	Analysis of Variance
BESS	Balance Error Scoring System
BMI	Body mass index
Bwd	Backward
CHREB	Conjoint Health Research Ethics Board
CI	Confidence interval
CISG	Concussion in Sport Group
DL	Disabled-list
ERA	Earned run average
Fwd	Forward
GSC	Graded Symptom Checklist
HCST	Hockey Canada Skills Test
ICC	Intraclass correlation coefficient
IIHF	International Ice Hockey Federation
IRR	Incidence rate ratio
KHL	Kontinental Hockey League
LOA	Limits of Agreement
MeSH	Medical subject heading
MLB	Major League Baseball
MPH	Miles per hour
MSK	Musculoskeletal
mTBI	Mild traumatic brain injury
NBA	National Basketball Association
NFL	National Football League
NHL	National Hockey League
PER	Player Efficiency Rating System
PFF	ProFootballFocus
RIST	Repeat Ice Skating Test
RSS	Reed Repeat Sprint Skate
SAC	Standardized Assessment of Concussion
SOT	Sensory Organizational Test
tw	Text words
UCL	Ulnar collateral ligament
VIF	Variance inflation factor
WHIP	Walks hits innings pitched

## Chapter One: Introduction

### 1.1 Problem Statement

Ice hockey is one of the most popular winter sports in Canada with 634,892 registered players during the 2013-2014 hockey season.<sup>1</sup> Unfortunately, the sport of ice hockey has a high incidence of injury. Between 1990 and 2003, ice hockey accounted for an estimated 172,128 injuries that presented to United States emergency departments alone.<sup>2</sup> Within Canada, research indicates that 10% of all youth sport-related injuries are in ice hockey.<sup>3,4</sup> Concussion, specifically, is a major concern for all youth sport participants, but youth ice hockey players may be at an even higher risk compared with other sports. In a systematic review, Koh et al. (2003) found that ice hockey had the highest concussion incidence rates in male high school athletes among team sports (American Football, ice hockey, rugby, and soccer).<sup>5</sup> Additionally, Emery & Meeuwisse (2006) concluded that concussion is the most common specific injury type in youth (ages 9-16) ice hockey accounting for 18% of all injuries; although, more recent youth ice hockey studies suggest this is higher and may be anywhere from 25-66%.<sup>6-8</sup> Adding to the severity of this issue, those who incur a concussion are at an increased risk of incurring a future concussion or injury.<sup>6,7,9,10</sup>

Though the incidence of injury is high, there is a paucity of research that has examined the impact of injury, particularly concussion, on sport-specific skill performance in youth ice hockey players. Most of the studies that have investigated injury and performance are either based on sports other than ice hockey or focused on professional athletes.<sup>11-13</sup> Nevertheless, knowledge gained from these studies may be relevant for youth ice hockey players and can help inform studies involving youth. In such a popular sport with a high incidence of injury, further research is needed involving injury and performance, especially in youth ice hockey players.

Hockey Canada has recently developed and released a series of tests designed to measure the on-ice hockey-specific skills that are essential to the sport, called the Hockey Canada Skills Test (HCST). These tests may be instrumental in detecting changes in performance post-injury. It is important to build the knowledge between injury and performance in order to better inform the development of injury risk reduction and concussion management strategies.

## **1.2 Research Purpose**

The purpose of this study was to examine the association between history of previous concussion and on-ice sport-specific skill performance in youth ice hockey players, as measured using components of the HCST. Additionally, the purpose was to determine the association between on-ice sport-specific skill performance (Hockey Canada Skills) and the number of previous concussions sustained, the time since the last concussion, and the length of recovery period following the most recent concussion in youth ice hockey. Additionally, the 10-day test retest reliability of the HCST was evaluated.

## **1.3 Background**

### ***1.3.1 Ice Hockey***

#### **1.3.1.1 Participation**

The sport of ice hockey is one of the most popular sports in the world and continues to grow in popularity globally. The International Ice Hockey Federation (IIHF) annual Survey of Players, a survey that tracks the number of registered ice hockey players of 68 countries, found that the number of registered players has grown to 1, 779, 911 in 2014 up 8.47% from the year before.<sup>14</sup> Canada leads the world in registration numbers with nearly 550, 000 male and 90, 000 female players.<sup>1,14</sup> The next largest country in participation is the United States with over 500,000 total players.<sup>15</sup> Interestingly, non-traditional hockey countries have had the biggest five-

year growth in registration numbers with Hong Kong increasing 796%, followed by the United Arab Emirates with 350%. Of the more-traditional hockey countries, Belarus (153%), Hungary (119%), Great Britain (96%), Lithuania (53%), Canada (44%), and Slovakia (30%) have had the remaining largest five-year growths.<sup>14</sup>

### ***1.3.2 Injury and Concussion in Youth Ice Hockey***

A significant issue that the sport of ice hockey faces is the large number of injuries that occur; 10% of all youth sport-related injuries occur in ice hockey.<sup>3,4</sup> The overall injury rate in youth ice hockey was found to be 30.02 injuries per 100 players per season (95% CI 27.17 to 32.99), or 4.13 injuries per 1000 player hours (95% CI 3.67 to 4.62).<sup>4</sup> Ice hockey accounted for the largest proportion of injuries (53.6%) sustained by paediatric athletes presenting to the US emergency departments from 1990-2003, over lacrosse and field hockey.<sup>2</sup> Recent research has found consistent risk factors for injury and concussion in ice hockey. Participation in games compared with practices was associated with an increased risk of injury (incidence rate ratios ranging from 2.45 to 6.32).<sup>6,10,16-18</sup> In a systematic review including a meta-analysis, playing in a league allowing body checking increases the risk of all game related injuries (summary rate ratio: 2.45; 95% CI 1.7-3.6) and concussion (summary odds ratio: 1.71; 95% CI 1.2-2.44).<sup>10</sup> Additionally, those with a history of injury (including concussion) are at an increased risk of incurring a future concussion or injury.<sup>6,7,9,10</sup> Players that are lighter in body weight may also be at an increased risk of injury.<sup>7,17,19</sup> Other risk factors for injury may also exist such as age, level of play, and player position, yet the research remains inconclusive.<sup>10</sup>

Of all injuries, concussion is a significant problem in youth ice hockey. The highest concussion incidence rate in male high school team sports is in ice hockey, and concussion is the most common specific injury type for youth ice hockey players.<sup>5,6</sup> Once reported to represent

18% of all injuries,<sup>6</sup> more recent youth ice hockey studies suggest this may be higher.<sup>7</sup> In a separate Canadian study, concussion accounted for 32% of all injuries in Pee Wee (11-12 years old) players playing with body checking, and 25% in a league not allowing body checking.<sup>7</sup> This research was further supported by a landmark study by Emery et al. (2010) that compared a Pee Wee (ages 11-12) league that allowed body checking (Alberta) to a league that did not (Quebec), and found that the league allowing body checking had a 3.26-fold (95% CI 2.31-4.60) greater risk of injury and 3.88-fold (95% CI 1.91-7.89) greater risk for concussion.<sup>7</sup> This compelling research informed Hockey Canada in making an evidence-based policy change in 2013 to delay body checking from Pee Wee (11-12 years old) until the Bantam level (13-14 years old) nationally. In addition to making the game safer, this policy change may also allow more time for players to focus on skill development and improvement.

### ***1.3.3 Concussion***

#### **1.3.3.1 Definition**

According to the Consensus Statement on Concussion developed at the 4<sup>th</sup> International Conference on Concussion in Sport held in Zurich, November 2012, concussion is a: “brain injury and defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces. Several common features that incorporate clinical, pathologic and biomechanical injury constructs that may be utilised in defining the nature of a concussive head injury include:

- 1. Concussion may be caused either by a direct blow to head, neck, face, or elsewhere on the body with an “impulsive” force transmitted to the head.*

2. *Concussion typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously. However, in some cases, symptoms and signs may evolve over a number of minutes to hours.*
3. *Concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging studies.*
4. *Concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course. However, it is important to note that in some cases symptoms may be prolonged.*<sup>20</sup>

This definition is currently the most recent definition released by the Concussion in Sport Group (CISG) of the consensus statement, and reflects the culmination of years of research and clinical expertise. Previously, other terms have also been used to describe concussion in the sporting context and literature including mild traumatic brain injury (mTBI) and commotio cerebri. Some literature has used the term mTBI interchangeably with concussion; however, some authors, including the Concussion in Sport Group, use these terms to represent different injury constructs. The CISG states that a concussion is a subset of TBI.<sup>20</sup>

#### 1.3.3.2 Symptoms and Signs of Acute Concussion

The signs and symptoms of concussion may be unique to the individual, so diagnosis should involve the assessment of various domains including clinical symptoms, physical symptoms, cognitive impairment, neurobehavioral features, and sleep disturbance. In addition, it

is important to have a detailed concussion history of the individual as part of the evaluation process and when conducting a pre-participation examination.<sup>20</sup>

(4<sup>th</sup> International Concussion Consensus Statement, 2012) “A suspected diagnosis of concussion can include one or more of the following:

1. *Symptoms- somatic (e.g., headache), cognitive (e.g., feeling like in a fog) and/or emotional symptoms (e.g., lability);*
2. *Physical signs (e.g., loss of consciousness (LOC), amnesia);*
3. *Behavioural changes (e.g., irritability);*
4. *Cognitive impairment (e.g., slowed reaction times);*
5. *Sleep disturbance (e.g., insomnia)*

If any one or more of these components are present, a concussion should be suspected and the appropriate management strategy instituted.”<sup>20</sup>

#### 1.3.3.3 Effects of Concussions in Non-Sport Specific Functional Outcomes

Concussions are a specific injury type that has the potential to reduce functional performance, either from neurocognitive, psychomotor, psychological, or as yet unknown perspectives. In the acute post-injury period, there are many studies that have investigated the effect of concussions on neuropsychological and balance performance. Using a prospective case-control study, Echemendia et al. (2001) found that college athletes suffering a sports-related mild traumatic brain injury (mTBI) scored significantly lower than matched controls (matched on age, gender, sport played, and ethnicity) on a battery of neuropsychological tests at 2-hours post-injury and 48-hours post-injury.<sup>21</sup> Specifically, injured athletes at the 2-hour post injury mark scored significantly worse in areas of working memory, attention and concentration, and verbal

learning than non-injured controls, and at the 48-hour mark, injured athletes scored significantly lower in areas testing working memory, divided attention, and speed of information processing.<sup>21</sup>

In a case-control study design, Guskiewicz et al. (2001) compared balance changes after concussion in collegiate athletes. Thirty-six concussed athletes were matched to controls on age, height, weight, and amount of time played on the day the concussed athletes were injured. Repeated-measures ANOVA showed a significant group-by-day interaction for two different postural stability tests, the Sensory Organization Test (SOT) and the Balance Error Scoring System (BESS). Tukey post hoc analysis showed that on the first day post-injury concussed athletes demonstrated significantly decreased postural stability on both tests when compared to both their preseason baseline as well as to controls.<sup>22</sup>

In a cohort study, McCrea et al. (2003) found that collegiate football players who suffered a concussion (n=94) reported more severe symptoms on the Graded Symptom Checklist (GSC) (mean GSC score 20.93 [95% CI 15.65-26.21], points higher than controls), more cognitive impairments on the Standardized Assessment of Concussion (SAC) (mean SAC score 2.94 [95% CI 1.50-4.38], points lower than controls), and balance deficits on the BESS (5.81 [95% CI -0.67-12.30], points higher than non-injured matched controls (n=56; matched on age, years of education, and baseline performance on concussion assessment measures)).<sup>23</sup> Further, McCrea et al. (2003) reported that cognitive functioning improved to baseline levels within 5 to 7 days and balance deficits dissipated within 3 to 5 days after injury.<sup>23</sup> The time to recovery, and subsequently return to play, from cognitive dysfunction and postural instability may also vary based on the individual. Most concussions (80-90%) will resolve in a period of 7-10 days, although the recovery period may be longer in youth and adolescents.<sup>20,24</sup>

Although these studies did not directly measure changes in sport-specific skill performance associated with concussion, they suggest that a concussion could decrease sport-specific skills through deficits in cognition, balance, reaction time, and memory. Considering that these impairments generally resolve within a few days, it is unclear if players that have a history of concussion, but have already returned to play, will have deficits in sport-specific skill performance over time.

### ***1.3.4 Measurement of Sport-Specific Skills for Ice Hockey***

#### **1.3.4.1 Hockey Canada Skills Test**

At the 1999 Molson Open Ice Summit on Player Development held in Toronto, Ontario, it was recommended that Hockey Canada develop a nationally organized program to test and recognize skill acquisition and skill improvement in youth ice hockey players.<sup>25</sup> In response, Hockey Canada developed a program called the National Skills Standards and Testing Program in order to measure skills in minor hockey players with the goal of providing individual feedback throughout the entire season. This feedback would allow for the development of the fundamental skills required to play the game at the minor level.<sup>25</sup> The National Skills Standards and Testing Program is commonly referred to and named hereafter as the Hockey Canada Skills Test (HCST). The HCST allows for the ability to measure the hockey-specific skills of the players, which may be a better indication of performance than traditional point based performance measures.

A component of the HCST is based on previously developed test measures. Specifically, the 6-repeat endurance skate, also known as the Reed Repeat Sprint Skate (RSS), has been reported as a valid and reliable test of anaerobic capacity in hockey players.<sup>26,27</sup> Reed et al. (1979) first reported that drop-off time, a component of the RSS, correlated with off-ice test

measures that related to anaerobic lactic fitness measurements, and had a test-retest reliability of 0.78.<sup>26</sup> The RSS was further investigated by Watson and Sargeant (1986), who reported a test-retest correlation of 0.96.<sup>27</sup> Although the test-retest correlations are fairly strong, a limitation of a correlation is that it does not show the level of agreement between the methods. Further, both the study populations included collegiate and Junior A players, which may not generalize to younger aged populations. Despite these limitations, however, the RSS is a reasonable standard of practice for examining hockey-specific standardized endurance. Other components of the HCST such as the forward agility weave, transition agility, and forward/backward sprint skate, have not yet been previously validated.

#### **1.4 Research Rationale**

There is a paucity of research examining the association between injury, specifically concussion, and sport-specific performance outcomes. This lack of research is especially true in ice hockey. Since concussions represent a high proportion of total injuries in ice hockey, the scarcity of research in this area highlights the need for continued focus and evaluation.

Understanding whether or not concussions have a long-term effect on sport-specific skill performance is important as youth ice hockey players who sustain a concussion or other injury are at a greater risk of incurring another concussion or injury.<sup>4,7,9,10</sup> As such, the impact of previous concussion on reducing sport-specific skills performance may be related to this risk.

More specifically, a player who has sustained a concussion that has not yet resolved may present with hockey-specific skill deficits, which in turn may impair their ability to adjust to the high demands of the game. This inability to adjust to the demands of the game may predispose the player to a future risk of concussion or injury. Alternatively, regardless of prior concussion, those with poor skill performance may simply be at an increased risk for incurring a concussion

or other injury. Regardless, by using these skill performance scores, it may be possible to predict which players are at a higher risk of injury compared with other players. This information may then be used to inform injury risk reduction protocols. Performance outcomes may also be useful to coaches, parents, trainers, and health practitioners in injury and concussion management and return to play protocols. Finally, skill performance information can be valuable to coaches and players to assist with skill development/improvement programs.

### **1.5 Research Question and Specific Objectives**

#### *Research Questions*

What is the association between a previous history of concussion, the number of previous concussions sustained, the time since most recent concussion, the length of recovery after the most recent concussion and on-ice sport specific skill performance in youth ice hockey?

Secondly, what is the 10-day test-retest reliability of the HCST?

#### *Preliminary Objective*

1. To determine the 10-day test re-test reliability of the HCST in youth ice hockey players.

#### *Primary Objective*

1. To determine the difference in HCST component scores between youth ice hockey players (aged 11-17) who report a previous history of concussion and those who do not.

#### *Exploratory Objectives*

2. To examine the association between the number of previous concussions and HCST component scores in youth ice hockey players (aged 11-17).

3. To examine the association between the time since most recent concussion and HCST component scores in youth ice hockey players (aged 11-17).
4. To examine the association between the length of recovery following most recent concussion and HCST component scores in youth ice hockey players (aged 11-17).
5. To examine potential effect modifiers and confounders on the relationship between previous history of concussion, the number of previous concussions sustained, the time since last concussion, and the length of recovery after the most recent concussion and on-ice sport specific skill performance in youth ice hockey.

## **1.6 Research Significance**

Recovery from injury and return to full function is desired to ensure there are no lasting effects in the developing athlete, and to increase the likelihood of long term participation in sport with all of its known benefits. As such, the HCST may be instrumental in showing whether a previous concussion has an effect on sport-specific skill performance. Hockey Canada intends to implement the HCST nationally across minor hockey leagues as a way to measure skill acquisition and development in ice hockey players. It is important for hockey coaches, parents, and players to be aware of the importance of skill development and the need to establish a system to measure these skills. By increasing knowledge in the area of concussion and skill performance, injury prevention and concussion management strategies can be developed and evaluated in the future.

## **1.7 Summary of Thesis Format**

This thesis contains seven chapters, including an introduction, literature review, methods, main results, exploratory results, discussion, and conclusions. Chapter one introduces the thesis and contains the purpose, research question and specific objectives, rationale, along with a

summary of the thesis format. Chapter two is a literature review examining the association between injury and sport-specific skill performance. It includes the background, limitations of the current body of literature, and highlights the significance and need for more research in this area. Chapter three describes the methodology used for this research study, including the study design, study population, procedures, statistical methods, and a statement of ethical considerations. Chapter four reports the study population and the preliminary and main results of the study. This includes the test retest reliability of the HCST and the association between HCST components and previous history of concussion. Chapter five reports the exploratory results of the study. This includes the association between the number of previous concussions, the time since last concussion, and the length of recovery following most recent concussion and the HCST components. Chapter six includes a discussion on the results and study limitations and strengths. Chapter seven concludes the thesis and discusses future directions for research in this area. Finally, appendices serve to supplement the chapters of this thesis and include a sample size calculation, a full description of the HCST design and recording sheets, the questionnaire used in this study, and parent consent and player assent forms.

## **Chapter Two: Injury and Sport-Specific Skill Performance: A Review of the Literature**

### **2.1 Introduction**

Although concussions have received a great deal of attention in the media and sporting world over the last few years, there is a paucity of literature examining the relationship between concussion and sport-specific performance in ice hockey as the current body of knowledge is virtually non-existent. Research investigating concussion in sports other than hockey and performance has seen minimal development. The objective of this review is to examine the quality and quantity of research that has investigated injury and sport-specific skill performance. Finally, a critical appraisal of the current literature in injury and skill performance is used to help evaluate and summarize the current body of knowledge in this area. Due to the paucity of knowledge surrounding injury and skill performance, this review of the literature will provide an important base of knowledge for this thesis.

### **2.2 Methods**

#### ***2.2.1 Data Sources***

Seven electronic databases were searched for relevant research articles during October and November 2014, from: Medline (OVID) (1946-present), PubMed (1960-present), SPORTDiscus (1960-present), CINAHL Plus (1960-present), Web of Science (1900-present), ProQuest (1960-present), and Google Scholar (1900-present). Bibliographies of selected articles were also searched to find additional relevant publications. Databases were reviewed again in June 2015 to update the review with any new articles published.

### 2.2.1.1 Search Terms

**Table 2.1 Medical subject headings and text words used for article extraction**

Medical subject headings (MeSH) (also used as text words in each search)	Text words (tx)
1. “Wounds and Injuries”	7. “Injury”
2. “Athletic Injuries”	8. “Concussion”
3. “Brain Concussion”	9. “Performance”
4. “Athletic Performance”	10. “Skills”
5. “Hockey”	11. “Ice Hockey”
6. “Sports”	12. “Youth”

### 2.2.1.2 Search Strategy

- A. Athletic performance: 4 or 9 or 10
- B. Athletic performance and athletic injuries: A and (1 or 2 or 3 or 7 or 8)
- C. Athletic performance and athletic injuries and sport: B and 6
- D. Athletic performance and athletic injuries and hockey: B and (5 or 11)
- E. Athletic injuries and athletic performance and youth: B and 12

Each medical subject headings “MeSH” or text word “tw” was searched using the electronic databases to obtain the total number of articles in the area of study. If the search strategies A-E yielded fewer than 200 articles, the study titles and abstracts were reviewed with the selection criteria (Chapter 2.2.2) in order to identify potentially relevant studies. If the search strategies yielded greater than 200 articles, the search was narrowed using each subsequent step (A-E). If a

study articles' title was of interest but no abstract was found, the full article was retrieved in order to ensure that no potentially relevant study was missed.

### ***2.2.2 Study Selection Criteria***

Initial abstract screening criteria:

- English language abstracts
- Peer reviewed abstracts
- Included some measure or analysis of injury (including concussion) and skill performance

Inclusion criteria for all articles were:

- Investigated injury and/or concussion
- Investigated athletic performance
- Study designs were randomized controlled trials, quasi-experimental, pre-experimental, cohort, case-control, cross-sectional, case series, or systematic review

Exclusion criteria for all articles were:

- Case studies
- Non-English language

### ***2.2.3 Data Extraction***

Data were extracted from all articles that met the study inclusion criteria. Study design, study population, and results of the study specific to injury and performance were extracted.

#### ***2.2.4 Data Synthesis***

Due to differences in objectives, methodology, and statistical analysis in the included studies, meta-analysis was not appropriate for this review. Instead, the extracted data are summarized in Tables 2.2-2.6.

### **2.3 Results**

#### ***2.3.1 Included Studies***

Articles were identified from electronic databases after title and abstract review. Additional articles were identified from electronic databases in June 2015. A total of 18 articles met the inclusion criteria for this review.

**Table 2.2 Studies examining injury and sport-specific performance in basketball**

<b>Study (year)</b>	<b>Study Design</b>	<b>Study Population</b>	<b>Injury</b>	<b>Results of the Study</b>
Namdari et al. (2009)	Case-control	24 National Basketball Association players	Microfracture surgery	Sixteen (66%) injured players returned to play in the NBA. Post-operative players had less minutes played ( $p=0.014$ ), points scored per game ( $p=0.002$ ), rebounds per game ( $p=0.018$ ), assists per game ( $p=0.027$ ), and rebounds per 40 minutes of play ( $p=0.004$ ) than pre-operative. However, after correcting for multiple comparisons, the only statistically significant difference was points scored per game. When compared with controls, cases experienced a significant decline in points per game ( $p=0.013$ ).
Cerynik et al. (2009)	Case-control	24 National Basketball Association players	Microfracture surgery	Seventeen (71%) players returned to play in the NBA. Compared to pre-injury, cases played fewer minutes per game the first season back ( $p<0.05$ ) and PER performance were also significantly lower ( $p<0.001$ ). Compared with controls, cases played significantly fewer minutes per game ( $p<0.001$ ) and had decreased performance ( $p<0.01$ ).
Busfield et al. (2009)	Case-control	27 National Basketball Association players	Anterior cruciate ligament	Twenty-one (78%) players returned to play following injury. Of those that did return, 44% had decreases in PER performance by more than 1 point (12 players), although changes were not statistically significant compared with controls. The number of games played, field goal percentage, and number of turnovers was significantly lower from pre to post-injury ( $p<0.05$ ).

Amin et al. (2013)	Case-control	18 National Basketball Association players	Achilles tendon	Eleven (61%) players returned to play. Player performance after return was significantly reduced in both the first (4.57 points; $p=0.003$ ) and second season (4.38; $p=0.01$ ) compared to pre-injury. Compared with controls, PER was significantly lower for cases in the first ( $p=0.038$ ) and second ( $p=0.081$ ) season after return.
Yeh et al. (2011)	Descriptive epidemiological	128 National Basketball Association players (129 meniscal tears)	Isolated meniscal tears	One hundred three (80%) players returned to play. For those that did return, there was no statistical difference in PER from their post-injury performance to their pre-injury performance ( $p>0.05$ ).

**Table 2.3 Studies examining injury and sport-specific performance in baseball**

Study (year)	Study Design	Study Population	Injury	Results of the Study
Gibson et al. (2007)	Case-control	68 Major League Baseball pitchers	Ulnar collateral ligament	Fifty-six (82%) pitchers returned to play in the MLB. There was no significant change in ERA ( $p=0.14$ ) and WHIP ( $p=0.83$ ) post-injury compared to pre-injury. Although the mean innings pitched per season was significantly lower from pre to post-injury ( $p=0.003$ ), this was not significantly different when compared with controls ( $p=0.02$ ).
Erickson et al. (2013)	Case-control	179 Major League Baseball pitchers	Ulnar collateral ligament	One hundred forty-eight pitchers (83%) were able to return to play in the MLB. After surgery, pitchers showed significantly improved performance from pre-injury in fewer losses ( $p<0.001$ ), losing percentage ( $p=0.001$ ), ERA ( $p<0.001$ ), hits given up ( $p=0.001$ ), home runs given up ( $p=0.002$ ), walks ( $p<0.001$ ), and WHIP ( $p<0.001$ ), after adjusting for multiple comparisons. Compared with controls, cases had significantly fewer losses ( $p=0.003$ ), losing percentage ( $p<0.001$ ), ERA ( $p=0.001$ ), and WHIP ( $p<0.001$ ).
Jiang & Leland (2014)	Case-control	38 Major League Baseball pitchers	Ulnar collateral ligament	Thirty players (78.9%) were able to return to play in the MLB. There was a small but statistically significant reduction in pitch speed velocity for fastball (1.3 mph; $p<0.001$ ) and changeup (1.2 mph; $p=0.02$ ) in the first year after return, and curveball velocity (1.0 mph; $p=0.03$ ) in the second year. These decreases in velocity were not significantly different than controls ( $p>0.05$ ). There were no differences between cases and controls in mean ERA, WHIP, batting average, walks per 9 innings, or strike outs per nine innings ( $p>0.05$ ).

Makhni et al. (2014)	Case-control	147 Major League Baseball pitchers	Ulnar collateral ligament	One hundred eighteen (80%) returned to pitch at least 1 MLB game. Of established pitchers (those that appeared in >10 games/season), 67% returned to the same level of competition post-injury. Post-injury performance was significantly decreased in ERA (p=0.027), batting average (p=0.046), WHIP (p=0.029), percentage of pitches thrown in the strike zone (p<0.001), innings pitched (p=0.001), percentage of fastballs thrown (p<0.001), and average fastball velocity (p=0.023). These differences, however, were not statistically different when compared with age-matched controls (p>0.05).
Wasserman et al. (2015)	Case-control	66 concussive injuries in Major League Baseball players	Concussion	In the 2 weeks after return to play, concussed players' batting performance was significantly lower for batting average (p=0.005), on-base percentage (p=0.01), slugging percentage (p=0.004), and on-base slugging (p=0.003) relative to controls. In weeks 4-6 after leave, these metrics were slightly lower in concussed players, but not statistically significant (p>0.05).

**Table 2.4 Studies examining injury and sport-specific performance in American and Australian football**

<b>Study (year)</b>	<b>Study Design</b>	<b>Study Population</b>	<b>Injury</b>	<b>Results of the Study</b>
Carey et al. (2006)	Case-control	31 running backs and wide receivers playing in the National Football League (33 ACL injuries)	Anterior cruciate ligament	Twenty-six (79%) players returned to play in the NFL. Post-injury performance, as measured by their power rating per game played, decreased from $9.9 \pm 1.1$ to $6.5 \pm 0.9$ . This change in power rating per game was statistically significant compared with the change in performance in control players ( $p=0.002$ ). There were not, however, any statistically significant differences in power rating between post-injury cases and controls ( $p>0.05$ ).
Makdissi et al. (2009)	Prospective case-control	97 elite Australian football players (138 concussive injuries)	Concussion	Of the 138 concussive injuries assessed, 127 players returned to play without missing a game (92%). The ratio of disposal rates (a performance metric) between pre and post-concussion were not significantly different from their pre-injury performance for both a 3-game average (ratio 1.04; 95% CI 0.99 to 1.10) and a single game (1.08; 95% CI 0.99 to 1.11). Similarly, the ratio of concussed players' disposal rates to the ratio of control players disposal rate found concussed players had a small increase in disposal rates for both the 3-game average (1.04; 95% CI 0.97 to 1.12) and a single game (1.20; 95% CI 1.03 to 1.38).
Kumar et al. (2014)	Case-control	124 National Football League players (131 concussive injuries)	Concussion	Fifty-five percent of players missed no games. Post-injury ProFootballFocus performance scores were similar to pre-injury scores in players without any games missed (0.16 vs. 0.33; $p=0.129$ ) and players that missed at least 1 game (-0.06 vs. 0.10; $p=0.219$ ).

**Table 2.5 Studies examining injury and sport-specific performance in ice hockey**

Study (year)	Study Design	Study Population	Injury	Results of the Study
McDonald et al. (2014)	Case-control	17 professional hockey players (National Hockey League or American Hockey League)	Femoroacetabular impingement and microfracture surgery	Fourteen (82%) players returned to play. The only statistically significant difference between pre and post-injury was a reduction in shots ( $p=0.024$ ); games played, goals, assists, and points were not statistically different ( $p>0.05$ ). Although there were no significant differences in performance between cases and controls ( $p>0.05$ ), there was a trend towards cases playing fewer games and having fewer points post-injury than to controls.
Erickson et al. (2014)	Case-control	36 National Hockey League players (37 ACL injuries)	Anterior cruciate ligament	Thirty-five (97%) players returned to play in the NHL and the other 1 player returned to play professionally in the KHL. Post-injury performance was not statistically different than pre-injury performance ( $p>0.01$ ). When compared with controls, cases had significantly more goals ( $p=0.009$ ), points ( $p=0.009$ ), even-strength goals ( $p=0.007$ ), power-play goals ( $p=0.004$ ), shots ( $p=0.007$ ), shooting percentage ( $p=0.007$ ), and time on ice ( $p=0.007$ ).

Emery et al. (2011)	Cohort study	140 teams from Alberta (n=2081) and 137 teams from Quebec (n=2081) Pee Wee (ages 11-12) and Bantam (ages 13-14)	Musculoskeletal injury and concussion	Alberta players suffered 451 game-related injuries, of which 121 were concussions (27%). Quebec players suffered 280 injuries, of which 62 were concussions (22%). For game-related injuries, the IRR between players from teams with more than 50% of wins and players with less or equal to 50% of wins was 0.78 (95% CI 0.64 to 0.95) for all injuries, 0.75 (95% CI 0.52 to 1.08) for concussions, 0.64 (95% CI 0.47-0.88) for injuries resulting in time loss of more 7 days, and 0.74 (95% CI 0.39-1.40) for concussions resulting in time loss of more than 10 days, after adjusting for clustering by team and important risk factors (province, age, level of play, previous injury, weight, and position).
Eliason et al. (2014)	Cross-sectional	131 elite Bantam and Midget ice hockey players (ages 13-17)	Musculoskeletal injury and concussion	Exploratory analysis by comparing 95% confidence intervals suggested that there was no difference between the mean scores of sport-specific skills on the HCST between those with a history of concussion, those with an injury within 6 weeks, or those with an injury within the last 1 year, and those without.

**Table 2.6 Study examining injury and return to play performance**

<b>Study (year)</b>	<b>Study Design</b>	<b>Study Population</b>	<b>Injury</b>	<b>Results of the Study</b>
Ardern et al. (2014)	Systematic review	69 articles (7556 participants) reporting number of patients returning to play after ACL reconstruction surgery	Anterior cruciate ligament	On average, 81% of people were able to return to sport. Of those, 65% returned to their pre-injury level of sport and 55% returned to their competitive level after surgery.

## ***2.3.2 Musculoskeletal Injury and Sport-Specific Performance***

### **2.3.2.1 Basketball**

A majority of the research investigating injury on performance has been in the sport of basketball and focuses on musculoskeletal injury. Namdari et al. (2009) examined professional athletes playing in the National Basketball Association (NBA) who required microfracture surgery to treat chondral defects of the knee. Using a case-control study design, cases were identified from team injury reports, press releases, and player profiles. Twenty-four cases were identified and two controls were matched for every case (48 controls). Controls were matched on age, position, body mass index (BMI), and experience in the league (years played). Player performance metrics including games played, field goal percentage, points, assists, blocks, and steals were compared within-group (pre to post-surgery) and between matched controls. Those who required surgery were at risk of not returning to sport. Specifically, they were 8.15 times less likely to remain in the NBA than controls ( $p=0.005$ ). When comparing performance from pre to post-injury, injured players had reduced minutes per game (mean difference 6.00; 95% CI 1.38 to 10.59;  $p=0.014$ ), points per game (mean difference 3.89; 95% CI 1.72 to 6.06;  $p=0.002$ ), rebounds per game (mean difference 1.04; 95% CI 0.21 to 1.88;  $p=0.018$ ), rebounds per 40 minutes (mean difference 2.44; 95% CI 0.86 to 4.02;  $p=0.004$ ) and assists per game (mean difference 0.62; 95% CI 0.86 to 1.16;  $p=0.027$ ). However, after accounting for multiple comparisons using a Bonferroni correction, the only statistically significant difference from pre-injury was points per game. When the cases were compared with healthy matched controls, cases experienced a significant decline in points per game ( $p=0.013$ ).<sup>28</sup>

Other researchers have also investigated the association of microfracture treatment and performance outcomes. Cerynik et al. (2009) compared 24 NBA players after microfracture comparing their performance from pre to post-injury as well as to matched controls (matched on position and years of experience) using the Player Efficiency Ratings (PER) system. The PER system rates players by summing positive performance metrics, such as points, rebounds, and steals, and compares them to negative performance metrics, such as turnovers and fouls. This rating system is an objective and standardized method for assessing a players performance, and allows for comparisons of player performance across different seasons.<sup>29</sup> In order to minimize the effect of team or playing time variables, the PER is adjusted to a per-minute basis and there are allowances for team pace and playing style to represent a players overall team contribution.<sup>30</sup> Cerynik et al. (2009) also found that players that underwent microfracture treatment were less likely to return to competition (21% did not return to competition), and pre-injury PER was significantly decreased compared to post-injury PER (15.5 vs. 12.0;  $p < 0.01$ ).<sup>31</sup> Players that returned also had a decrease in minutes played per game the first season back after injury (mean of 4.9 minutes;  $p < 0.05$ ). When compared with matched controls, a multivariable comparison found that during the 2 years after surgery injured athletes power rating (a calculation from the PER) was significantly lower (decrease of 3.1 points;  $p = 0.0007$ ), and had significantly reduced minutes played per game (decrease of 5.2 minutes;  $p < 0.001$ ).

The PER system has also been used to compare performance changes after other musculoskeletal injuries in basketball. Busfield et al. (2009) compared PER between NBA players that underwent anterior cruciate ligament (ACL) reconstruction surgery and matched controls. Controls matched on demographics (age, height, weight, and years of NBA experience)

as well as offensive productivity and defensive statistics. In addition, standard basketball performance statistics were compared from pre to post-injury. Of the 27 players included in the study, 6 players did not return to competition after ACL surgery (22%). Of those that did return, PER performance decreased from pre-injury by more than 1 PER point in 44% (12 players), yet there were no statistically significant differences in PER between cases and controls. When comparing traditional basketball performance statistics from pre to post-injury, the number of games played, field goal percentage, and number of turnovers was significantly lower from pre to post-injury ( $p < 0.05$ ). It should be noted that a decrease in turnovers from pre to post-injury actually represents a positive performance change, and PER actually increased post-injury in 15% of the players (4 players).<sup>32</sup>

Amin et al. (2013) compared PER in 18 NBA players who required surgical repair of complete Achilles tendon ruptures over a 23-year period (1988-2011). Injured players ( $n=18$ ) were also matched with healthy controls in: playing position, number of seasons played in the league, and similarly rated career performance statistics. These researchers also found that a large proportion that underwent Achilles repair surgery did not return to play in the NBA (7 players; 39%), and those that did had significant reductions compared to pre-injury performance in minutes played per game in first season back (5.11; 95% CI 0.99 to 9.23;  $p=0.01$ ) and PER performance (4.57; 95% CI 1.72 to 7.42;  $p=0.003$ ). Similarly, post-injury performance was also significantly worse than pre-injury performance in their second year post-return in both minutes played per game (4.42; 95% CI -0.01 to 8.86;  $p=0.003$ ) and PER (4.38; 95% CI 0.92 to 7.84;  $p=0.01$ ).<sup>33</sup> Additionally, when comparing PER from cases to controls, injured players also

showed significant decreases in their first season ( $p=0.038$ ) and second ( $p=0.081$ ), although these were compared using a higher than traditional alpha level of 0.10.

Finally, Yeh et al. (2012) examined 129 isolated meniscal tears in NBA athletes over 21 seasons, also comparing PER the season before the injury to the first full season back from injury (full season defined as having played in at least 75% of games). Although 25 players (19.4%) did not return to sport, paired sample t-tests found no statistically significant differences in PER performance between pre-injury ( $14.1 \pm 4.6$ ) and post-injury return ( $13.4 \pm 4.4$ ) ( $p>0.05$ ).<sup>34</sup>

These studies suggest that professional basketball players incurring select types of MSK injury are at risk of not returning to sport.<sup>28,31-33</sup> Of those that are able to return, their playing performance may decrease compared to their pre-injury performance and healthy controls, although this may depend on the type of injury sustained.

#### 2.3.2.2 Baseball

Gibson et al. (2007) investigated pitching performance of pitchers playing in Major League Baseball (MLB) after ulnar collateral ligament reconstructive surgery. Ulnar collateral ligament (UCL) surgery, commonly called “Tommy John surgery”, was conducted on 68 MLB pitchers between 1998 and 2003. Commonly used pitching performance metrics such as innings pitched, earned run average (ERA), and walks hits innings pitched (WHIP) were calculated for each reconstructed pitcher during 7 consecutive seasons. ERA represents the average number of earned runs allowed per 9 innings pitched (one complete game); an earned run is any run that is scored for which the pitcher is responsible (a run that is scored not as a result of fielding errors). WHIP is calculated by taking the sum of walks and hits allowed divided by the number of innings pitched. The averages of these pitching performance metrics were compared between the

three consecutive years previous to the injury year to the three consecutive years after injury. Control players were selected by taking every fifth player from an alphabetical list of all pitchers playing during the 2001 season (n=112). Pitchers with a history of UCL injury were excluded before control selection. Fifty-six players (82%) returned to play professional baseball after UCL surgery. Of those that returned, pre-injury performance was similar to post-injury performance in mean ERA (4.12 vs. 4.21; p=0.14) and WHIP (1.362 vs. 1.356; p=0.83). Mean innings pitched was significantly lower between pre-injury and post-injury in reconstructed players (97.10 to 70.17; p=0.003), however, this was also seen in control players between pre and post-index years (94.73 to 79.29; p=0.02). Compared with controls, there were no statistically significant results in either reconstructed pitchers ERA or WHIP in any of the three post-index seasons.<sup>35</sup>

In a similar study, Erikson et al. (2014) evaluated performance changes pre-post UCL surgery as well as to matched controls in MLB pitchers. One hundred seventy-nine pitchers with UCL tears were matched to controls on sex, age, BMI, years of experience in the MLB, pitching performance in the MLB, year of injury, pitching position, and handedness. Eighty-three percent of pitchers returned to play in the MLB (n=148), and of those, performance was statistically better post-surgery for losses (4.40 vs. 3.08, p<0.001), losing percentage (19.3 vs. 14.1; p=0.001), ERA per season (5.67 vs. 4.18; p<0.001), hits given up (77.1 vs. 57.8; p=0.001), home runs given up per season (8.73 vs. 6.70; p=0.002), walks given up per season (30.3 vs. 21.6; p<0.001), and WHIP per season (1.60 vs. 1.39; p<0.001), after adjusting for multiple comparisons using a Bonferroni correction. However, since pitcher's post-surgery also had significantly less innings pitched per season than pre-surgery (77.4 vs. 58.7; p=0.001), it could be argued that it is only appropriate to compare performance statistics that adjust for innings

pitched such as ERA and WHIP. When comparing with controls, cases had significantly fewer losses per season (3.08 vs. 4.30;  $p=0.003$ ), losing percentage (14.1 vs. 22.8;  $p<0.001$ ), ERA per season (4.18 vs. 6.36;  $p=0.001$ ), and WHIP per season (1.39 vs. 1.70;  $p<0.001$ ), while innings pitched per season was not significantly different (58.7 vs. 65.3;  $p=0.358$ ).<sup>36</sup>

In addition to comparing common pitching performance metrics, Jiang & Leland (2014) also compared pitch velocity for 4 commonly thrown pitches (fastball, changeup, curveball, and slider) between pitchers pre post-UCL surgery as well as with controls. Controls were active MLB pitchers with no history of UCL injury and similar career statistics before the index year. In the first season after return, reconstructed pitchers had a small but significant decrease in their average fastball (mean decrease 1.3 miles per hour [mph];  $p<0.001$ ; 95% CI 0.78 to 1.88 mph) and changeup velocity (mean decrease 1.2 mph;  $p=0.02$ ; 95% CI 0.25 to 2.19 mph). In their second year after return to play, post-injury players' curveball also became significantly slower (mean decrease 1.0 mph;  $p=0.03$ ; 0.13 to 1.76 mph). However, when the differences in mean change in velocity were compared with controls, there were no statistically significant differences in any season for any pitch type. There were also no performance differences between cases and controls in mean ERA, batting against average, walks per 9 innings, or WHIP, although controls did pitch more innings than cases in their first year after return.<sup>37</sup>

This research is contrary, however, to Makhni et al. (2014) who compared pitchers that required UCL surgery to randomly selected age-matched controls. Of the 147 pitchers that required UCL surgery and were included in this study, 118 (80%) were able to return to play in at least 1 MLB game. Sixty-seven percent of established pitchers (those that appeared in greater than 10 games during the course of a single season) were able to return to established play after

surgery. When comparing reconstructed pitcher's performance from pre to post-injury, performance decreased in ERA (4.23 vs. 4.63;  $p=0.027$ ), batting average against (0.249 vs. 0.257;  $p=0.046$ ), WHIP (1.368 vs. 1.432;  $p=0.029$ ), percentage of pitches thrown in the strike zone (51.9% vs. 49.6%;  $p<0.001$ ), innings pitched (94.3 vs. 77.3;  $p=0.001$ ), percentage of fastballs thrown (63.9% vs. 59.0%;  $p<0.001$ ), and average fastball velocity (91.2 vs. 90.8 mph;  $p=0.023$ ). When cases were compared with controls, however, these declines were not statistically different.<sup>38</sup>

The change in performance from pre to post-UCL injury in performance remains unclear, as the studies presented are in contradiction to each other. However, they are similar in that each suggests that performance is equal to the performance level of control players.

#### 2.3.2.3 American Football

Carey et al. (2006) investigated 33 ACL injuries in 31 players over the course of 1998-2002 in running backs and wide receivers playing in the National Football League (NFL), comparing their performance from pre to post-injury with control players. Controls were other running backs and wide receivers without an identified ACL injury that competed in the 2000 playing season. Performance was measured using the players' power rating. Power rating is a weighted sum of total yards and touchdowns (equal to total yards/ [10 + 6 x touchdowns]), which can be argued to be the two most important statistics for running backs and wide receivers. The use of power rating as an indication of player performance in NFL running backs and receivers appears to be valid and reliable performance tool.<sup>39</sup> The test re-test reliability had an intraclass correlation coefficient (ICC) of 0.835, and although this represents a good ICC value, a limitation with ICCs is that they are influenced by the variability of the data.<sup>40</sup> Concurrent

criterion-oriented validity was assessed using a 2-sided t-test comparing Power Ratings by Pro Bowl selection for each season of the running backs and wide receivers studied. For the seasons not associated with Pro Bowl selection the mean power rating was  $76.2 \pm 2.1$ , and for seasons associated with Pro Bowl selection the mean power rating was  $198.1 \pm 6.1$ . This difference was statistically significant ( $p < 0.0001$ ), and suggests, although crudely, that calculating performance using power ratings is reliable and valid.

Of the players injured, 7 (21%) did not return to play in the NFL again. When comparing the change in performance per season from pre to post-injury return, performance decreased from  $138.3 \pm 16.7$  to  $64.1 \pm 13.2$  (mean change per season:  $-74.2$ ; 95% CI  $-112.0$  to  $-36.3$ ), which was statistically significant when compared with the change in controls ( $p = 0.0012$ ). By comparison, the mean change in power rating per season for the control group was  $-14.8$  (95% CI  $-28.2$  to  $-1.3$ ).<sup>39</sup> Further, when comparing the change in power rating per game played, performance in injured players decreased from  $9.9 \pm 1.1$  pre-injury to  $6.5 \pm 0.9$  post-injury. This mean change in performance ( $-3.4$ ; 95% CI  $-5.9$  to  $-1.0$ ) was also significantly different when compared with controls ( $p = 0.002$ ). By comparison, the mean change in power rating per game for the control group was  $0.1$  (95% CI  $-0.7$  to  $0.9$ ).<sup>39</sup> Although this analysis did not directly compare the performance change from pre to post-injury, the magnitude of the decrease was approximately one-third after return to play. When compared with controls, each of the three seasons after the injured players returned had a decrease in mean power rating, but these were not statistically different. However, for the 2 seasons immediately preceding the ACL injury, the mean power-rating for ACL-injured players was greater than the mean of the controls (2 seasons

prior:  $133.7 \pm 20.5$  vs.  $97.6 \pm 6.1$ ;  $p=0.042$ ; 1 season prior:  $146.8 \pm 20.1$  vs.  $98.1 \pm 5.7$ ;  $p=0.0027$ ),<sup>39</sup> which suggests that this may not been a valid comparison group.

The extent of investigations into the relationship between MSK injury and performance in American football is quite limited. This single study suggests that although performance after an ACL tear may be reduced in comparison to their pre-injury performance, this decrease was not significantly different compared with control players.<sup>39</sup>

#### 2.3.2.4 Systematic Review of ACL Injuries

In a systematic review of ACL reconstruction surgery and return to sport, Ardern et al. (2014) found that out of 69 published articles ( $n=7556$ ), on average, 81% (95% CI 74-87%) of people that required ACL surgery returned to sport. Of those that did return, 65% of those (95% CI 59-72%;  $I^2=95\%$ ) returned to their pre-injury level of sport. For those that returned to competitive sport after surgery, 55% (95% CI 46-63%) returned to sport.<sup>41</sup>

#### 2.3.2.5 Ice Hockey

Two studies were identified that investigated the effects of musculoskeletal injury on performance in ice hockey, and one that investigated risk of injury and concussion with team performance. The first, by McDonald et al. (2014), investigated performance metrics in professional hockey players playing in either the National Hockey League (NHL) or the American Hockey League (AHL), following arthroscopic treatment of femoroacetabular impingement and microfracture of the hip. Using a case-control study design, performance characteristics were compared pre post-injury as well as to age, years of experience, games played per season, average time on ice, and all-star selection matched controls (2 controls matched for every case). Performance metrics for forwards and defenceman included games

played, goals, assists, points, shots, and shooting percentage. Goalie performance metrics included wins, losses, goals, shots against, and goals against percentage. Seventeen players underwent surgery, of which 14 (82%) returned to play and were included for analysis. The only statistically significant difference from pre to post-injury was a reduction in shots by non-goalie players (n=10) (157 vs. 140; p=0.024). There were no statistically significant differences between cases and controls in all performance metrics analyzed, although there was a trend towards cases having less games played and fewer points.<sup>42</sup>

The other study investigating MSK injury in ice hockey is Erickson et al. (2014), who investigated ACL reconstruction in NHL players. Thirty-six players were identified from 1990-2013 and included in the study, and were matched to healthy controls on sex, age, BMI, years of experience in the NHL, position, and performance variables (such as goals, assists, and time on ice). The performance metrics compared were mainly traditional point based metrics such as goals, assists, points, plus/minus, shots, and shooting percentage. Of the injured players, 34 (97%) were able to return to play in the NHL, and the other 1 player returned to play professionally in the Kontinental Hockey League (KHL). Of those that returned to play in the NHL, post-injury performance was similar to pre-injury performance on all performance measures. When compared with controls, post-injury players scored statistically better in mean goals (13.9 vs. 6.82; p=0.009), points per season (32.5 vs. 18.3; p=0.009), mean power-play (4.43 vs. 1.84; p=0.004) and even-strength (10.3 vs. 5.20; p=0.007) goals per season, mean shots (138 vs. 87.1; p=0.007), and shooting percentage (9.94 vs. 6.96; p=0.007), even after accounting for multiple comparisons using a Bonferroni correction. However, cases also had significantly

more time on ice per season than controls (1172 vs. 860 mins;  $p=0.007$ ),<sup>43</sup> which increases the likelihood of getting more points.

Emery et al. (2011) investigated the association between risk of individual injury and concussion associated with team performance based on win-loss record. Based on a secondary data analysis from a 2-year cohort study in Alberta and Quebec over the 2007-2008 (Pee Wee) and 2008-2009 (Bantam) seasons, estimated incidence rate ratios (IRRs) for game-related injuries were compared between teams with more than 50% wins to teams with less than 50% wins. The estimated IRR's were calculated using Poisson regression for game-related injury and concussion and were adjusted for cluster by team and risk factors such as province, age, level of play, previous injury, weight, and position. A total of 451 game-related injuries occurred in Alberta (121 concussions; 27%) and 280 (62 concussions; 22%) in Quebec. For game-related injuries, the IRR between players from teams with more than 50% wins and players on teams with less than or equal to 50% wins was 0.78 (95% CI 0.64 to 0.95) for all injuries, and 0.75 (95% CI 0.47 to 0.88) for concussions, 0.64 (95% CI 0.47-0.88) for injuries resulting in a time loss greater than 7 days, and 0.74 (95% CI 0.39 to 1.40) for concussions resulting in a time loss greater than 10 days. This suggests that teams that perform better (win more than 50% of their games) have a 22% lower injury rate and a 25% lower concussion rate in Pee Wee and Bantam ice hockey.<sup>44</sup>

The two studies investigating MSK injury and performance suggest that there is little change after injury and individual performance may actually improve following treatment.<sup>42,43</sup> Additionally, teams seem to perform better (based on winning percentage) when they have fewer injuries.<sup>44</sup>

### ***2.3.3 Limitations of the Literature between Musculoskeletal Injury and Sport-Specific Performance***

Although there are a number of studies that have investigated the association between MSK injury and sport-specific performance, the literature is mainly limited to investigations of UCL, ACL, and microfracture injuries. Moreover, most of these studies examined sports other than ice hockey. Based on the literature presented, MSK injuries have the potential to decrease performance, but this may be both injury and sport-specific. This is understandable given some MSK injuries are more severe than others and may require a longer recovery time, and different sports require different skills and movements. There are, however, numerous limitations to the studies presented that should be addressed.

A common problem observed in many of these studies was either a failure to correct for multiple comparisons or a lack of power. Many studies did not correct for multiple comparisons.<sup>28,32,33,35,37-39,42</sup> This increases the risk of committing a type I error (finding a difference when one actually does not exist). Further, one study did not even report the number of comparisons conducted, which makes it difficult to appraise.<sup>34</sup> Additionally, some of the studies used relatively small sample sizes that increase the potential for type II error (the failure to see a difference when one actually exists). These issues make it difficult to understand the relationship between the MSK injury and athletic performance. Further, most of these studies used their injury data from publicly available data, such as from media reports and online databases. Although this method of subject selection has been used in many sports medicine studies, there is the potential from this selection method to miss cases. If this were true, these missed cases could have performed worse on performance outcomes after their return, which would ultimately underestimate the true association of MSK injury and performance. However, it

could also be argued that the opposite is also likely in that missed cases could have performed equal or better in performance outcomes after return.

It is difficult to compare the proportion of players that return to play in different professional sports due to some sports having guaranteed contracts and others not. Since players in the NFL are not on guaranteed contracts, they may be less inclined to return than other sports, such as hockey, where their salary is being paid regardless of injury.

Most of these studies relied on the quantification of performance through traditional point-based performance statistics. Although not necessarily a limitation, the issue with traditional performance measures is that point performance can fluctuate from year to year regardless of the health of the player. Many additional factors contribute to a player's point-based performance such as the quality of the teammates, the coaching style, or the tactical system used by the coach. Further, player performance in ice hockey is a combination of many factors both with and without the puck, which can be difficult to measure. Therefore, potentially other sport characteristics in more appropriate context would be a better measurement. For instance, measuring the fundamental sport-specific skills might be a better measure of performance, and could better represent the association between injury and skill performance. Moreover, although some of these research papers report statistically different results in performance after an MSK injury, it is unclear if these differences are practically relevant.

It is important to note that injured players may differ from control players on other important characteristics. As such, there is the potential for effect modification and/or confounding to be an important consideration. Players may have a characteristic that increases the likelihood of injury and results in reduced performance, independent of injury. This

highlights the need for additional cohort studies to examine the association between injury history and skill performance.

Finally, all but one of the studies only investigated professional adult male athletes. Again, although not necessarily a limitation, there are many differences between adult and youth competitors including the demands placed on the athlete, mechanisms of injury, age, physique, and physical and mental strength, which suggest these findings may not even be generalizable to a youth ice hockey population. Further, it is unlikely that MSK injuries and performance have much relation to the association between concussion and performance outcomes, which further questions the relevance of this research to the current thesis topic.

#### ***2.3.4 Concussion on Sport-Specific Performance***

Although the relationship between musculoskeletal injury and sport performance has received some interest, there is a paucity of research that has investigated the relationship between concussion and sport performance. Only three published studies and one abstract were found that have investigated this association, and each involved different sporting activities.

##### ***2.3.4.1 Australian Football***

Makdissi et al. (2009) investigated the effect of concussion on a sport-specific skill performance measure in Australian Football. Using a prospective cohort design, this study followed professional Australian Football players playing in the Australian Football League (AFL) over four seasons of play (2000-2003) (aged 16-36 years, males). Players that incurred a physician diagnosed concussion (138 concussions in 117 players) were matched to uninjured controls and compared on their performance of “disposals”, the skill of moving the ball by hand or foot to facilitate team scoring. Disposal rates were compared between pre and post-injury

concussed players and between the concussed and the control group for both a single game and three games prior to and after returning from injury. When comparing the ratio of disposal rates per hour per match time in the concussed group, disposal performance level on their return to playing was not significantly different from their pre-injury rates for both a single game (1.08; 95% CI 0.99 to 1.11), and three games (1.04; 95% CI 0.99 to 1.10). Additionally, when comparing the ratio of disposal rates between the concussed group and the control group, performance level of concussed players was actually higher than the rates for the control group in a single game (1.20; 95% CI 1.03 to 1.38) and similar over three games (1.04; 95% CI 0.97 to 1.12). This suggests that Australian football players returning to play after a concussion have no deficits in one sport-specific skill performance metric.<sup>11</sup>

#### 2.3.4.2 American Football

Kumar et al. (2014) compared the on-field in-game performance pre and post-concussion in professional football players playing in the National Football League (NFL). Using a case-control study design, concussed players (131 concussions in 124 players; 7 players sustained a second concussion that met inclusion criteria) were identified through Internet searches of weekly injury reports from sports news media. Players were separated into those that returned to play within 7 days (missed no games due to injury; 72 players) and players that missed at least one game (returned to play was greater than 7 days; 59 players). On-field performance (player ratings) was determined through ProFootballFocus (PFF) performance scores, which are position-specific ratings that are calculated through analysis of the players' individual performance on each play of every game. The scores utilize position-related performance metrics and are unrelated to play outcome or performance of teammates or opponents. Performance

ratings for each player are normalized across the specific position, with a score of 0.0 representing average performance with a standard deviation of 0.5. Players needed to have played in four games prior to and post-concussion within the same playing year in order to be included in this study. Fifty-five percent of the concussed players missed no games and 45% missed at least 1 game. Pre-injury performance scores were similar to post-injury performance in players with no games missed (0.16 vs. 0.33;  $p=0.129$ ) and players with at least one game missed (-0.06 vs. 0.10;  $p=0.219$ ). Further, correlation analysis using univariate linear regression found that factors such as age at injury (estimate=0.01,  $p=0.647$ ), body mass index (estimate=0.04,  $p=0.095$ ), career year at injury (estimate=0.01,  $p=0.787$ ), career games played at injury (estimate=0.00,  $p=0.596$ ), games played before injury within injury season (estimate=0.371,  $p=0.371$ ), and previous concussion (estimate=0.24,  $p=0.178$ ) did not have a statistically significant correlation to changes in on-field performance.<sup>12</sup> These results suggest that there are no differences in football player performance measures after concussion whether the player miss a game or not before return.

#### 2.3.4.3 Baseball

Wasserman et al. (2015) compared different batting performance metrics between players that suffered a concussion and non-injured controls that were away for paternity or bereavement leave during the same time period, for players playing professionally in the MLB. Using a retrospective cohort design, concussed players ( $n=66$ ) were identified from 2007-2013 through MLB's online league disabled-list (DL) records and Baseball Prospectus databases. During the same time period (2007-2013) players that were away for either paternity leave or bereavement leave ( $n=68$ ) were identified through DL list. Various batting performance metrics such as

batting average (hits per official at-bats), on-base percentage ( $[\text{hits} + \text{walks} + \text{hit-by-pitch}]/[\text{at-bats} + \text{walks} + \text{hit-by-pitch} + \text{sacrifice fly-outs}]$ ), slugging percentage ( $[\text{singles} + (2 \times \text{doubles}) + (3 \times \text{triples}) + (4 \times \text{home-runs})]/[\text{official at-bats}]$ ), on-base percentage plus slugging percentage, walk percentage (walks per plate appearances), strikeout percentage (strikeouts per at-bats), and home run percentage (home runs per at-bats) were compared between the two groups. The various batting performance metrics were compared between the two groups for the two weeks after returning to sport (post-leave), as well as 4-6 weeks after return (long-term post-leave). In the two-weeks after return to sport, concussed athletes scored significantly worse in batting average (0.235 vs. 0.266,  $p=0.005$ ), on-base percentage (0.294 vs. 0.326,  $p=0.010$ ), slugging percentage (0.361 vs. 0.423,  $p=0.004$ ), and on-base percentage plus slugging percentage (0.650 vs. 0.749,  $p=0.003$ ) than non-injured players on leave. After controlling for pre-batting performance, number of days missed, and position, concussed players scored significantly worse on base plus slugging percentage in the two weeks post-leave than non-injured players (0.650 vs. 0.749,  $p=0.45$ ).<sup>13</sup>

#### 2.3.4.4 Ice Hockey

To our knowledge, the only research that has examined the effect of previous concussion on sport-specific skill performance in ice hockey is a pilot study conducted by Eliason et al. (2014). This study included ten elite Bantam and Midget teams ( $n = 131$ , male and female, ages 13-17, top 20% by division of play) over the 2012-2013 playing season, using self-reported previous concussion history. Rather than measuring performance based on traditional point systems, this study measured performance based on the ability of the players to complete fundamental on-ice skills tests in a controlled environment. This pilot study was conducted in

order to determine the feasibility, methodology, and logistical issues associated with conducting on-ice skills testing in such a study in youth ice hockey. By comparing the 95% confidence intervals, the exploratory analysis suggested that there was no difference between the mean scores of sport-specific skills on the components of the Hockey Canada Skills Testing protocol between: those with a history of concussion and those without; those with an injury within 6 weeks and those without; or those with an injury within 1 year and those without.<sup>45</sup>

## **2.4 Discussion**

### ***2.4.1 Critical Appraisal of the Current Body of Knowledge***

The major strength of the studies reviewed is that they are the first to investigate the association between concussion and performance in their respective sports and have started a foundation on which future research should build. The body of literature evaluating concussion history and sport-specific performance is sparse. Only four studies were found that have investigated this association, and only one of those investigated ice hockey.<sup>45</sup> Much like the weaknesses of the studies that investigated the association between MSK injury and performance, there are common limitations to these studies. Two of the four studies classified cases from publicly available data such as from media reports or online databases.<sup>12,13</sup> There is the possibility from this classification system to miss cases which, depending on their performance outcome on return, may influence the results of the study. Potentially, missed cases could have performed worse on performance outcomes after their return, which would ultimately underestimate the true association of concussion and performance. Additionally, three of the four studies had professional male athletes as the study population,<sup>11-13</sup> which may not generalize to youth due to a myriad of differences. Two of these studies were limited by using traditional

performance metrics,<sup>12,13</sup> which may not be the ideal way to measure performance post-concussion. An issue in measuring performance through traditional point-based statistics is that these numbers can fluctuate from year to year due to a variety of reasons.

Each of the studies also had specific limitations. Although the study by Makdissi et al. (2009) was sufficiently powered to detect differences in performance, the low number of injuries observed increases the potential for type II error. It is also important to realize that this study only looked at one sport-specific skill performance metric, and it is unclear if other performance metrics, which may be more sensitive, would show different results. Kumar et al. (2014) reports that because the PFF performance score is calculated by multiple metrics it provides an objective view of performance.<sup>12</sup> However, the validity and reliability of the PFF was not stated and many of the categories used to calculate the PFF are obtained from a subjective film study component. No information was provided about who or how these components were rated. Wasserman et al. (2015) did not correct for the number of statistical tests used, and based on the large number of tests conducted, some of the statistically significant results reported may be due simply from chance (type I error). There was also no mention of a sample size calculation for this study, so this study may have also been underpowered. Further, the authors did not account for the time spent on rehabilitation assignment in the minor leagues for players who went on the DL, which may have large implications on the players' performance when they return. Finally, even though the authors found statistically significant differences, it is unclear if these are clinically significant differences. Lastly, the pilot study by Eliason et al. (2014) was not sufficiently powered, and therefore, inferential statistics could not be employed so future investigations may yield different results.

Despite these shortcomings, understanding of the relationship between injury/concussion and performance is growing. The studies presented have provided a framework on which to build future studies. Because injury and performance has not received substantial attention yet, this highlights the need for future investigations in this area.

#### ***2.4.2 Recommendations for Future Research***

There is a paucity of published research investigating the association between injury, particularly concussion, and athletic performance. The current body of knowledge would greatly benefit from more methodologically and statistically rigorous studies that are appropriately powered, in order to better understand the complexity of measuring player performance and understanding the relationship between injury and performance.

#### **2.5 Conclusions**

There is a need for further research in the areas of injury, mainly concussion, and skill performance as the current body of knowledge is quite limited. Although select MSK injuries and performance have had some investigations, there are many other MSK injuries that have not. The association between concussion and performance has only been examined by few studies. Further evidence and clarification is needed in order to determine the association between concussion and performance, which may help to better inform future injury prevention and concussion management strategies. A better understanding of the association between concussion and performance in ice hockey will help to inform future studies.

## **Chapter Three: METHODS**

### **3.1 Study Design**

A cross-sectional study design was used. Data on demographics, concussion history including the number, date, and length of recovery of all previous concussions were collected using a baseline questionnaire that was distributed to elite and non-elite ice hockey players. In addition, players sport-specific skill performance was measured using components of the HCST.

### **3.2 Study Population**

Our estimated sample size was calculated based on the proportion of those with and without a previous history of concussion that fell in the upper 25<sup>th</sup> percentile (the slowest players) on the HCST component forward agility weave without the puck.<sup>45</sup> This component was chosen because it demonstrates fundamental skating skills, and may show the largest difference between those with and without a history of concussion. The size required for each separate sample (those with a history of concussion and those with no history of concussion) was 259 participants (N = 518). This calculation was based on an alpha level of 0.05 and 80% power to detect a difference of approximately 12% in the proportion in the highest 25<sup>th</sup> percentile of the HCST. The calculations are the customary ones based on the normal approximation to the binomial distribution. Although the sample size was calculated based on statistical significance, our results may also aid in the determination of clinical relevance. For full sample size calculations including exact proportions used, see Appendix A.

Hockey teams from Calgary, Alberta were targeted for participant recruitment for this study. The study population included males and females, aged 11-17 years.

Inclusion criteria for recruitment were any:

1. Pee Wee, Bantam, or Midget team registered with Hockey Calgary.
2. Bantam or Midget team playing for Edge School in Calgary, Alberta.

Exclusion criteria for recruitment were:

1. Refusal to participate.
2. Incomplete or missing player assent form, parent consent form, or HCST scores.
3. Players that entered the study at time of concussion.

This study used a convenience sample comprised of teams in 2012-2013 that was recruited by Hockey Canada, and teams in 2013-2014 and 2014-2015 seasons that were recruited by self-selection from a larger longitudinal cohort study. The methods used to collect the data in 2012-2013 were identical to the methods used to collect the 2013-2014 and 2014-2015 data.

The 2012-2013 data are comprised of seven elite male teams from the northwest zone of Calgary, and three female elite teams composed of players from all over the city of Calgary (top 20% by level of play). Both the male and female teams played within Hockey Calgary. Male teams were recruited from Bantam AA, Bantam AAA, Midget 15 AAA, Midget AA, and Midget AAA levels. Female teams were recruited from Bantam AAA and Midget AAA levels. For Bantam and Midget, “AAA” is the most elite category of play followed by “AA” and then house league tiers (1-7). Both male and female Bantam players were between the ages of 13 to 14, while male and female Midget players were between the ages of 15 to 17.

All Pee Wee and Bantam teams that were recruited to participate either in the 2013-2014 or 2014-2015 season were registered with Hockey Calgary or played for the Edge School in

Calgary, Alberta. The Pee Wee teams represented the various districts and community associations throughout the city, were recruited from all levels of play (tiers 1 through 12), and were between the ages of 11 and 12 years old. Elite Pee Wee teams were defined as the upper 30% by division of play (tiers 1-3). Non-elite Pee Wee teams were defined as the lower 70% by division of play (tiers 4-12). The Bantam teams also represented various districts and community associations throughout the city, were recruited from all levels of play (AAA, AA, and tiers 1 through 7), and were between the ages of 13 and 14 years old. Elite Bantam teams were defined as the upper 30% by division of play (AAA, AA, and tier 1). Non-elite Bantam teams were defined as the lower 70% by division of play (tiers 2-7). At the Pee Wee and non-elite Bantam level, Hockey Calgary divides the city into different community districts that are further designated to local Community Hockey Associations. At the elite Bantam level, male teams were divided into four zones based on living address, and female teams were made up of players from all over the city. Twenty-six players were represented in more than one year in the study and were treated as independent subjects.

**Figure 3.1 Subject recruitment flow chart by year**



### **3.3 Procedures**

#### **3.3.1 Data Collection**

##### **3.3.1.1 Study Questionnaire**

Players completed a self-reported baseline questionnaire regarding any and all previous concussions they had sustained prior to the start of their recruitment season (either the 2012-2013, 2013-2014, or 2014-2015 season). The questionnaire included details regarding demographics (including date of birth and sex), playing history, and the date(s) and length of recovery time of any previous concussion. Specifically, players were asked “have you ever had a concussion or been ‘knocked out’ or had your ‘bell rung’?” The players did not have to be officially diagnosed by a doctor, seek medical attention, or require time loss in order to report having a previous concussion. Additionally, players were asked if they had any other injury

requiring medical attention or at least one day of missed participation from sport or physical activity in the past 12 months.

### 3.3.1.2 Injury Report Forms

Because players may have sustained a concussion between the time that they completed the preseason baseline questionnaire and the time of HCST, injury data, including concussion, were recorded during the season for players that consented to participate in the study. This information was entered prior to the analysis to allow for a more complete and accurate concussion history of the players prior to completing HCST.

### 3.3.1.3 Hockey Canada Skills Test (HCST)

#### 3.3.1.3.1 Equipment

The equipment needed to run the HCST stations included: 6 pucks, 1 tape measure, 1 can of spray paint, 4 hand stop watches, 14 pylons, and 4 clipboards and pens. Each test station required 2 timing personnel: one person to measure the times of the players and the other to record the times on the recording sheets (Appendix B).

#### 3.3.1.3.2 Procedure

Research assistants were trained by Hockey Canada personnel on how to properly set up and measure the HCST components. The HCST testing was done at various arenas throughout the city of Calgary. Prior to the beginning of each testing session, research assistants measured and marked with spray paint the location of the cones for the drills. The spray paint allowed the cones to be replaced in the exact same location every time a cone got knocked out of position. To prevent ruts in the ice during the transition and forward agility weave, multiple sets of dots were measured and marked approximately one metre apart. This allowed each group of players a fresh

patch of ice that was rut free. If multiple teams were tested on the same night and on the same sheet of ice, then the area on the ice where the stations are located was rotated for every new team. This allowed the teams to have a different location for the stations in order to reduce the number of ruts formed.

All of the four skill testing stations were completed during one ice session (either 60 or 75 minutes). Three of the testing stations, the agility weave, agility transition skate, and speed skate (both forwards and backwards) were administered simultaneously at the beginning of the ice session. These three tests were measured twice, once with a puck and once without. The final station, the 6-repeat endurance skate, was run after the other three tests were completed. The 6-repeat indicates a player's endurance and was measured only once, and without a puck. Timing personnel using a hand stopwatch (accurate to one-hundredth of a second) measured each test. For a full description of the drill set up and protocol of each drill see Appendix C.

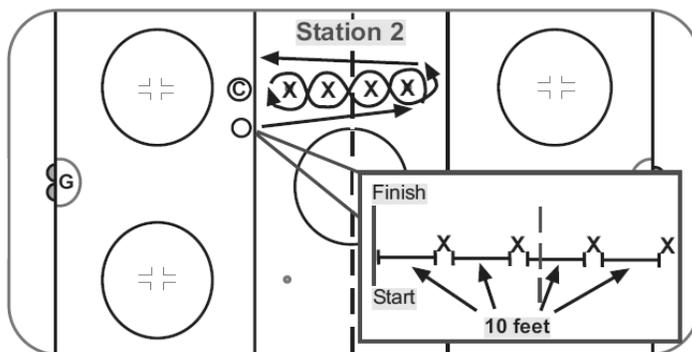
Players, including goaltenders, were divided evenly between three groups (typically based alphabetically by last name). Each group started at one of the three beginning stations and participated in that drill. Players remained at that station until each player in that group had a time recorded for that station. Only when each player had a time recorded were they allowed to proceed to the next testing station. If a player fell, stumbled, or lost the puck during a drill, they had the option of either continuing the drill or start the drill over again. If a player knocked a cone out of place during a trial his/her time was only allowed if he/she continued the drill properly. If timing personnel deemed a player did not correctly complete the drill, the player was instructed to start the drill over again. A maximum of three attempts was allowed on any one testing station. If a player was unable to finish the drill in three attempts they received a "no

time” on that station. If during the final station, the 6 repeat, a player was unable to complete a lap in the maximum allotted time of 30 seconds, or the player stopped on their own accord, they received a no time for that lap and any additional lap(s) remaining. Testing sheets can be found in Appendix B. Testing was administered once and occurred either over the 2012-2013, 2013-2014, or 2014-2015 playing season. Players that completed HCST testing over both the 2013-2014 and 2014-2015 season were treated as independent subjects. Players that entered the study at time of concussion were excluded from analysis. The date of testing depended on team, research assistant, and arena ice time availability.

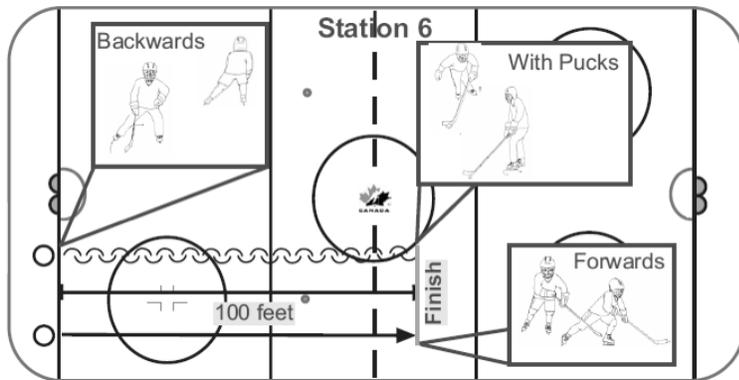
### 3.3.2 Outcome Measures

The primary outcome measure of interest was the time (in seconds) on the HCST components: forward agility weave (Figure 3.2), forward/backward speed skate (Figure 3.3), transition agility (Figure 3.4), and the 6-repeat endurance skate (Figure 3.5). Forward agility weave without the puck was our primary outcome and all other test components were secondary.

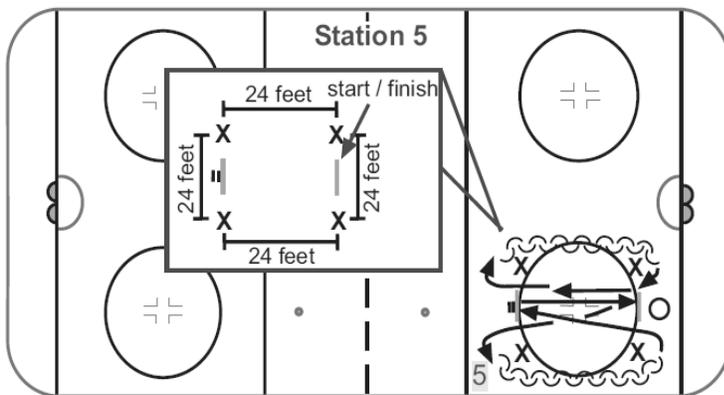
**Figure 3.2 Forward Agility Weave**



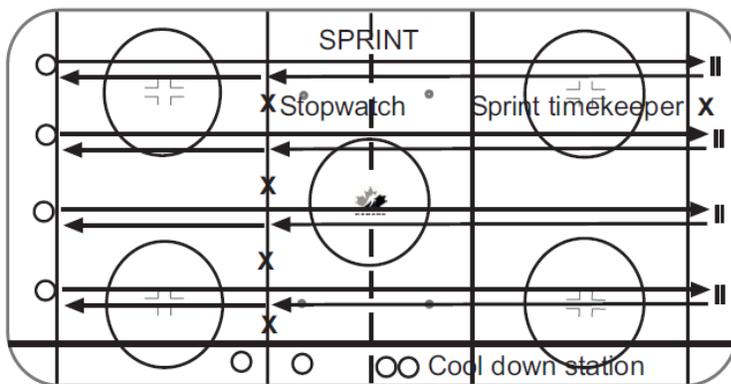
**Figure 3.3 Forward/Backward Speed Skate**



**Figure 3.4 Transition Agility**



**Figure 3.5 6-Repeat Endurance Skate**



### ***3.3.3 Exposure Variables***

The self-reported history of concussion was considered the exposure variable in this study, and was collected on a paper baseline questionnaire (Appendix D). This form contained demographics including age, sex, position, as well as history of previous concussion. Specifically, the question asked was “have you ever had a concussion or been ‘knocked out’ or had your ‘bell rung’?” The questionnaire was filled out by the player or their parent and was completed prior to on-ice testing. Previous history of concussion was dichotomized as those with no history of concussion “0” and history of concussion “1”. The number of previous concussions sustained was categorized into those with none, one, two, or three or more. The time since last concussion and completing HCST and length of recovery following the most recent concussion were measured in whole number days.

## **3.4 Statistical Methods**

All statistical analyses were carried out using STATA 13 (Statacorp, College Station, TX). Descriptive statistics were used to describe baseline characteristics (sex, age, history of MSK injury within the last year, experience, height, and weight) by history of concussion using either medians and ranges, or means and 95% CI's. A preliminary analysis was first conducted in order to assess the test re-test reliability of the HCST. Intraclass correlation coefficients (ICCs) and Bland & Altman plots with 95% Limits of Agreement (LOA) were used to examine reliability.

### ***3.4.1 Primary Objective***

A crude and adjusted odds ratio (adjusted for relative age, sex, level of play, position, whether the player was elite or non-elite, and previous MSK injury within the last year, while

accounting for clustering by team) was calculated using logistic regression for each HCST outcome (forward agility weave without and with puck, transition agility without and with puck, forward/backward speed without and with puck, and 6-repeat drop-off time), in order to determine if those that scored in the upper 25<sup>th</sup> percentile (the slowest players) by sample of each test were more likely to have a previous history of concussion. The 25<sup>th</sup> percentile was decided as our cut-off point as similar risk factor analyses in this population have used the same strategy,<sup>7,9</sup> and have shown meaningful differences. Relative age was measured continuously and was calculated from the players' date of birth to September 1<sup>st</sup> of the season they entered the study at. Sex was coded as either female ("0") or male ("1"). Level of play was defined and coded as either Pee Wee (11-12 years old; "0"), Bantam (13-14 years old; "1"), or Midget (15-17 years old; "2"). Playing positions were defined and coded as either forward ("0"), defensemen ("1"), goaltender ("2"), or "missing" ("3") if not entered on the baseline questionnaire. Elite level of play was defined and coded as the upper 30% by division of play ("0"), while non-elite was defined as the lower 70% by division of play ("1"). Finally, previous MSK injury within the previous year was coded as either no ("0") or yes ("1"). As a general guideline, it has been suggested that multivariable statistical models should not exceed 10% of the number of patients in the least frequency outcome category (in this analysis, those with a history of concussion).<sup>46</sup> Given the sample size of this study, the number of covariates included in the models are below this 10% "rule of thumb".<sup>46</sup>

The mean scores of each HCST outcome were then compared using t-tests between those with and without a previous history, stratified by sex and level of play. In order to account for multiple comparisons, a Bonferroni correction was used ( $0.05/18=0.0028$ ).

### ***3.4.2 Exploratory Objectives***

A multiple linear regression was then conducted controlling for cluster by team using previous history of concussion (0=no; 1=yes) as the exposure and the various HCST scores as continuous outcomes. Other independent variables included in the multiple linear regression model included: relative age, sex, level of play, playing position, previous MSK injury within the last year, and whether the player was elite or non-elite. The multiple linear regression models required a baseline group to be referenced to; those with no history of concussion or MSK injury, forwards, females, and elite were selected to be the baseline. The assumptions of the multiple linear regression (the conditional mean is a linear combination of the predictor variables, the conditional variance is constant, independence of errors, the conditional distribution is normally distributed, and a lack of multicollinearity) were checked first to ensure that they were not violated. Multicollinearity between variables was assessed using the variance inflation factor (VIF). As a general guideline, it has been suggested that a VIF value greater than 10 suggests high multicollinearity.<sup>47</sup> A Bonferroni correction was used in order to account for the number of multiple linear regression models ( $0.05/9=0.0056$ ).

Effect modification occurs in a study when a third variable influences the magnitude or direction of the causal association between a study exposure and outcome.<sup>48</sup> Potential effect modifiers that were included in the analysis were relative age and sex, as it was hypothesized that these variables may modify the effect of concussion on HCST times. There was no evidence to suggest, nor reason to believe, that the exposure variable would be modified by the other independent variables (e.g., level of play, previous MSK injury within the last year, playing position, and whether the player was elite or non-elite). Therefore, effect modification was not

assessed for these variables. Because the multiple linear regression models were adjusted for clustering by team, effect modification was assessed using an a-priori alpha level of 0.05 based on the Wald test.

Confounding is a distortion in the magnitude of the true effect of a study exposure on a study outcome due to mixing of effects between the exposure and an extraneous factor.<sup>48</sup> It is unknown whether the listed variables will be confounders, and therefore, all covariates were treated as potential confounders. Confounders were assessed based on a change of 10% or more in the  $\beta$  of the main exposure.

Additionally, multiple linear regression models were fit to assess the number of previous concussions, time since last concussion, and length of recovery following most recent concussion and all HCST outcomes, while controlling for clustering by team. Due to the small number of players reporting a history of 3 previous concussions, those with 2 and 3 previous concussions were combined into a two or more category. Therefore, history of concussion was compared between those that had no history (0), one previous concussion (1), and two or more previous concussions (2+). Those with no history (0) were selected as the baseline group for this outcome. For those with a previous history of concussion, the time since their last concussion and length of recovery following their most recent concussion were treated as continuous variables, and were measured in whole number days. In order to account for the number of multiple linear regression models, a Bonferroni correction was used for each outcome separately (i.e.,  $0.05/9=0.0056$ ). These models also included the variables relative age, level of play, playing position, previous MSK injury within the last year, and whether the player was elite or non-elite. Potential effect modifiers that were included in these analyses were relative age and sex, and were assessed using

an a-priori alpha level of 0.05 based on the Wald test. All covariates were added to the model as potential confounders and assessed based on a change of 10% or more in the  $\beta$  of the main exposure.

### **3.4.3 Inclusion**

The number of players that were included in the primary final analysis depended on a) the number of players that completed, signed, and handed in the player assent form (Appendix E); b) the number of parents that completed, signed, and handed in the parent consent form (Appendix F); and c) the number of players that completed, signed, and handed in the preseason baseline questionnaire regarding any and all previous concussions they had sustained prior to the start of the year the team was recruited. Of those players who complied, only those that participated in the on-ice testing were included in the final analysis. If players did not complete any of the required forms or on-ice testing, they were considered a listwise deletion and were not included in the final analysis. Players with missing covariate data were excluded from the adjusted models. Due to the small amount of missing covariate data, imputation techniques were not warranted. Players that completed more than one year of on-ice testing were included as independent subjects.

### **3.5 Ethical Considerations**

The proposal for this study was approved by the Office of Medical Bioethics, University of Calgary, CHREB on October 2, 2012 and August 21, 2014, and was an extension of two original approvals for the project received August 4, 2011 and April 17, 2007 (Ethics ID# 24026 Title: Evaluation of a Neurocognitive Tool in Youth Ice Hockey Players Before and After a

Sport-Related Concussion; Ethics ID# 20252 Title: The Risk of Injury Associated with Body Checking among Paediatric Ice Hockey Players).

This study did not inflict or increase the risk of harm to any players. Having players complete components of the HCST did not increase the risk of injury greater than the risk of a normal practice. All eligible teams and players were allowed to perform the HCST. Players were required to give assent since they were under the age of 18, and parents must have given consent in order to be included in the final analysis of our study. Some players wished to participate in the HCST without consenting to be included in the final analysis. These players were allowed to participate in the testing and their scores were given to them, but their results were not retained. Coaches received a copy of the scores of all players that performed the HCST and were informed that the scores should only be used for skill development purposes, and that the results should not influence ice time or any other tactical decisions. For those that wished to be included in the study, their information was kept private and confidential. The questionnaire and HCST results were entered into REDCap, with subjects only identifiable by a unique study identification number. REDCap is a secure on-line web application for building and managing research study databases. It is only assessable by study personnel, each with a unique password. All data files that contained identifying information were entered onto a secure and encrypted server on a password protected computer and network. Preseason baseline questionnaires and hard copy HCST information have been stored in a locked file folder in secure room B2215 within the Sport Injury Prevention Research Centre at the University of Calgary. Only research team members with necessary ethics approval were allowed to access the study information. No information was, or will be, disclosed to anyone other than project personnel for any purpose.

## Chapter Four: RESULTS

### 4.1 HCST Test Re-Test Reliability

#### 4.1.1 Study Participants

Three elite Bantam ice hockey teams (n=46; ages 13-14; AA, AAA; top 20% by division of play) were recruited to participate in the test re-test reliability portion of the study. Of those recruited, 23 players were included for final analysis (50%). Players were excluded from final analysis if they did not complete both testing sessions (n=23). Participant characteristics are summarized in Table 4.1. Male and female participants accounted for 60% and 40% of the total sample population, respectively.

**Table 4.1 Baseline characteristics of test re-test participants (n=23)**

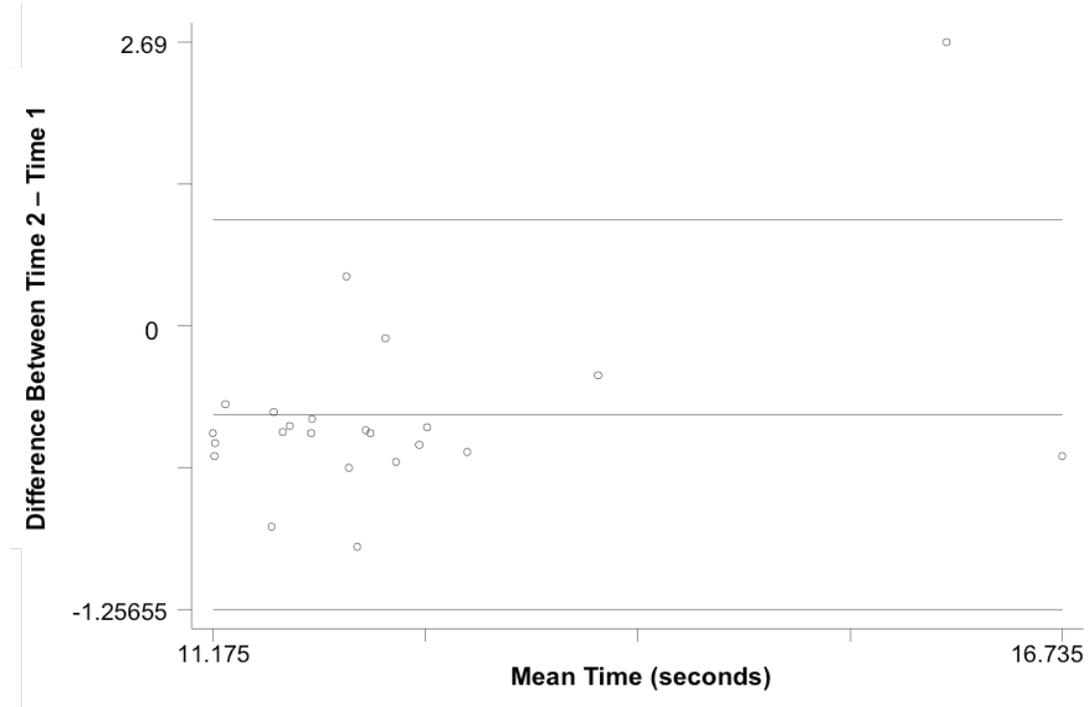
<b>Characteristic</b>	<b>Male (n=14)</b>	<b>Female (n=9)</b>
Age-years (median, range)	13.85 (13.02-14.55)	13.83 (13.16-14.34)
Height-cm (median, range)	172.7 (157.5-188)	162.6 (160-165.1)
Weight-kg (median, range)	62.14 (49.9-93)	52.7 (47.3-59.1)
Experience-years played (median, range)	9 (7-11)	8 (5-10)

The mean difference between the times from testing session 2 and 1, as well as the 95% limits of agreement, and the intraclass correlation coefficients are presented in Table 4.2. The Bland Altman plots for each HCST outcome are presented in Figures 4.1-4.9.

**Table 4.2 Mean difference, Bland and Altman Limits of Agreement (LOA), and Intraclass Correlation Coefficients (ICCs) by HCST components**

<b>HCST Component</b>	<b>Mean Difference (seconds)</b>	<b>95% LOA (seconds)</b>	<b>ICC (95% CI)</b>
Fwd Agility Weave Without Puck	0.099	-1.257-1.454	0.89 (0.81-0.98)
Fwd Agility Weave With Puck	0.303	-1.897-2.507	0.85 (0.74-0.97)
Transition Agility Without Puck	0.117	-1.193-1.427	0.92 (0.85-0.98)
Transition Agility With Puck	-0.397	-3.892-3.098	0.74 (0.56-0.93)
Fwd Speed Without Puck	0.019	-0.520-0.558	0.82 (0.68-0.95)
Fwd Speed With Puck	0.033	-0.664-0.729	0.75 (0.58-0.93)
Bwd Speed Without Puck	0.001	-0.723-0.726	0.81 (0.67-0.95)
Bwd Speed With Puck	0.072	-0.604-0.748	0.86 (0.76-0.97)
Drop-off Time	0.200	-1.480-1.881	0.50 (0.19-0.80)

**Figure 4.1 Bland Altman plot of forward agility weave without puck**



**Figure 4.2 Bland Altman plot of forward agility weave with puck**

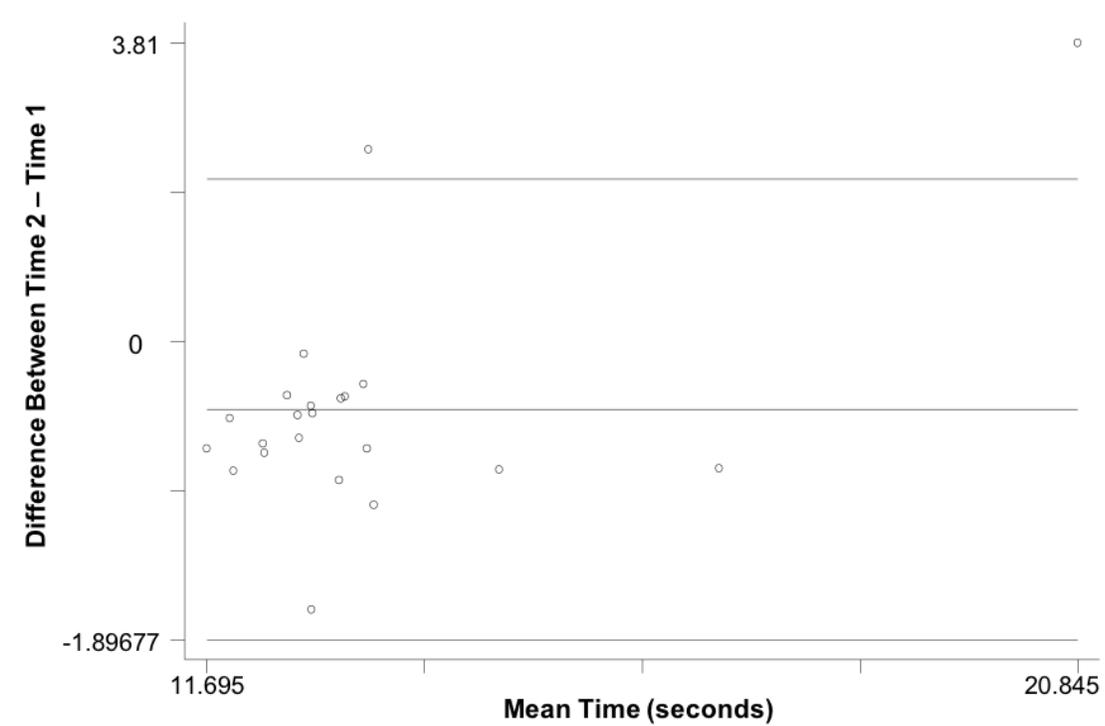


Figure 4.3 Bland Altman plot of transition agility weave without puck

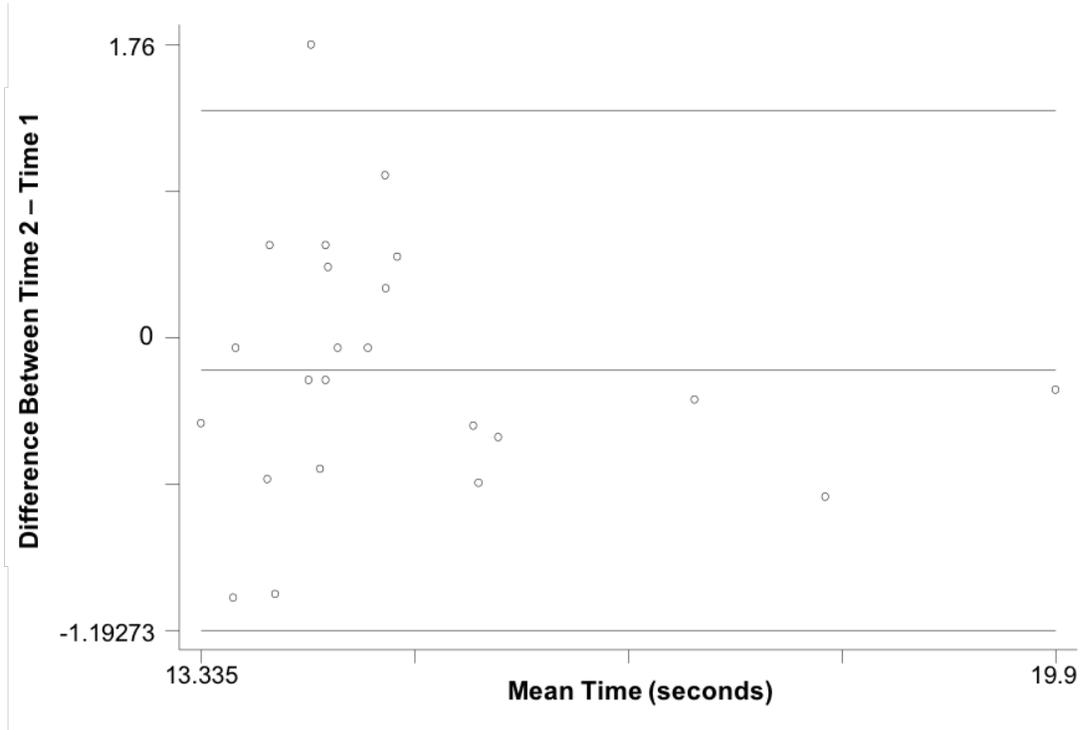


Figure 4.4 Bland Altman plot of transition agility weave with puck

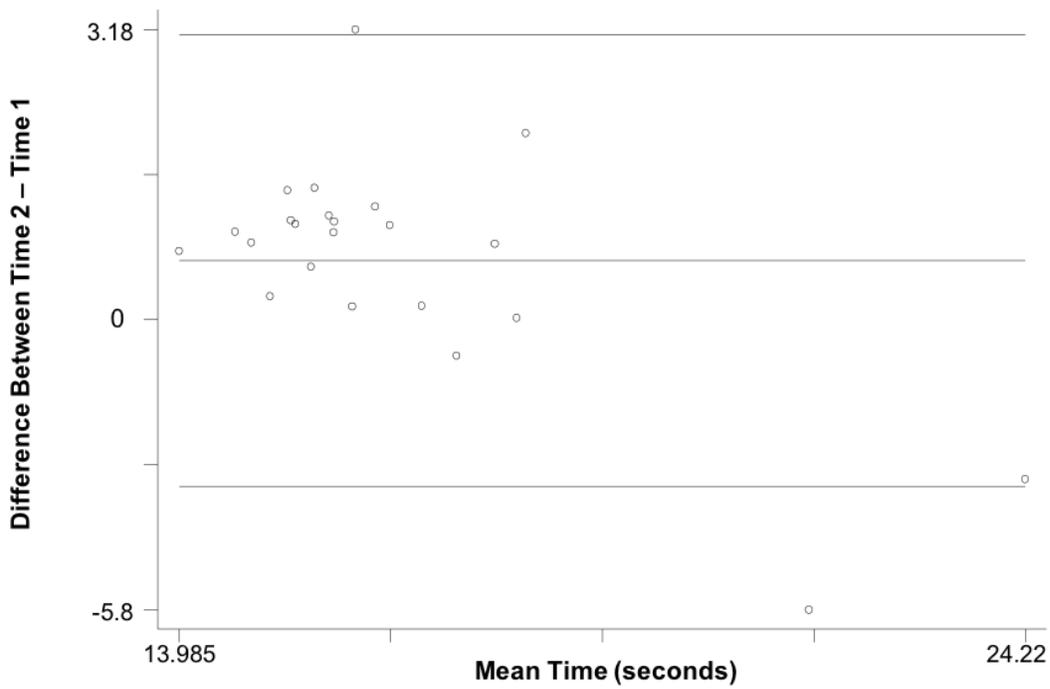


Figure 4.5 Bland Altman plot of forward speed skate without puck

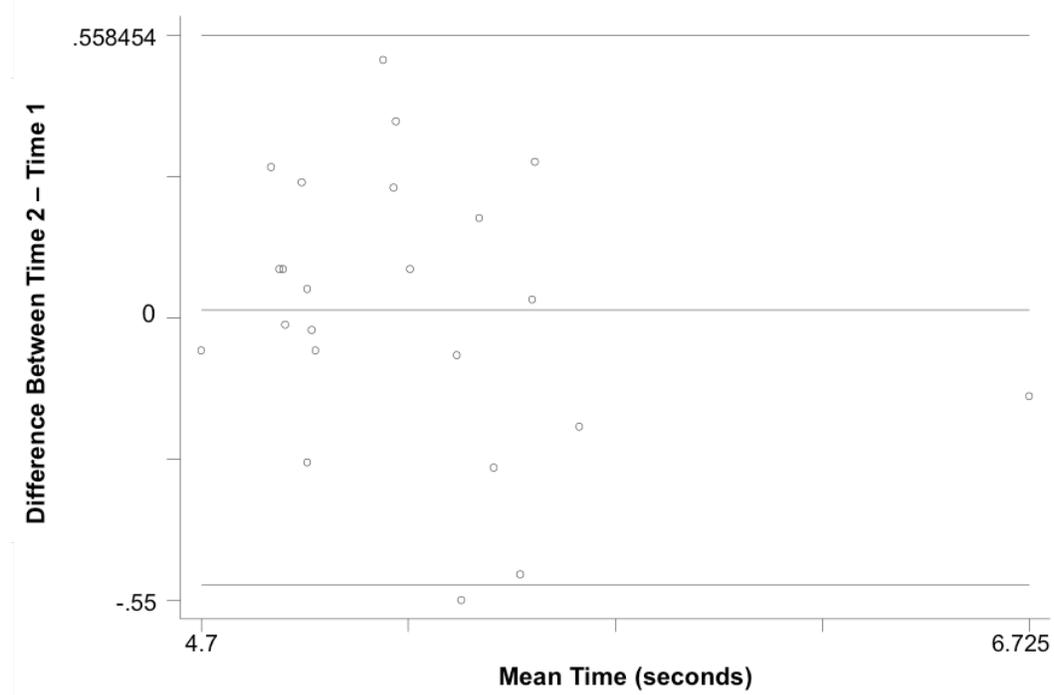
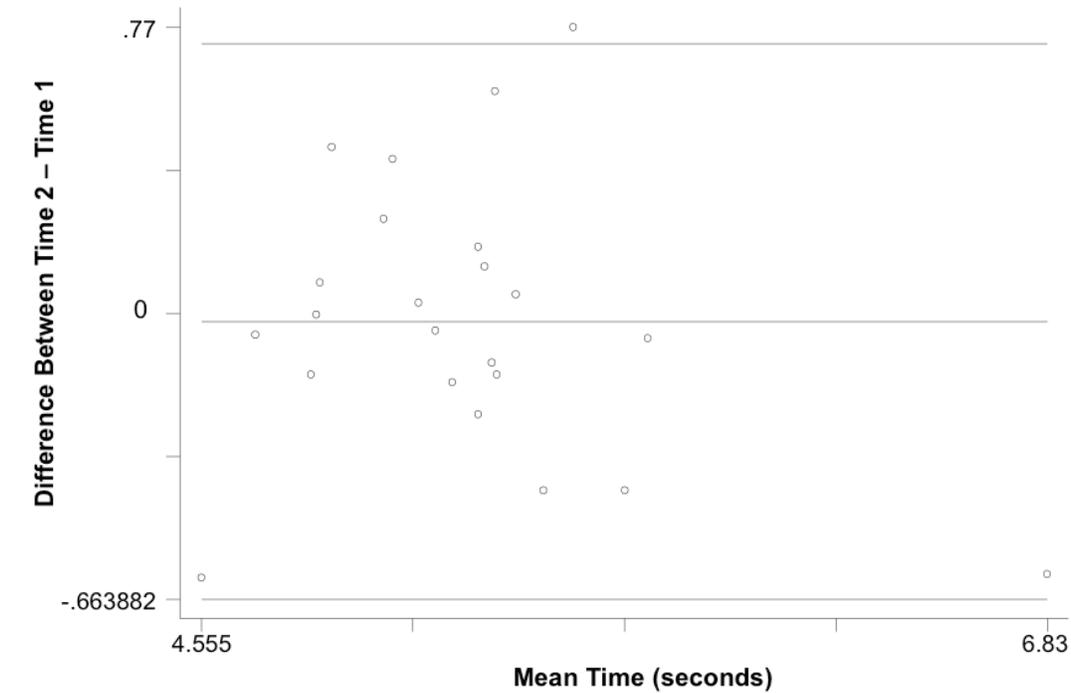
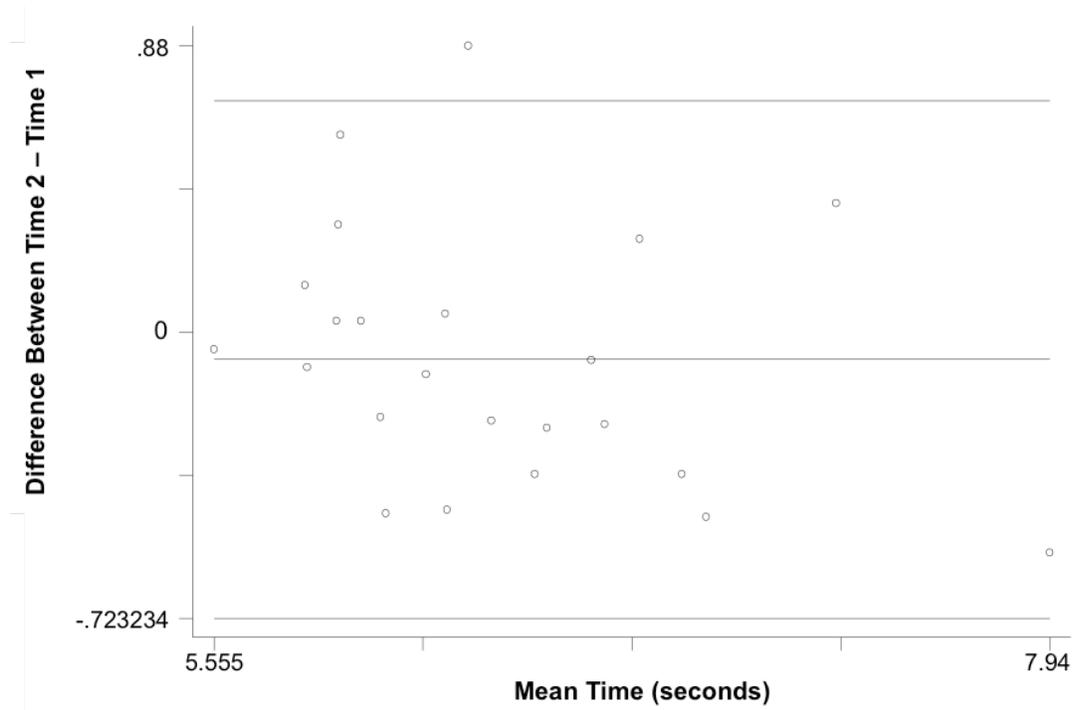


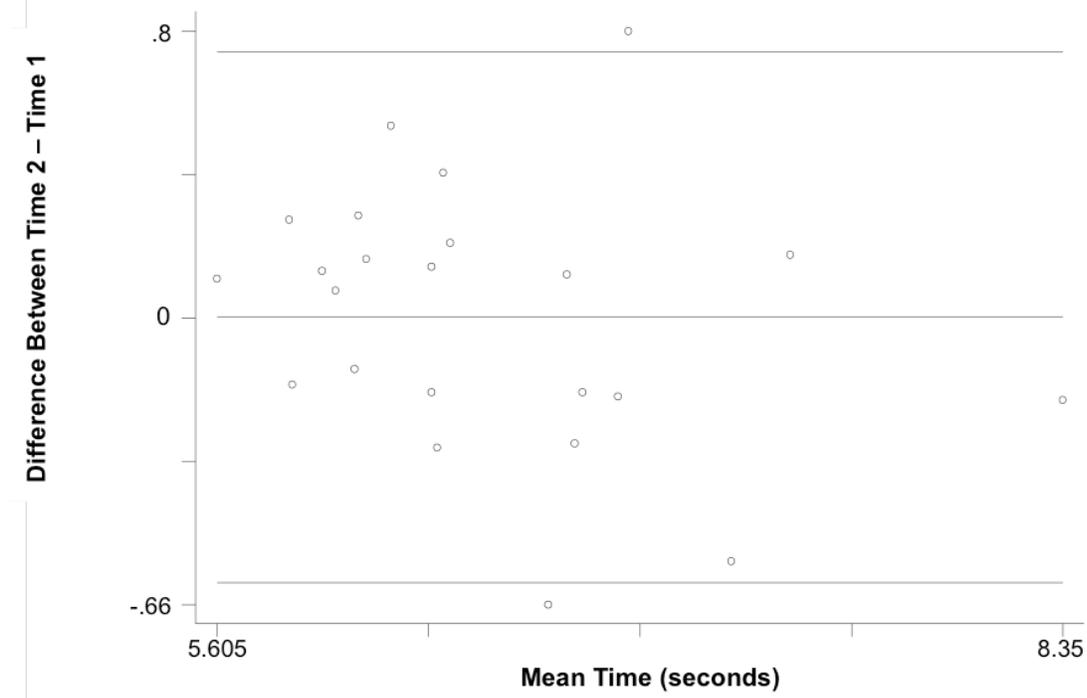
Figure 4.6 Bland Altman plot of forward speed skate with puck



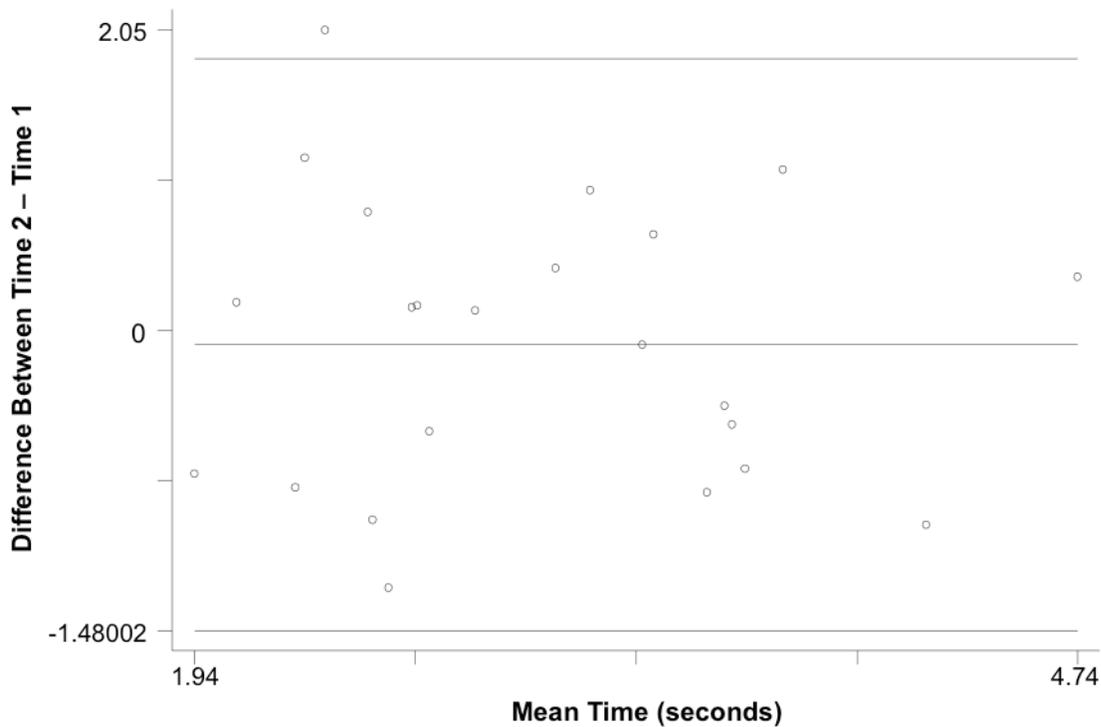
**Figure 4.7 Bland Altman plot of backward speed skate without puck**



**Figure 4.8 Bland Altman plot of backward speed skate with puck**



**Figure 4.9 Bland Altman plot of drop-off time**



Intraclass correlation coefficients ranged from 0.50-0.92. Transition agility without the puck showed the highest ICC value of 0.92 (95% CI 0.85-0.98), whereas 6-repeat drop-off time showed the lowest ICC of 0.50 (95% CI 0.19-0.80) (Table 4.2). The mean difference between the scores ranged from 0.001 seconds (backward speed without the puck) to -0.397 seconds (transition agility with the puck). Bland Altman 95% LOA suggests that the second score will fall within approximately one second of the score from the first test session for most HCST components. In addition to having the largest mean difference, the component transition agility weave with the puck also had the largest 95 % LOA ranging from -3.892 to 3.098 seconds.

## **4.2 Previous History of Concussion**

Five hundred and ninety-six players from 65 teams were recruited to participate from three levels of play (Pee Wee, Bantam, and Midget). Five hundred twenty-five (88%) of the participants were male, and seventy-one (12%) were female. Two hundred two players reported a history of concussion (34%), and three hundred ninety-four (66%) reported no history of concussion. Four players (0.7%) indicated they had a previous history of concussion but did not indicate the number, date, or time loss associated with the concussion(s). Therefore, these players were only included for previous history of concussion analysis. Participant characteristics are summarized in Table 4.3.

**Table 4.3 Baseline characteristics of participants, by level of play and history of concussion (n=596)**

Characteristic		Pee Wee (n=348)		Bantam (n=175)		Midget (n=73)		Missing (#)
		No Concussion History (n=246)	Concussion History (n=102)	No Concussion History (n=108)	Concussion History (n=67)	No Concussion History (n=40)	Concussion History (n=33)	
Sex	Male	234 (95%)	99 (97%)	86 (79%)	58 (87%)	26 (65%)	22 (67%)	0
	Female	12 (5%)	3 (3%)	22 (21%)	9 (13%)	14 (35%)	11 (33%)	
Median (Range)								
Age (years)		11.53 (10.68-13.13)	11.48 (10.69-13.2)	13.67 (10.2-15)	13.86 (11.67-17.83)	15.91 (13.85-17.61)	16.27 (13.93-17.59)	3
Weight (kg)	Male	40.80 (25.4-82.2)	40.4 (28.1-61.2)	56.75 (34-93)	54.5 (39-81.6)	74.1 (56.8-93.2)	78.4 (59.1-97.7)	130
	Female	36.5 (30.8-42.9)	47.6 (47.6-47.6)	50.0 (42.2-70.3)	54.5 (45.4-63.5)	59.1 (50-67.3)	65.9 (54.5-70.5)	6
Mean (95% Confidence Interval)								
Height (cm)	Male	151.92 (150.53-153.3)	149.69 (147.6-151.8)	168.95 (166.6-171.2)	168.16 (165.5-170.8)	179.84 (177.2-182.5)	179.31 (176.8-181.8)	130
	Female	147.62 (141.8-153.43)	156.5 (112.0-201.0)	163.3 (161.9-164.8)	162.46 (156.6-168.3)	167.3 (164.5-170.0)	170.4 (167.7-173.1)	8
Years' experience		6.35 (6.15-6.55)	6.39 (6.07-6.70)	7.70 (7.34-8.05)	8.15 (7.73-8.57)	9.53 (8.67-10.38)	9.76 (8.94-10.58)	6
Proportion (95% CI)								
Previous MSK injury within last year	Yes	7 (3%)	4 (4%)	15 (20%)	8 (17%)	10 (25%)	14 (42%)	70
	No	227 (97%)	91 (96%)	60 (80%)	39 (83%)	30 (75%)	19 (58%)	
Number of Previous Concussions			1x: 88 2x: 13 3x: 1		1x: 56 2x: 8 3x: 2		1x: 28 2x: 3 3x: 2	4

#### 4.2.1 Univariate and Adjusted Logistic Regression Analysis

Preliminary univariate analyses were conducted in order to determine if players with a history of concussion were more likely to fall in the upper 25<sup>th</sup> percentile (i.e., the slowest players) than those without a history of concussion. Crude odds ratios (ORs) and ORs adjusted for relative age, sex, position, level of play, elite/non-elite, and previous MSK injury within the last year, while accounting for clustering by team were estimated and presented in Table 4.4.

**Table 4.4 Crude and adjusted odds ratios from univariate logistic regression models predicting HCST performance and previous history of concussion**

HCST component	Crude OR (95% CI) (n=595)	Adjusted OR** (95% CI) (n=453)
Fwd Agility Weave Without Puck	0.66 (0.45-0.96)*	0.80 (0.48-1.32)
Fwd Agility Weave With Puck	0.73 (0.50-1.08)	0.89 (0.52-1.54)
Transition Agility Without Puck	0.77 (0.52-1.14)	0.97 (0.62-1.51)
Transition Agility With Puck	0.76 (0.51-1.11)	1.09 (0.68-1.76)
Fwd Speed Without Puck	0.93 (0.62-1.38)	1.08 (0.69-1.68)
Fwd Speed With Puck	0.79 (0.54-1.17)	0.94 (0.61-1.45)
Bwd Speed Without Puck	0.71 (0.48-1.04)	0.90 (0.56-1.45)
Bwd Speed With Puck	0.68 (0.46-0.99)*	0.77 (0.50-1.18)
Drop-off Time	0.90 (0.60-1.35)	0.91 (0.53-1.55)

\*statistically significant at  $p < 0.05$

\*\*adjusted for relative age, sex, playing position, level of play, elite/non-elite, previous MSK injury within the last year, while accounting for clustering by team

Based on the crude models, the only statistically significant results were for the components forward agility weave without the puck and backward speed with the puck ( $p < 0.05$ ). Based on the direction of these ratios, this suggests that having a history of concussion puts you at decreased odds of falling in the upper 25<sup>th</sup> percentile. In other words, those with a history of concussion were faster on the components forward agility

weave without the puck and backward speed with the puck. However, the remaining crude ORs as well as all of the adjusted odds ratios included the null value of 1.0, indicating no evidence of a difference in the odds of being slow between those without and without a history of previous concussion.

#### ***4.2.2 Mean HCST Performance***

The mean scores by level of play and sex for each HCST component for those with and without a history of concussion are presented in Tables 4.2, 4.3, and 4.4, and presented graphically in Figures 4.1, 4.2, and 4.3. There were no statistically significant differences for any HCST component between those with and without a history of concussion for males or females in any level of play.

**Table 4.5 Mean Pee Wee scores on HCST components, by sex and history of concussion (n=348)**

HCST Component		No History of Concussion (mean, 95% CI)	History of Concussion (mean, 95% CI)	Mean Difference (95% CI)	T-Statistic	P-value
Fwd Agility Weave Without Puck	Male	14.15 (13.89-14.41)	13.87 (13.54-14.20)	0.28 (-0.17-0.72)	1.2210	0.2230
	Female	14.16 (13.11-15.22)	17.56 (7.75-27.37)	-3.40 (-6.43- -0.37)	-2.4215	0.0308
Fwd Agility Weave With Puck	Male	16.19 (15.74-16.63)	15.94 (15.27-16.61)	0.24 (-0.56-1.05)	0.5931	0.5536
	Female	16.38 (14.28-18.48)	20.32 (9.41-31.23)	-3.94 (-8.81-0.94)	-1.7451	0.1045
Transition Agility Without Puck	Male	17.43 (17.13-17.73)	17.05 (16.67-17.42)	0.38 (-0.14-0.91)	1.4370	0.1517
	Female	18.18 (16.44-19.91)	20.92 (12.94-28.90)	-2.74 (-6.66-1.17)	-1.5136	0.1541
Transition Agility With Puck	Male	20.69 (20.11-21.28)	19.97 (19.25-20.70)	0.72 (-0.29-1.73)	1.3954	0.1638
	Female	22.38 (19.84-24.92)	28.31 (11.75-44.88)	-5.93 (-12.22-0.35)	-2.0392	0.0623
Fwd Speed Without Puck	Male	5.69 (5.62-5.80)	5.58 (5.50-5.66)	0.11 (-0.01-0.24)	1.7813	0.0758
	Female	5.79 (5.38-6.19)	6.44 (5.48-7.39)	-0.65 (-1.49-0.19)	-1.6689	0.1190
Fwd Speed With Puck	Male	6.01 (5.91-6.12)	5.89 (5.72-6.07)	0.12 (-0.08-0.32)	1.2084	0.2278
	Female	6.06 (5.57-6.55)	6.56 (5.23-7.89)	-0.50 (-1.53-0.53)	-1.0453	0.3149

Bwd Speed Without Puck	Male	7.69 (7.56-7.82)	7.50 (7.32-7.68)	0.19 (-0.03-0.42)	1.6634	0.0972
	Female	7.95 (6.93-8.96)	8.40 (6.28-10.53)	-0.46 (-2.56-1.64)	-0.4712	0.6453
Bwd Speed With Puck	Male	8.42 (8.25-8.60)	8.07 (7.82-8.33)	0.35 (0.03-0.67)	2.1702	0.0307
	Female	8.62 (7.63-9.61)	8.51 (6.43-10.59)	0.11 (-1.94-2.17)	0.1198	0.9065
Drop-off Time	Male	3.43 (3.21-3.65)	3.43 (2.94-3.92)	-0.01 (-0.46-0.45)	-0.0171	0.9863
	Female	3.37 (2.43-4.30)	3.77 (-0.88-8.43)	-0.41 (-2.56-1.74)	-0.4089	0.6893

\*statistically significant at 0.0028 (0.05/18=0.0028) using Bonferroni correction

**Table 4.6 Mean Bantam scores on HCST components, by sex and history of concussion (n=175)**

HCST Component		No History of Concussion (mean, 95% CI)	History of Concussion (mean, 95% CI)	Mean Difference (95% CI)	T-Statistic	P-value
Fwd Agility Weave Without Puck	Male	12.84 (12.54-13.14)	12.67 (12.24-13.10)	0.16 (-0.34-0.67)	0.6448	0.5201
	Female	13.53 (12.71-14.35)	13.34 (11.58-15.10)	0.18 (-1.42-1.79)	0.2379	0.8136
Fwd Agility Weave With Puck	Male	14.10 (13.70-14.51)	13.90 (13.38-14.42)	0.21 (-0.44-0.89)	0.6372	0.5250
	Female	15.00 (13.80-16.23)	14.76 (12.04-17.48)	0.24 (-2.19-2.67)	0.2024	0.8410
Transition Agility Without Puck	Male	15.49 (15.14-15.85)	15.35 (14.84-15.87)	0.14 (-0.46-0.74)	0.4664	0.6416
	Female	16.24 (15.35-17.14)	16.19 (13.64-18.75)	0.05 (-1.93-2.03)	0.0518	0.9591
Transition Agility With Puck	Male	17.23 (16.78-17.68)	17.18 (16.56-17.80)	0.04 (-0.70-0.78)	0.1190	0.9055
	Female	18.76 (17.46-20.07)	18.81 (14.67-22.94)	-0.04 (-3.10-3.12)	-0.0289	0.9771
Fwd Speed Without Puck	Male	5.17 (5.07-5.27)	5.14 (5.02-5.26)	0.03 (-0.13-0.18)	0.3255	0.7453
	Female	5.25 (4.86-5.64)	5.49 (4.84-6.14)	-0.24 (-0.93-0.46)	-0.7038	0.4874
Fwd Speed With Puck	Male	5.38 (5.28-5.48)	5.31 (5.16-5.46)	0.07 (-0.10-0.24)	0.7772	0.4383
	Female	5.58 (5.30-5.86)	5.52 (4.79-6.25)	0.06 (-0.53-0.66)	0.2162	0.8304

Bwd Speed Without Puck	Male	6.58 (6.43-6.72)	6.50 (6.28-6.72)	0.08 (-0.17-0.33)	0.6174	0.5380
	Female	6.71 (6.40-7.02)	7.03 (5.89-8.17)	-0.32 (-1.11-0.48)	-0.8193	0.4193
Bwd Speed With Puck	Male	6.92 (6.75-7.10)	6.80 (6.57-7.02)	0.12 (-0.16-0.40)	0.8742	0.3835
	Female	7.11 (6.76-7.46)	7.29 (6.78-7.54)	-0.18 (-1.03-0.67)	-0.4320	0.6690
Drop-off Time	Male	2.94 (2.61-3.26)	3.03 (2.68-3.38)	-0.09 (-0.58-0.39)	-0.3796	0.7050
	Female	3.82 (3.42-4.21)	3.70 (2.84-4.56)	0.11 (-0.66-0.89)	0.3025	0.7646

\*statistically significant at 0.0028 (0.05/18=0.0028) using Bonferroni correction

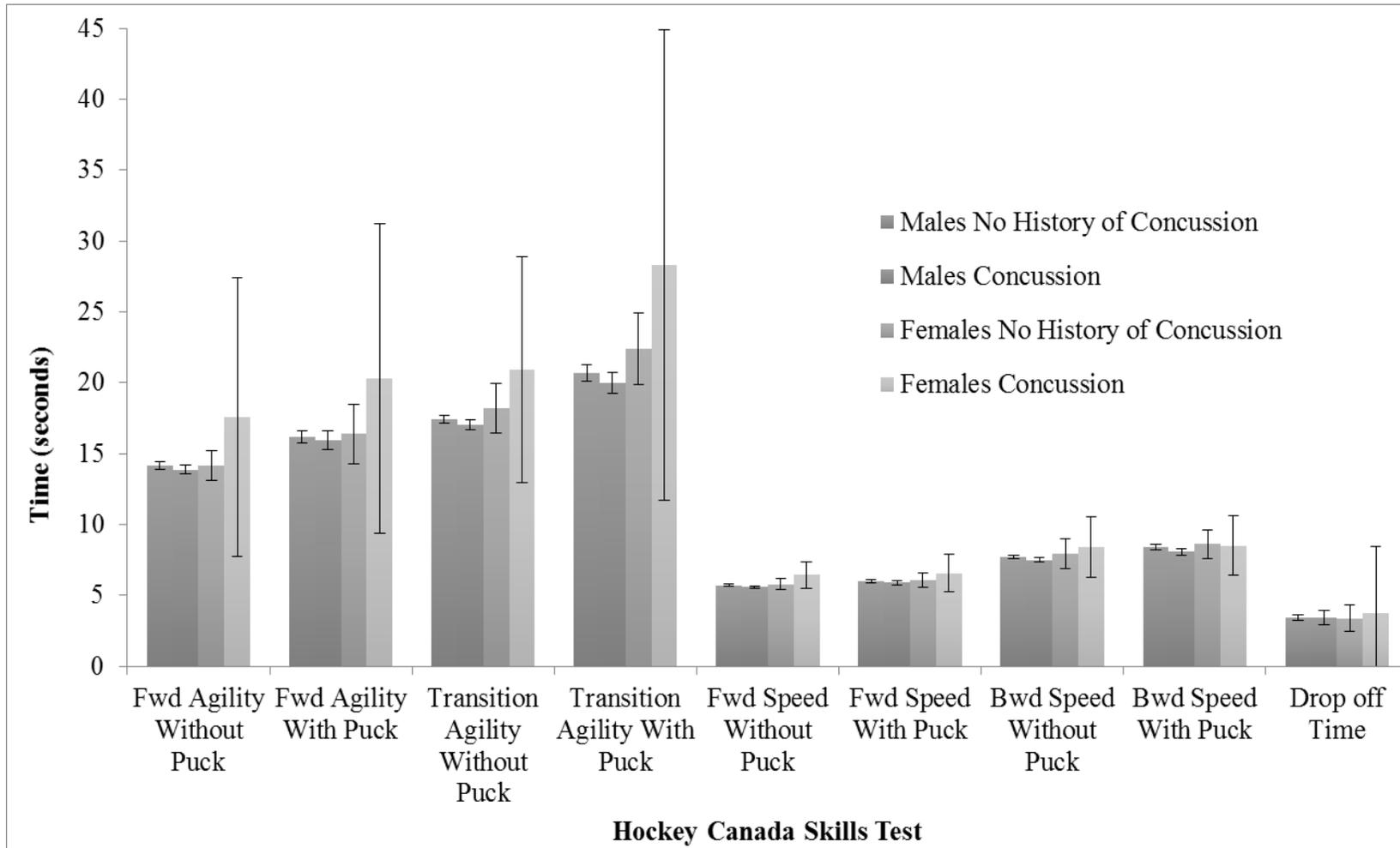
**Table 4.7 Mean Midget scores on HCST components, by sex and history of concussion (n=73)**

HCST Component		No History of Concussion (mean, 95% CI)	History of Concussion (mean, 95% CI)	Mean Difference (95% CI)	T-Statistic	P-value
Fwd Agility Weave Without Puck	Male	11.44 (10.93-11.96)	11.65 (11.12-12.19)	-0.21 (-0.94-0.52)	-0.5846	0.5617
	Female	12.56 (11.80-13.32)	12.62 (11.91-13.32)	-0.06 (-1.06-0.95)	-0.1204	0.9052
Fwd Agility Weave With Puck	Male	12.50 (11.82-13.19)	12.64 (11.95-13.33)	-0.14 (-1.09-0.81)	-0.2919	0.7717
	Female	13.42 (12.47-14.37)	13.28 (12.52-14.04)	0.14 (-1.07-1.35)	0.2426	0.8105
Transition Agility Without Puck	Male	12.97 (12.53-13.40)	12.86 (12.04-13.69)	0.11 (-0.76-0.97)	0.2469	0.8060
	Female	14.74 (13.80-15.68)	15.13 (14.27-15.99)	-0.39 (-1.63-0.85)	-0.6552	0.5188
Transition Agility With Puck	Male	14.67 (13.98-15.37)	14.22 (13.15-15.29)	0.46 (-0.76-1.67)	0.7572	0.4541
	Female	16.66 (15.74-17.58)	16.70 (15.85-17.55)	-0.04 (-1.26-1.18)	-0.0743	0.9414
Fwd Speed Without Puck	Male	4.60 (4.50-4.70)	4.52 (4.40-4.64)	0.08 (-0.07-0.23)	1.0680	0.2911
	Female	5.08 (4.88-5.29)	5.23 (4.96-5.51)	-0.15 (-0.47-0.17)	-0.9778	0.3384
Fwd Speed With Puck	Male	4.74 (4.61-4.86)	4.59 (4.45-4.73)	0.14 (-0.04-0.33)	1.5973	0.1172
	Female	5.10 (4.88-5.32)	5.28 (4.99-5.58)	-0.18 (-0.52-0.16)	-1.0951	0.2848

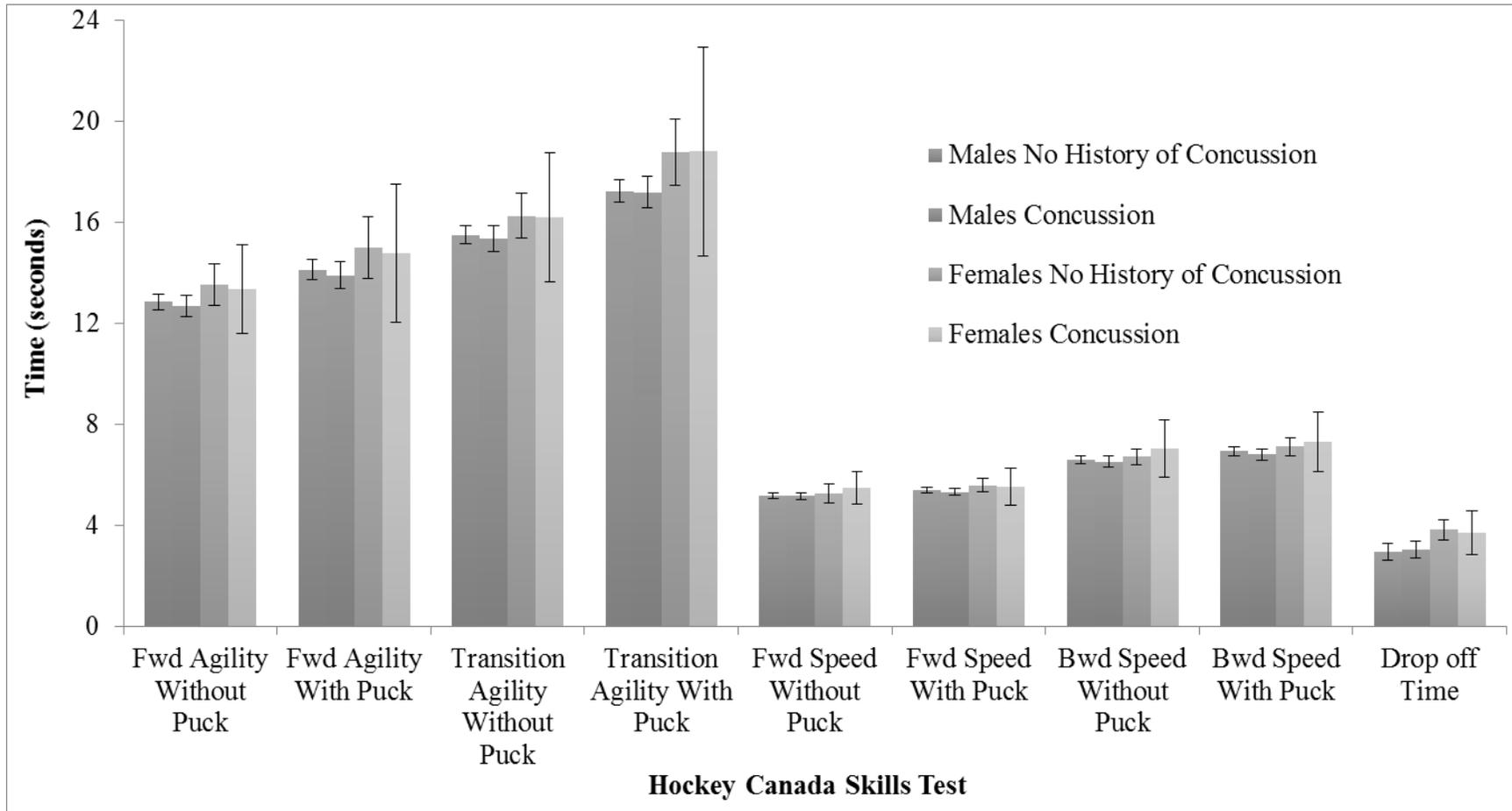
Bwd Speed Without Puck	Male	5.55 (5.34-5.75)	5.47 (5.29-5.66)	0.07 (-0.20-0.35)	0.5509	0.5843
	Female	6.12 (5.79-6.44)	6.22 (5.78-6.65)	-0.10 (-0.60-0.40)	-0.4057	0.6887
Bwd Speed With Puck	Male	5.72 (5.47-5.96)	5.62 (5.43-5.80)	0.10 (-0.21-0.41)	0.6494	0.5194
	Female	6.41 (6.11-6.71)	6.46 (6.00-6.91)	-0.05 (-0.54-0.45)	-0.1930	0.8486
Drop-off Time	Male	2.77 (2.45-3.09)	2.43 (1.98-2.88)	0.34 (-0.18-0.87)	1.3083	0.1974
	Female	3.37 (2.83-3.91)	3.93 (3.37-4.49)	-0.56 (-1.31-0.18)	-1.5635	0.1316

\*statistically significant at 0.0028 (0.05/18=0.0028) using Bonferroni correction

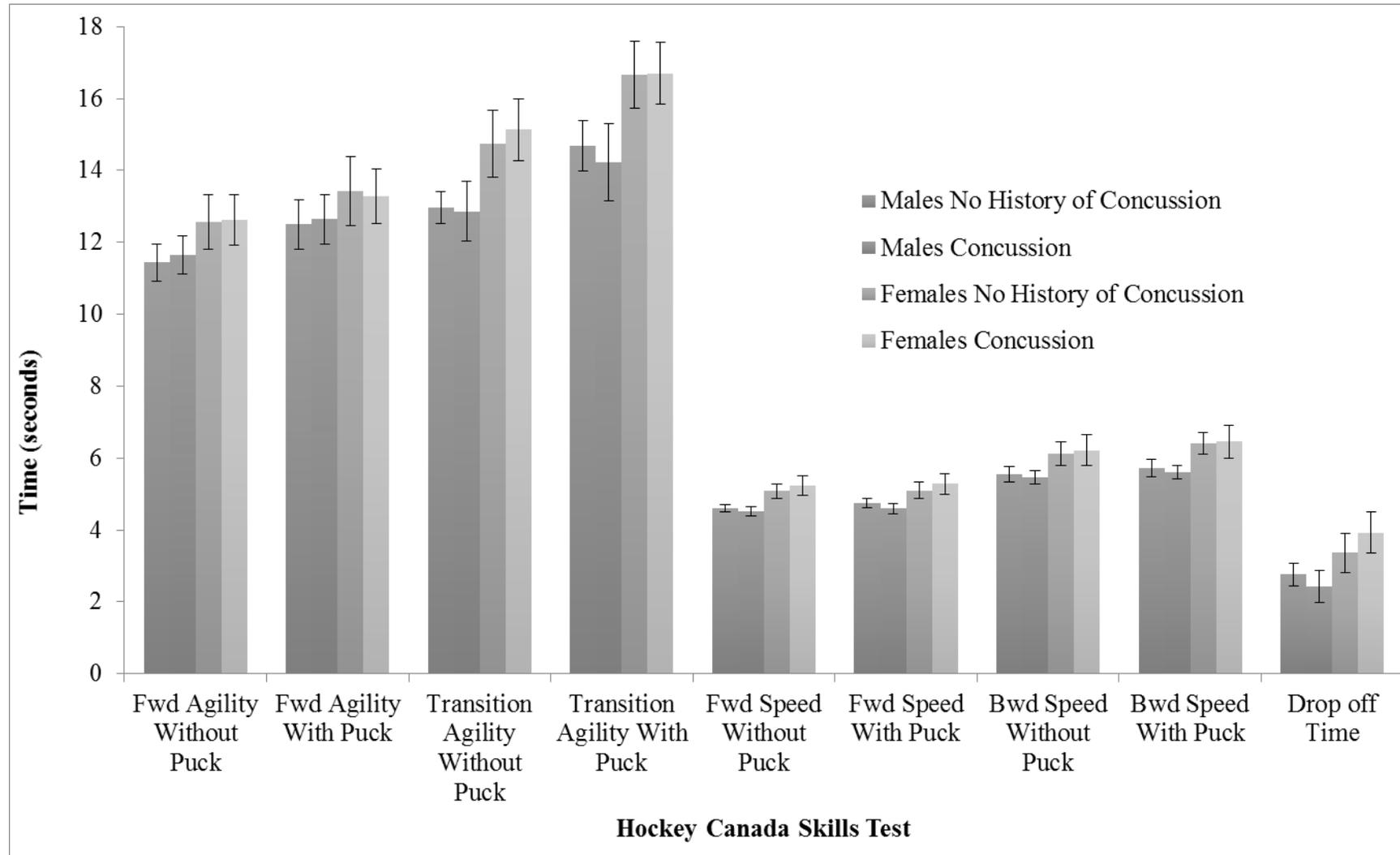
**Figure 4.10 Mean Pee Wee HCST scores by sex and history of concussion**



**Figure 4.11 Mean Bantam HCST scores by sex and history of concussion**



**Figure 4.12 Mean Midget HCST scores by sex and history of concussion**



## Chapter Five: EXPLORATORY RESULTS

### 5.1 Multiple Linear Regression

The model for the exploratory multiple regression analyses were derived using the covariates relative age, sex, playing position, level of play, elite/non-elite, and previous MSK injury within the last year (adjusting for clustering by team). Relative age was measured continuously and was calculated from the players' date of birth to September 1<sup>st</sup> of the season they entered the study. Sex was coded as either female ("0") or male ("1"). Level of play was coded as Pee Wee ("0"), Bantam ("1"), or Midget ("2"). Playing positions were coded as either forward ("0"), defensemen ("1"), goaltender ("2"), or "missing" ("3") if not entered on the baseline questionnaire. Elite level of play was defined and coded as the upper 30% by division of play ("0"), while non-elite was defined as the lower 70% by division of play ("1"). Finally, previous MSK injury within the previous year was coded as either no ("0") or yes ("1"). The multiple linear regression models required a baseline group in order to make comparisons. Those with no history of concussion, females, Pee Wee, forwards, elite, and no previous MSK injury within the last year were selected as the baseline.

#### *5.1.1 Previous History of Concussion*

Previous history of concussion was coded as either yes "1" or no "0". In the presence of the other independent variables, previous history of concussion was not a statistically significant independent variable of any HCST outcome. Table 5.1 summarizes the estimated coefficients of the main exposure, previous history of concussion, as well as the final model characteristics. Each regression equation significantly predicted performance score. There was no evidence of effect modification

by either sex or relative age on all HCST performance outcomes. Position, level of play, sex, and whether the player was elite or non-elite were all statistically significant independent variables for each HCST outcome. Specifically, goalies were the slowest position; Midget was the fastest level of play followed by Bantam then Pee Wee; males were faster than females; and elite players were faster than non-elite players. Relative age was statistically significant for the components forward speed with the puck and backward speed without and with the puck. Specifically, older players were significantly faster than younger aged players. There was no evidence of multicollinearity between variables for each outcome. The specific equations calculated for each HCST outcome are presented below.

For the components forward agility weave without the puck, transition agility without and with the puck, and forward speed without the puck, previous MSK injury within the last year and relative age were not statistically significant independent variables. When assessing the change of the  $\beta$  coefficient of the main exposure (history of concussion) when each of these variables were removed from the model, previous MSK injury was found to confound the exposure/outcome relationship for these components, but relative age did not. Therefore, previous MSK injury remained for these models while relative age was removed.

**Forward Agility without Puck:** =  $13.433 + [-0.046 * \text{concussion history}] + [\text{position}] + [0.909 * \text{elite/non-elite}] + [0.169 * \text{previous MSK injury}] + [\text{level of play}] + [-0.657 * \text{sex}]$

Position: defenseman (0.485), goaltenders (5.159), missing position (0.577)

Level of play: Bantam (-0.796), Midget (-1.196)

**Forward Agility with Puck:** = 14.581 + [-0.032\*concussion history] + [position] +  
[1.621\*elite/non-elite] + [0.356\*previous MSK injury] + [level of play] + [-0.679\*sex]  
Position: defenseman (0.763), goaltenders (8.665), missing position (1.386)  
Level of play: Bantam (-1.231), Midget (-1.513)

**Transition Agility without Puck:** = 17.031 +  $\beta_1$  [-0.110\*concussion history] +  $\beta_2$   
[position] +  $\beta_3$  [1.352\*elite/non-elite] +  $\beta_4$  [-0.030\*previous MSK injury] +  $\beta_5$  [level of  
play] +  $\beta_6$  [-1.240\*sex]  
 $\beta_2$  Position: defenseman (0.321), goaltenders (5.401), missing position (0.762)  
 $\beta_5$  Level of play: Bantam (-1.452), Midget (-2.612)

**Transition Agility with Puck:** = 19.899 + [-0.213\*concussion history] + [position] +  
[2.579\*elite/non-elite] + [0.328\*previous MSK injury] + [level of play] + [-1.912\*sex]  
Position: defenseman (0.210), goaltenders (8.779), missing position (0.309)  
Level of play: Bantam (-2.209), Midget (-3.456)

**Forward Speed without Puck:** = 5.632 + [-0.027\*concussion history] + [position] +  
[0.192\*elite/non-elite] + [-0.035\*previous MSK injury] + [level of play] + [-0.284\*sex]  
Position: defenseman (0.174), goaltenders (1.308), missing position (0.306)  
Level of play: Bantam (-0.467), Midget (-0.685)

Unlike the previous components, relative age was a statistically significant independent variable for the components forward speed with the puck and backward speed without and with the puck. Specifically, older players were significantly faster than younger players. Previous MSK injury within the last year was not a significant independent variable for these HCST components, but changed the magnitude of the main  $\beta$  coefficient more than 10% when removed from the model. Therefore, previous MSK injury confounded the exposure/outcome relationship and remained for these final models. The components backward speed without and with the puck were the only components where defenseman were expected to score faster than forwards.

**Forward Speed with Puck:** = 7.443 + [-0.059\*concussion history] + [position] + [0.273\*elite/non-elite] + [0.002\*previous MSK injury] + [level of play] + [-0.266\*sex] + [-0.139\*relative age]

Position: defenseman (0.203), goaltenders (1.734), missing position (0.182)

Level of play: Bantam (-0.189), Midget (-0.193)

**Backward Speed without Puck:** = 8.970 + [-0.096\*concussion history] + [position] + [0.641\*elite/non-elite] + [level of play] + [-0.417\*sex] + [-0.125\*relative age]

Position: defenseman (-0.107), goaltenders (1.627), missing position (0.135)

Level of play: Bantam (-0.644), Midget (-0.913)

**Backward Speed with Puck:** = 10.366 + [-0.197\*concussion history] + [position] + [0.893\*elite/non-elite] + [level of play] + [-0.444\*sex] + [-0.191\*relative age]

Position: defenseman (-0.161), goaltenders (1.401), missing position (0.139)

Level of play: Bantam (-0.794), Midget (-0.981)

Lastly, for the component 6-repeat drop-off time, previous MSK injury within the last year, level of play, and relative age were not statistically significant independent variables. When assessed for confounding, each of these variables changed the magnitude of the main  $\beta$  coefficient more than 10% when removed from the model. Therefore, each of these variables confounded the exposure/outcome relationship and remained for the final model.

**Drop-off Time:** = 3.793 + [0.009\*concussion history] + [position] + [0.760\*elite/non-elite] + [0.287\*previous MSK injury] + [level of play] + [-0.617\*sex] + [-0.050\*relative age]

Position: defenseman (0.320), goaltenders (2.514), missing position (0.320)

Level of play: Bantam (0.097), Midget (0.243)

**Table 5.1 Summary of  $\beta_1$  previous history of concussion coefficient**

HCST	Exposure Variable			Model Characteristics		
	Coefficient	95% CI	P-value	F-Statistic	P-value	R <sup>2</sup>
Fwd Agility Weave Without Puck	-0.046	-0.238-0.146	0.613	(9, 57) = 38.84	P<0.0001	0.6319
Fwd Agility Weave With Puck	-0.032	-0.358-0.293	0.843	(9, 57) = 22.20	P<0.0001	0.6126
Transition Agility Without Puck	-0.110	-0.392-0.171	0.436	(9, 58) = 80.92	P<0.0001	0.6566
Transition Agility With Puck	-0.213	-0.644-0.217	0.325	(9, 58) = 20.96	P<0.0001	0.5570
Forward Speed Without Puck	-0.027	-0.100-0.046	0.462	(9, 58) = 46.65	P<0.0001	0.6003
Forward Speed With Puck	-0.059	-0.179-0.060	0.324	(10, 58) = 43.50	P<0.0001	0.5548
Backward Speed Without Puck	-0.096	-0.221-0.028	0.128	(9, 63) = 69.99	P<0.0001	0.6220
Backward Speed With Puck	-0.197	-0.371-0.022	0.028	(9, 63) = 50.57	P<0.0001	0.5436
Drop-off Time	0.009	-0.313-0.330	0.958	(10, 56) = 8.76	P<0.0001	0.1902

\*statistically significant at 0.0056 (0.05/9=0.0056) using Bonferroni correction

### ***5.1.2 Number of Previous Concussions***

The categories “2 previous concussions” and “3 previous concussions” were collapsed into a “2 or more concussions” due to the low number of players reporting 3 previous concussions or more. In the presence of the other independent variables, number of previous concussions was a statistically significant independent variable for the HCST component forward agility weave with the puck. Specifically, those with 2 or more previous concussions were significantly faster than those with no previous concussions (-7.317; 95% CI -11.047- -3.586). In the presence of the other independent variables, number of previous concussions was not a statistically significant independent variable for any other component score (Table 5.2).

Each regression equation significantly predicted HCST performance score. Again, position, sex, and whether the player was elite or non-elite were all significant independent variables for each HCST outcome. Goalies were the slowest position, males were faster than females, and elite players were faster than non-elite players. Level of play was a significant independent variable for all HCST outcomes except for 6-repeat drop-off time; Midget players were the fastest level of play. Older players were also found to be faster than younger aged players. There was no evidence of multicollinearity between variables. Each equation calculated for the various HCST outcomes are presented below.

There was sufficient evidence to suggest that relative age modified the relationship between number of previous concussions and performance on the component forward agility without the puck. Specifically, players with 2+ previous concussions were predicted to score slower as their age increases. Previous MSK injury was not a

statistically significant independent variable but changed the magnitude of the main  $\beta$  coefficient by more than 10% when removed from the model. This suggests that previous MSK injury within the last year confounded the exposure/outcome relationship, and remained in the final model for this component.

**Forward Agility without Puck** = 14.313 + [number of previous concussions] + [position] + [0.905\*elite/non-elite] + [0.185\*previous MSK injury] + [Level of play] + [-0.650\*sex] + [-0.076\* relative age] + [ $\beta_8$ \*relative age]

Number of previous concussions: 1 (0.428), 2+ (-2.771)

Position: defenseman (0.473), goaltenders (5.153), missing position (0.529)

Level of play: Bantam (-0.600), Midget (-0.881)

$\beta_8$  Number of previous concussions: 1 (-0.039), 2+ (0.222)

For the component forward agility with the puck there was sufficient evidence to suggest the presence of effect modification by both relative age and sex. Specifically, for sex, males with a history of 2+ previous concussions were predicted to score slower than females with the same number of previous concussions (1.147 seconds). Additionally, players with a history of 2+ concussions were expected to score slower as their age increases. Previous MSK injury within the last year was the only variable that did not statistically significantly predict performance on these two components, but altered the magnitude of the main  $\beta$  coefficient more than 10% when removed from the model. This suggests that previous MSK injury confounded the exposure/outcome relationship and remained in the final model for this component.

**Forward Agility with Puck** = 15.579 + [number of previous concussions] + [position] + [1.642\*elite/non-elite] + [0.370\*previous MSK injury] + [level of play] + [-0.797\*sex] + [-0.078\* relative age] + [ $\beta_8$ \*relative age] + [ $\beta_9$ \*sex]

Number of previous concussions: 1 (0.673), 2+ (-7.317)

Position: defenseman (0.751), goaltenders (8.695), missing position (1.373)

Level of play: Bantam (-1.048), Midget (-1.158)

$\beta_8$  Number of previous concussions: 1 (-0.074), 2+ (0.455)

$\beta_9$  Number of previous concussions: males with 1 concussion (0.345), males with 2+ concussions (1.147)

Similarly, relative age and sex modified the exposure/outcome relationship for the component transition agility without the puck. In this model, however, males with a history of 2+ previous concussions were expected to score 2.007 seconds faster than females with the same number of previous concussions. Further, for those with 2+ concussions, older players were expected to be faster than younger players. Previous MSK injury was not a statistically significant independent variable on its own, but confounded the exposure/outcome relationship when removed from the model.

Therefore, this variable was included in the final model.

**Transition Agility without Puck** = 18.767 + [number of previous concussions] + [position] + [1.299\*elite/non-elite] + [0.001\*previous MSK injury] + [level of play] + [-1.152\*sex] + [-0.154\* relative age] + [ $\beta_8$ \*relative age] + [ $\beta_9$ \*sex]

Number of previous concussions: 1 (-0.085), 2+ (5.314)

Position: defenseman (0.319), goaltenders (5.400), missing position (0.723)

Level of play: Bantam (-1.099), Midget (-1.936)

$\beta_8$  Number of previous concussions: 1 (0.014), 2+ (-0.299)

$\beta_9$  Number of previous concussions: males with 1 concussion (-0.178), males with 2+ concussions (-2.007)

There was no evidence of effect modification by either sex or relative age on the component transition agility with the puck. Previous MSK injury and relative age were not statistically significant independent variables and were assessed for confounding. Previous MSK injury within the last year confounded the exposure/outcome relationship, but relative age did not. Therefore, the final model for this component included previous MSK injury but not relative age.

**Transition Agility with Puck** = 19.859 + [number of previous concussions] + [position] + [2.624\*elite/non-elite] + [0.319\*previous MSK injury] + [Level of play] + [-1.905\*sex]

Number of previous concussions: 1 (-0.055), 2+ (-1.271)

Position: defenseman (0.207), goaltenders (8.820), missing position (0.372)

Level of play: Bantam (-2.199), Midget (-3.409)

There was no evidence of effect modification by either sex or relative age on the component forward speed without the puck. Relative age and previous MSK injury were not statistically significant independent variables, but both confounded the

exposure/outcome relationship when removed from the model. Therefore, both variables were included in the final model for this component.

**Forward Speed without Puck** = 6.225 + [number of previous concussions] + [position] + [0.183\*elite/non-elite] + [-0.034\*previous MSK injury] + [Level of play] + [-0.285\*sex] + [-0.050\* relative age]

Number of previous concussions: 1 (-0.025), 2+ (-0.044)

Position: defenseman (0.168), goaltenders (1.304), missing position (0.283)

Level of play: Bantam (-0.348), Midget (-0.469)

There was sufficient evidence of effect modification by sex on the component forward speed with the puck, but not by relative age. Specifically, males with 2+ previous concussions were expected to score 0.400 seconds faster than females with the same number of concussions. Although not a statistically significant independent variable on its own, previous MSK injury within the last year confounded the exposure/outcome relationship when removed from the model. Therefore, previous MSK injury remained for the final model for this component.

**Forward Speed with Puck** = 7.430 + [number of previous concussions] + [position] + [0.273\*elite/non-elite] + [0.007\*previous MSK injury] + [Level of play] + [-0.240\*sex] + [-0.139\* relative age] + [ $\beta_8$ \*sex]

Number of previous concussions: 1 (-0.021), 2+ (0.328)

Position: defenseman (0.204), goaltenders (1.734), missing position (0.181)

Level of play: Bantam (-1.185), Midget (-1.199)

$\beta_8$  Number of previous concussions: males with 1 concussion (-0.048), males with 2+ concussions (-0.400)

There was no evidence of effect modification by either sex or relative age on the components backward speed without and with the puck. Although not a statistically significant independent variable, previous MSK injury within the last year confounded the relationship on both of these components, and therefore, was included in the final models for these components. These were the only components where defenseman were expected to be faster than forwards.

**Backward Speed without Puck** = 8.993 + [number of previous concussions] + [position] + [0.643\*elite/non-elite] + [0.050\*previous MSK injury] + [level of play] + [-0.457\*sex] + [-0.125\* relative age]

Number of previous concussions: 1 (-0.106), 2+ (-0.011)

Position: defenseman (-0.097), goaltenders (1.606), missing position (0.185)

Level of play: Bantam (-0.726), Midget (-0.938)

**Backward Speed with Puck** = 10.598 + [number of previous concussions] + [position] + [0.898\*elite/non-elite] + [0.088\*previous MSK injury] + [level of play] + [-0.487\*sex] + [-0.208\* relative age]

Number of previous concussions: 1 (-0.238), 2+ (0.160)

Position: defenseman (-0.178), goaltenders (1.388), missing position (0.156)

Level of play: Bantam (-0.839), Midget (-0.954)

There was no evidence of effect modification by either sex or relative age on the component 6-repeat drop-off time. Previous MSK injury within the last year, relative age, and level of play were all not statistically significant independent variables for this component. Additionally, these variables did not confound the exposure/outcome relationship when removed from the model, and therefore, were not included in the final model.

**Drop-off Time** = 3.301 + [number of previous concussions] + [position] +  
[0.673\*elite/non-elite] + [-0.630\*sex]

Number of previous concussions: 1 (-0.089), 2+ (0.551)

Position: defenseman (0.286), goaltenders (2.279), missing position (0.275)

**Table 5.2 Summary of  $\beta_1$  number of previous concussions coefficient**

HCST	Exposure Variable				Model Characteristics			
	Number of Concussions <sup>#</sup>	Coefficient	95% CI	P-value	Modification by Relative Age**	F-Statistic	P-value	R <sup>2</sup>
Fwd Agility Weave Without Puck	1	0.428	-1.349-2.206	0.631	(-0.039*10.68) = -0.42 (-0.039*17.59) = -0.68	(13, 57) =28.52	P<0.0001	0.6361
	2+	-2.771	-5.088- -0.453	0.020	(0.222*10.68) = 2.37 (0.222*17.59) = 3.90			
Fwd Agility Weave With Puck	1	0.673	-2.979-4.360	0.713	(-0.074*10.68) = -0.79 (-0.074*17.59) = -1.30	(15, 57) =21.07	P<0.0001	0.6172
	2+	-7.317	-11.047- -3.586	<0.001*	(0.455*10.68) = 4.86 (0.455*17.59) = 8.00			
Transition Agility Without Puck	1	-0.085	-3.119-2.949	0.956	(0.014*10.68) = 0.15 (0.014*17.59) = 0.25	(15, 58) =59.22	P<0.0001	0.6624
	2+	5.314	1.103-9.525	0.014	(-0.299*10.68) = -3.19 (-0.299*17.59) = -5.26			
Transition Agility With Puck	1	-0.055	-0.522-0.412	0.815	N/A	(10, 58) =22.05	P<0.0001	0.5599
	2+	-1.271	-2.308- -0.234	0.017	N/A			
Forward Speed Without Puck	1	-0.025	-0.102-0.053	0.522	N/A	(11, 58) =45.02	P<0.0001	0.6029
	2+	-0.044	-0.186-0.097	0.533	N/A			
Forward Speed With Puck	1	-0.021	-0.301-0.260	0.884	N/A	(13, 58) =36.08	P<0.0001	0.5555
	2+	0.328	-0.011-0.667	0.058	N/A			
Backward Speed Without Puck	1	-0.106	-0.251-0.038	0.147	N/A	(11, 58) =57.35	P<0.0001	0.6331
	2+	-0.011	-0.301-0.278	0.939	N/A			

Backward Speed With Puck	1	-0.238	-0.422- -0.054	0.012	N/A	(11, 58) =38.11	P<0.0001	0.5499
	2+	0.160	-0.443-0.762	0.598	N/A			
Drop-off Time	1	-0.089	-0.322-0.144	0.448	N/A	(7, 58) =9.34	P<0.0001	0.1777
	2+	0.551	-0.778-1.879	0.410	N/A			

#baseline is 0 concussions

\*statistically significant at 0.0056 ( $0.05/9=0.0056$ ) using Bonferroni correction

\*\*using the minimum relative age (10.68) and the maximum relative age (17.59)

### ***5.1.3 Time Since Most Recent Concussion***

In the presence of the other independent variables, time since most recent concussion was not a statistically significant independent variable for any HCST outcome (Table 5.3). Each regression equation statistically significantly predicted HCST performance score. Similar to the other exposure variables, goalies were the slowest position, males were faster than females, elite players were faster than non-elite players, and older players were faster than younger players. The specific equations calculated for each HCST outcome are presented below. There was no evidence of multicollinearity between variables for each outcome.

There was insufficient evidence to suggest the presence of effect modification by relative age or sex on the component forward agility weave without the puck. Previous MSK injury within the last year, level of play, sex, and relative age were all non-statistically significant independent variables in predicting performance on forward agility without the puck, and were assessed for confounding. Each of these variables changed the  $\beta$  of the main exposure by more than 10% when removed from the model, suggesting that each of these independent variables confounded the exposure/outcome relationship. Therefore, these variables remained in the final model for the component forward agility without the puck.

**Forward Agility without Puck** = 13.813 + [-0.0000162\*days since last concussion] + [position] + [1.021\*elite/non-elite] + [-0.010\*previous MSK injury] + [level of play] + [-0.714\*sex] +  $\beta_7$  [-0.029\*relative age]

Position: defenseman (0.406), goaltenders (5.031), missing position (0.274)

Level of play: Bantam (-0.825), Midget (-0.888)

There was no evidence of effect modification by either sex or relative age on the component forward agility with the puck. Previous MSK injury within the last year, relative age, and sex were all non-statistically significant independent variables but confounded the exposure/outcome relationship when removed from the model. Therefore, each of these variables remained in the final model for this component.

**Forward Agility with Puck** = 12.534 + [0.0000358\*days since last concussion] + [position] + [1.567\*elite/non-elite] + [0.240\*previous MSK injury] + [level of play] + [-0.520\*sex] + [0.185\*relative age]

Position: defenseman (0.318), goaltenders (7.491), missing position (0.760)

Level of play: Bantam (-1.996), Midget (-2.482)

There was no evidence of effect modification by either sex or relative age on the component transition agility without the puck. Previous MSK injury within the last year, relative age, and level of play were not statistically significant independent variables for this component, but each confounded the exposure/outcome relationship when removed. Therefore, each of these variables remained in the final model for this component.

**Transition Agility without Puck** = 20.633 + [-0.000036\*days since last concussion] + [position] + [1.175\*elite/non-elite] + [-0.418\*previous MSK injury] + [level of play] + [-1.358\*sex] + [-0.284\*relative age]

Position: defenseman (0.028), goaltenders (4.767), missing position (0.059)

Level of play: Bantam (-0.857), Midget (-1.297)

There was no evidence of effect modification by either sex or relative age on the component transition agility without the puck. Previous MSK injury within the last year and relative age were not statistically significant independent variables, and did not confound the exposure/outcome relationship when removed from the model. Therefore, these variables were not included in the final model for this component.

**Transition Agility with Puck** = 20.652 + [0.0004481\*days since last concussion] + [position] + [2.287\*elite/non-elite] + [level of play] + [-2.508\*sex]

Position: defenseman (-0.613), goaltenders (4.792), missing position (-0.358)

Level of play: Bantam (-2.557), Midget (-4.247)

There was sufficient evidence to suggest the presence of effect modification by sex but not by relative age on the component forward speed without the puck. Specifically, for every day since a male players latest concussion, their time on this component is expected to increase by 0.0001262 seconds. Previous MSK injury and relative age were not statistically significant independent variables and did not confound the exposure/outcome relationship when removed. Therefore, these variables were not included in the final model for this component.

**Forward Speed without Puck** = 5.942 + [-0.0000871\*days since last concussion] + [position] + [0.240\*elite/non-elite] + [level of play] + [-0.677\*sex] + [0.0001262]\*[days since last concussion\*sex]

Position: defenseman (0.147), goaltenders (0.981), missing position (0.122)

Level of play: Bantam (-0.401), Midget (-0.749)

There was sufficient evidence to suggest the presence of effect modification by sex but not by relative age on the component forward speed with the puck. Specifically, for every day since a male players latest concussion, their time is expected to increase by 0.0001839 seconds. Previous MSK injury was not a statistically significant independent variable and did not confound the exposure/outcome relationship when removed from the model. Therefore, it was not included in the final model for this component.

**Forward Speed with Puck** = 7.260 + [-0.0001247\*days since last concussion] + [position] + [0.246\*elite/non-elite] + [level of play] + [-0.569\*sex] + [0.0001839]\*[days since last concussion\*sex] + [-0.102\* relative age]

Position: defenseman (0.083), goaltenders (1.323), missing position (-0.069)

Level of play: Bantam (-0.286), Midget (-0.436)

There was insufficient evidence to suggest the presence of effect modification by either sex or relative age on the component backward speed without the puck. Previous MSK injury and relative age were not statistically significant independent variables but confounded the

exposure/outcome relationship when removed from the model. Therefore, both of these variables were included in the final model for this component.

**Backward Speed without Puck**= 8.371 + [0.0000181\*days since last concussion] + [position] + [0.673\*elite/non-elite] + [-0.101\*previous MSK injury] + [level of play] + [-0.511\*sex] + [-0.078\* relative age]

Position: defenseman (-0.123), goaltenders (1.265), missing position (-0.027)

Level of play: Bantam (-0.748), Midget (-1.011)

There was insufficient evidence to suggest the presence of effect modification by either sex or relative age on the component backward speed with the puck. Previous MSK injury within the last year, relative age, and sex were not statistically significant independent variables but all confounded the exposure/outcome relationship when removed from the model. Therefore, each of these variables was included in the final model for this component.

**Backward Speed with Puck** = 9.893 + [-0.0000125\*days since last concussion] + [position] + [0.947\*elite/non-elite] + [-0.138\*previous MSK injury] + [level of play] + [-0.372\*sex] + [-0.170\*relative age]

Position: defenseman (-0.414), goaltenders (1.242), missing position (-0.303)

Level of play: Bantam (-0.745), Midget (-0.905)

There was sufficient evidence to suggest the presence of effect modification by relative age but not by sex on the component 6-repeat drop-off time. Specifically, for a given time since a player's most recent concussion, their 6-repeat drop-off time increases as their relative age increases. Position and sex were not statistically significant independent variables but both were found to confound the exposure/outcome relationship when removed. Therefore, these variables remained in the final model. Level of play and previous MSK injury within the last year were also not statistically significant independent variables and did not confound the exposure/outcome relationship. Therefore, these variables were not included in the final model for this component.

**Drop-off Time** = 5.299 + [-0.0019785\*days since last concussion] + [position] + [0.854\*elite/non-elite] + [-0.899\*sex] + [0.0001197]\*[days since last concussion\*relative age] + [-0.115\*relative age]

Position: defenseman (0.230), goaltenders (3.616), missing position (0.351)

**Table 5.3 Summary of  $\beta_1$  time since most recent concussion coefficient**

HCST	Exposure Variable			Model Characteristics			
	Coefficient	95% CI	P-value	Modification by Relative Age**	F-Statistic	P-value	R <sup>2</sup>
Fwd Agility Weave Without Puck	-0.0000162	-0.0003-0.0003	0.896	N/A	(10, 52) =15.31	P<0.0001	0.6146
Fwd Agility Weave With Puck	0.0000358	-0.0003-0.0004	0.824	N/A	(10, 52) =24.11	P<0.0001	0.6501
Transition Agility Without Puck	-0.000036	-0.0003-0.0003	0.803	N/A	(10, 53) =47.40	P<0.0001	0.6660
Transition Agility With Puck	0.0004481	-0.0004-0.0013	0.278	N/A	(8, 57) =20.96	P<0.0001	0.5528
Forward Speed Without Puck	-0.0000871	-0.0002-0.0001	0.195	N/A	(9, 57) =51.63	P<0.0001	0.6951
Forward Speed With Puck	-0.0001247	-0.0003-0.0001	0.138	N/A	(10, 57) =34.30	P<0.0001	0.7050
Backward Speed Without Puck	0.0000181	-0.0001-0.0001	0.769	N/A	(10, 53) =37.82	P<0.0001	0.6800
Backward Speed With Puck	-0.0000125	-0.0002-0.0002	0.894	N/A	(10, 53) =22.52	P<0.0001	0.6026
Drop-off Time	-0.0019785	-0.0036-0.0003	0.021	0.072*10.68 =0.77 0.072*17.59 = 1.27	(5, 49) =3.35	P=0.0158	0.2333

\*statistically significant at 0.0056 (0.05/9=0.0056) using Bonferroni correction

\*\*using the minimum relative age (10.68) and maximum relative age (17.59); based on the median time since most recent concussion (601 days)

#### ***5.1.4 Most Recent Concussion Severity Based on Time Loss Before Full Return to Sport***

In the presence of the other independent variables, severity of the most recent concussion based on time loss before full return to sport significantly predicted performance on the components forward agility weave without and with the puck, transition agility without the puck, and backward speed without and with the puck (Table 5.4). Specifically, as the number of days lost before full return to sport increased, the time on these components decreased. Based on the coefficients calculated from the models, for every 1-day increase in time lost due to concussion a players score is expected to decrease by 0.083 seconds (95% CI 0.131-0.036) on forward agility without the puck, 0.107 seconds (95% CI 0.160-0.055) on forward agility with the puck, 0.01 seconds (0.018-0.004) on transition agility without the puck, 0.05 seconds (0.074-0.026) on backward speed without the puck, and 0.06 seconds (0.097-0.032) on backward speed with the puck.

Similar to the other exposure variables, goaltenders were the slowest position, Midget was the fastest level of play, males were faster than females, elite players were faster than non-elite players, and older players were faster than younger players. There was no evidence of multicollinearity between variables for each outcome. The specific equations calculated for each HCST outcome are presented below.

For the component forward agility without the puck, there was sufficient evidence to suggest the presence of effect modification by both relative age and sex. Specifically, for sex, for every day lost before full return to sport males were predicted to score slower than females by 0.0095758 seconds (95% CI 0.0027923-0.0163593). Additionally, given the same number of days lost before full return to sport, older players were predicted to be slower than younger

players (0.0051665 seconds; 95% CI 0.0021853-0.0081476). Previous MSK injury within the last year and level of play were the only variables that did not statistically significantly predict performance on this component, but altered the magnitude of the main  $\beta$  coefficient more than 10% when removed from the model. This suggests that previous MSK injury within the last year and level of play confounds the exposure/outcome relationship and thus remained in the final model for this component. For every day lost before full return to sport the time on this component is expected to decrease (get faster) by 0.084 seconds (95% CI 0.131-0.036).

**Forward Agility without Puck** = 15.210 + [-0.0835287\*days of recovery] + [position] + [0.904\*elite/non-elite] + [-0.033\*previous MSK injury] + [Level of play] + [-0.994\*sex] + [-0.112\* relative age] + [0.0051665]\*[days of recovery\*relative age] + [0.0095758]\*[days of recovery\*sex]

Position: defenseman (0.533), goaltenders (5.236), missing position (0.251)

Level of play: Bantam (-0.763), Midget (-0.944)

There was sufficient evidence to suggest the presence of effect modification by both relative age and sex on the component forward agility with the puck. For every day lost before full return to sport, males were predicted to score slower than females by 0.0123013 seconds (95% CI 0.0039187-0.0206838). Additionally, given the same number of days lost before full return to sport, older players were predicted to be slower than younger players (0.0067783 seconds; 95% CI 0.003526-0.0100306). Previous MSK injury within the last year was not a statistically significant independent variable, but when removed from the model changed the

magnitude of the main  $\beta$  coefficient by more than 10%. Therefore, previous MSK injury confounded the exposure/outcome relationship and remained in the final model for this component. For every day lost before full return to sport, the time on this component is expected to decrease (get faster) by 0.107 seconds (95% CI 0.160-0.055).

**Forward Agility with Puck** = 15.040 + [-0.1074962\*days of recovery] + [position] + [1.357\*elite/non-elite] + [0.231\*previous MSK injury] + [Level of play] + [-0.911\*sex] + [0.017\* relative age] + [0.0067783]\*[days of recovery\*relative age] + [0.0123013]\*[days of recovery\*sex]

Position: defenseman (0.587), goaltenders (7.750), missing position (0.724)

Level of play: Bantam (-1.729), Midget (-2.278)

There was insufficient evidence to suggest effect modification by either sex or relative age on the components transition agility without or with the puck. Relative age and previous MSK injury within the last year were not statistically significant independent variables for both of these outcomes, and did not confound the exposure/outcome relationship when removed from the model. Therefore, these variables were not included in the final models for these components. For transition agility without the puck, for everyday lost before full return to sport the expected time on this component is expected to decrease (get faster) by 0.011 seconds (95% CI 0.018-0.004).

**Transition Agility without Puck** = 17.953 + [-0.0106422\*days of recovery] + [position] + [1.031\*elite/non-elite] + [Level of play] + [-1.735\*sex]

Position: defenseman (0.188), goaltenders (3.786), missing position (0.126)

Level of play: Bantam (-1.644), Midget (-2.861)

**Transition Agility with Puck** = 21.202 + [-0.0137863\*days of recovery] + [position] + [1.932\*elite/non-elite] + [Level of play] + [-2.680\*sex]

Position: defenseman (-0.201), goaltenders (6.429), missing position (-0.234)

Level of play: Bantam (-2.568), Midget (-3.944)

There was no evidence of effect modification by sex or relative age on the components forward speed without or with the puck. Previous MSK injury within the last year and relative age were not statistically significant independent variables but both confounded the exposure/outcome relationship when removed from the model. Therefore, these variables remained in the final model for these components.

**Forward Speed without Puck** = 6.388 + [-0.000426\*days of recovery] + [position] + [0.250\*elite/non-elite] + [0.021\*previous MSK injury] + [Level of play] + [-0.588\*sex] + [-0.044\*relative age]

Position: defenseman (0.183), goaltenders (0.868), missing position (0.138)

Level of play: Bantam (-0.309), Midget (-0.548)

**Forward Speed with Puck** = 6.760 + [-0.0014136\*days of recovery] + [position] + [0.247\*elite/non-elite] +[0.018\*previous MSK injury] + [Level of play] + [-0.435\*sex] + [-0.0687\*relative age]

Position: defenseman (0.162), goaltenders (1.128), missing position (-0.042)

Level of play: Bantam (-0.332), Midget (-0.513)

There was sufficient evidence that relative age modified the relationship for the components backward speed without and with the puck. Specifically, on the component backward speed without the puck, for the same number of days of recovery an older player is expected to score slower than a younger player (0.0032057 seconds; 95% CI 0.0016207-0.0047908). The modification by relative age was also seen for the component backward speed with the puck (0.0042368 seconds; 95% CI 0.0020622-0.0064114). Previous MSK injury within the last year was not a statistically significant independent variable for both of these components, and did not confound the exposure/outcome relationship when removed from the models. Therefore, previous MSK injury was not included in the final models for both of these outcomes. For every day lost before full return to sport, the time on backward speed without the puck is expected to decrease (get faster) by 0.050 seconds (95% CI 0.074-0.026). Similarly, for with the puck, the time is expected to decrease (get faster) by 0.065 seconds (95% CI 0.097-0.032).

**Backward Speed without Puck**= 9.455 + [-0.0500434\*days of recovery] + [position] + [0.564\*elite/non-elite] + [Level of play] + [-0.560\*sex] + [-0.149\* relative age] + [0.0032057]\*[days of recovery\*relative age]

Position: defenseman (-0.085), goaltenders (1.268), missing position (-0.074)

Level of play: Bantam (-0.619), Midget (-0.994)

**Backward Speed with Puck** = 10.852 + [-0.0645658\*days of recovery] + [position] + [0.799\*elite/non-elite] + [Level of play] + [-0.509\*sex] + [-0.226\*relative age] + [0.0042368]\*[days of recovery\*relative age]

Position: defenseman (-0.283), goaltenders (0.868), missing position (-0.311)

Level of play: Bantam (-0.650), Midget (-1.052)

There was no evidence of effect modification by either sex or relative age on the component 6-repeat drop-off time. Previous MSK injury within the last year, position, level of play, and relative age were all not statistically significant independent variables of performance on this component. When assessed for confounding, previous MSK injury and position changed the main  $\beta$  coefficient by more than 10%, suggesting these variables confounded the exposure/outcome relationship. Therefore, these variables remained in the final model for this component. Level of play and relative age did not change the magnitude of the main  $\beta$  coefficient by more than 10%, and were therefore excluded from the final model.

**Drop-off Time** = 2.894 + [0.0035422\*days of recovery] + [position] + [0.781\*elite/non-elite] + [0.133\*previous MSK injury] + [-0.239\*sex]

Position: defenseman (0.197), goaltenders (6.929), missing position (0.055)

**Table 5.4 Summary of  $\beta_1$  time of recovery following most recent concussion coefficient**

HCST	Exposure Variable			Model Characteristics			
	Coefficient	95% CI	P-value	Modification by Relative Age**	F-Statistic	P-value	R <sup>2</sup>
Fwd Agility Weave Without Puck	-0.0835287	-0.1308 - 0.0362	0.001*	0.036*10.68 = 0.38 0.036*17.59 = 0.63	(12, 50) =11.69	P<0.0001	0.5751
Fwd Agility Weave With Puck	-0.1074962	-0.1603 - 0.0547	<0.001*	0.047*10.68 = 0.5 0.047*17.59 = 0.83	(12, 50) =62.09	P<0.0001	0.6194
Transition Agility Without Puck	-0.0106422	-0.0177 - 0.0035	0.004*	N/A	(8, 55) =22.83	P<0.0001	0.5883
Transition Agility With Puck	-0.0137863	-0.0257 - 0.0018	0.024	N/A	(8, 55) =17.57	P<0.0001	0.6119
Forward Speed Without Puck	-0.000426	-0.0026 - 0.0017	0.695	N/A	(10, 51) =51.85	P<0.0001	0.6527
Forward Speed With Puck	-0.0014136	-0.0040 - 0.0012	0.276	N/A	(10, 51) =35.82	P<0.0001	0.6642
Backward Speed Without Puck	-0.0500434	-0.0740 - 0.0260	<0.001*	0.022*10.68 = 0.23 0.022*17.59 = 0.39	(10, 55) =40.21	P<0.0001	0.6653
Backward Speed With Puck	-0.0645658	-0.0968 - 0.0323	<0.001*	0.029*10.68 = 0.31 0.029*17.59 = 0.51	(10, 55) =20.33	P<0.0001	0.5922
Drop-off Time	0.0035422	-0.0056 - 0.0127	0.439	N/A	(7, 49) =2.02	P=0.0707	0.3147

\*statistically significant at 0.0056 (0.05/9=0.0056) using Bonferroni correction

\*\*using the minimum relative age (10.68) and maximum relative age (17.59); based on the median time of recovery following most recent concussion (7 days)

## 5.2 Summary of Results

Test-retest reliability of the HCST components was assessed using ICCs and Bland Altman 95% LOA. The ICCs ranged from 0.50-0.89. The mean difference between the scores ranged from 0.001 seconds to -0.397 seconds. Bland Altman 95% LOA suggests that the second time will fall within approximately one second of the time from the first test session for most HCST components.

Preliminary univariate analyses suggest that having a history of concussion puts players at decreased odds of falling in the upper 25<sup>th</sup> percentile for the components forward agility weave without the puck and backward speed with the puck. These differences, however, were no longer statistically significant once adjusted for other covariates. There were no statistically significant differences in the mean times for any HCST component between those with and without a history of concussion, for males or females in any level of play.

Multiple linear regression analyses found that previous history of concussion was not a statistically significant independent variable of performance for any HCST outcome. Players reporting 2+ concussions were found to be statistically significantly faster than those with no history on the component forward agility weave with the puck. Number of previous concussions did not statistically significantly predict performance on any other HCST outcome. Time since a player's most recent concussion was not a statistically significant independent variable of any HCST component. Time of recovery following most recent concussion statistically significantly predicted performance on the HCST components: forward agility weave without and with the puck, transition agility without the puck, and backward speed without and with the puck. For

each of these components, for every day of recovery following a concussion a players time is expected to get faster.

## **Chapter Six: Discussion**

Although studies have attempted to measure performance using off-ice protocols as a predictor of on-ice performance, many of these studies have found little to no relationship between the two.<sup>49-53</sup> The validity of using such tests has been argued due to the lack of specificity to on-ice demands, with some arguing the off-ice measurements are of limited value.<sup>53</sup> This highlights the need for performance testing to be specific to the sport of the athlete.

### **6.1 Test-Retest Reliability of the HCST**

In order to accurately assess the changes in on-ice performance in those with a history of concussion, a reliable measurement tool is required. Twenty-three players were included in the investigation of the HCST components' test-retest reliability, which evaluates consistency of the HCST components' results over time,<sup>40</sup> by evaluating the change in the scores with repeated test administration. To our knowledge, this is the first study to assess the reliability of this test battery.

Test-retest reliability was traditionally reported using Pearson correlation coefficients. One limitation associated with the correlation coefficient is that although it may show the association between the two units of measurement, they do not show the level of agreement. In certain situations, a correlation may show perfect association but poor reliability. Pearson correlations were then replaced by intraclass correlation coefficients (ICCs) as the preferred measurement of reliability, as the ICC reflects both correlation and agreement.<sup>40</sup> The ICC ranges from 0.00-1.00 with values closer to 1.00 representing stronger reliability. ICC values may be interpreted as poor if less than 0.40, moderate if between 0.4 to 0.75, good if between 0.75 to 0.90, and excellent if above 90.<sup>54</sup> However, ICCs are not without their limitations as well. Since

the ICC is an average based on variance across all raters, non-agreement may be between all, some, or a single rater.<sup>40</sup> This non-agreement would lead to a poor ICC value. The other factor that relates to an ICC value is the variance among subjects scores. The variability in the data must be large enough to demonstrate reliability. A homogenous sample, raters either very strict or lenient, or when the rating system falls within a restricted range can all lead to poor ICC values.<sup>40</sup> Even though the limitations of the ICC are discussed, they were calculated in the present study to provide reference to other reliability studies.

### ***6.1.1 Repeated Sprint Skating***

The movements of ice hockey are typically described as high intensity, short-duration sprints.<sup>55</sup> With the demand of intermittent sports such as ice hockey that require both the aerobic and anaerobic energy systems, there has been an recent increase in using repeated sprint tests to assess players' physical capacities.<sup>56</sup> The use of traditional anaerobic power measurement such as the Wingate anaerobic test has been questioned for intermittent sport athletes, and in particular ice skaters.<sup>57,58</sup> Additionally, these tests require specific laboratory equipment and trained administrators, which limits the number of youth teams able to perform these tests.<sup>56</sup> Therefore, on-ice measurements that are easily administered by coaches are ideal for use in a youth ice hockey population.

Reed et al. (1979) and Watson and Sargeant (1986) reported high test-retest correlation coefficients on the 6-repeat drop-off time ( $r=0.78$  and  $r=0.96$ , respectively).<sup>26,27</sup> Interestingly, the present study found that the 6-repeat drop-off time had the lowest ICC value of all HCST components measured (0.50; 95% CI 0.19-0.80). Some authors have criticized the 6-repeat endurance skate as being too physically exhausting on players, particularly in younger level of

plays.<sup>59</sup> Specifically, Power et al. (2012) argues that the 6-repeat endurance skate is ineffective in providing a valid assessment of anaerobic performance because some players are unable to perform the test to their maximal ability.<sup>59</sup> These authors created a new endurance skating test, called the Repeat Ice Skating Test (RIST), targeted for younger aged players (11-12 year olds). This RIST consists of players skating 3 half laps around the ice surface with a 10-second rest period between laps. After completing the first 3 laps, players take a minimum 10-minute break and then skate the remaining 3 laps. Even though the authors reported a very high 14-day test-retest reliability ICC value of 0.99 (95% CI 0.97-0.99), there are several methodological issues with this test protocol. The authors measured the distance of the skating lap as 49 metres, yet the actual skating path the players' took was not determined. Players may have skated different paths, which could have led to different distances covered. Further, the test-retest reliability of the RIST was based on a relatively small sample size of only 14 players. The advantage of using the 6-repeat endurance skate over the RIST is that each player skates the same pathway, and therefore, the same distance.

### **6.1.2 Agility**

Despite studies suggesting the importance of measuring agility on-ice,<sup>60-62</sup> it has rarely been tested on-ice in hockey players. One method of testing on-ice agility used in the literature has been the cornering S-skate. Originally developed by Greer et al. (1992), it involves the players skating an S shape-course at full speed.<sup>63</sup> Although two studies have found this method to have good test-retest reliability in experienced players ( $r=0.95$  and  $r=0.96$ ),<sup>63,64</sup> one study found much lower test-retest reliability in female players of mixed age and ability ( $r=0.64$ ).<sup>62</sup> In the present study, the HCST component forward agility weave without the puck had an ICC of

0.89 (95% CI 0.81-0.98), and an ICC of 0.85 (95% CI 0.74-0.97) with the puck. The cornering S-test has been criticised in the literature as being too complex for less experienced players to maintain balance at full speed, particularly during cornering.<sup>64</sup> Further, Farlinger et al. (2007) found that the cornering S-test did not differ enough from a straight sprint skate to measure agility, and therefore, argues it is not a true measure of on-ice agility.<sup>64</sup> Due to the relatively simple design of the HCST forward agility weave component, it may be a better indicator of agility than the cornering S-test.

### ***6.1.3 Concussion Assessment Tools***

Although the HCST was not designed to be a concussion assessment tool, it is important to reference the current study's test-retest reliability scores in the context of other concussion literature. McLeod et al. (2006) determined the test-retest reliability of multiple concussion assessments in youth athletes (male and female, 9-14 years old), using ICCs. The different assessment tools all yielded varying results from the Standardized Assessment of Concussion (0.46), Balance Error Scoring System (0.70), Trail Marking Test B (0.65), and Symbol Search (0.83).<sup>65</sup> When comparing the results of these reliability studies to the results of the current study, the HCST is a very reliable assessment tool. Additionally, the HCST protocol is sport-specific to ice hockey players and thus, is ideal for use in this population. Based on the crude representation of the ICC values, the ICCs calculated in this study vary between moderate (drop-off time and transition agility with puck), good (forward agility weave without and with puck, transition agility with puck, forward speed without and with puck, and backward speed without and with puck), and excellent (transition agility without puck).

#### **6.1.4 Bland-Altman Method**

Given the limitations of both the Pearson correlation and the ICC, an ideal way to measure test-retest reliability is the Bland Altman method. This method calculates the mean difference between the two measurements, known as the bias, and the 95% limits of agreement. Bland Altman 95% limits of agreement (LOA) are the expected range that approximately 95% of the difference of scores will fall between. The limits of agreement use the measurement scale of the instrument, which provides unique and specific information regarding the difference expected over multiple test administrations.<sup>40</sup> Although not specific to the LOA, it may also be used to measure the agreement between different tests for criterion or construct validity. This will facilitate standardized interpretation of the HCST in clinical practice. In the current study, the mean differences were quite small, ranging from 0.001 seconds for backward speed without the puck to -0.397 seconds for transition agility weave with the puck. The 95% LOA varied for each HCST component, with the widest range for the component transition agility weave with the puck at approximately  $\pm 3$  seconds. All other components were smaller and ranged approximately  $\pm 1$  second. Transition agility weave with the puck may be arguably the most technically difficult skill component of the HCST, which may be why it shows the largest LOA. The transition agility tests a players ability in forwards skating, pivoting from forwards skating to backwards, backwards skating, pivoting from backwards to forwards, and stopping, all while maintaining control of the puck.

The LOA suggests that 95% of individuals would need a change of approximately 1-3 seconds in either direction in order to be indicative of a change greater than what would be expected over 7-10 days in youth ice hockey players. For the HCST component transition agility

weave without the puck (Figure 4.3), the mean difference between the two time intervals was decreased in players who were slower, suggesting slower players' times were more consistent than faster players. It is not apparently clear for why this trend exists. The distribution of the differences of scores seemed to be unrelated to the magnitude of the scores for all other outcomes (Figures 4.1-4.3, 4.5-9).

Based on the mean difference, 95% LOA, and ICC values calculated from the current study, the results show that the HCST is a very consistent way to measure on-ice skill performance. This test protocol is novel in that it is specifically designed for ice hockey players and tests different areas of skill performance, which makes it ideal for use in a youth population. Due to the number of players recruited for HCST test-retest reliability portion, the present study was unable to determine the reliability of the HCST components between those with and without a history of concussion. This remains an area of future research.

## **6.2 Validity of the HCST**

Although the HCST has been determined to be a reliable measure of on-ice performance, the validity of the components of the protocol remains unknown. Only the 6-repeat drop-off time has been assessed as a valid measure of a player's anaerobic capacity.<sup>26</sup> Measurement validity may be defined as the degree to which an instrument measures what it is intended to measure.<sup>40</sup> There are four types of measurement validity that contribute evidence to support a test's overall measurement validity: face validity, content validity, criterion-related validity, and construct validity. Face validity indicates that a measurement appears to test what it is supposed to and that it is a plausible method for doing so.<sup>40</sup> Because experts at Hockey Canada developed the HCST, this testing protocol has sufficient face validity to warrant its use in this study. The other

measures of validity have not yet been assessed and remain a future direction for studies using the HCST.

### **6.3 Participant Characteristics**

There were a total of 596 youth ice hockey players that participated in this study. Of those, 202 (34%) reported a previous history of concussion and 394 (66%) did not. When broken down by level of play, 29% of Pee Wee, 38% of Bantam, and 45% of Midget players reported a previous history of concussion. The proportions reported in the current study are slightly higher than proportions reported in previous Canadian ice hockey studies. These studies found 18% of Pee Wee and 32% of Bantam players reported a previous concussion history.<sup>7,9</sup> Ice hockey is a male-dominated sport,<sup>1</sup> and this disparity is illustrated by the sample in the present study, where 525 players were male (88%) and 71 were female (12%). Players were separated by sex and level of play as differences have previously been shown between these groups.<sup>45</sup> Once separated by level of play and sex, those with a history of concussion did not differ significantly from those without in their age, height, weight, or years' experience playing.

### **6.4 Previous History of Concussion**

The way previous history of concussion was asked in the baseline questionnaire used terms such as “sustained a concussion”, been “knocked out”, or had your “bell rung”. This definition is inclusive of many different commonly used terms in the sporting community for a concussion, in order to maximize the capture of concussion in this study.

Examination of the crude odds ratios (ORs) suggest those with a history of concussion are not at higher odds of falling in the upper 25<sup>th</sup> percentile (i.e., those with a history of concussion are not more likely to be the slowest players). In fact, those that had a previous

history of concussion were more likely to be faster than those without, for the tests forward agility weave without the puck and backward speed with the puck. These results may be due to a selection bias in that those that have deficits post concussion are self-selected out by either no longer participating in hockey, or choosing not to participate in the present study. However, it is important to note that the crude analysis does not consider other covariates which may affect the results. Because, after adjusting for relative age, level of play, position, elite/non-elite play, previous MSK injury in the last year, while accounting for clustering by team, these odds ratios were no longer statistically significant. There were no significant differences in the mean scores between those with and without a previous history of concussion for either sex. These findings are consistent with the results of Eliason et al. (2014).<sup>45</sup> The 95% confidence intervals were quite wide for female players, particularly in Pee Wee and Bantam players. This is most likely due to the small number of female players recruited.

Based on the multiple linear regression models, previous history of concussion was not a significant independent variable of performance for any outcome. These results are similar to the findings by Makdissi et al. (2009) and Kumar et al. (2014) who reported no change in performance in male athletes after concussion.<sup>11,12</sup> Players reporting 2+ concussions were found to be statistically significantly faster than those with no history on the component forward agility weave with the puck (7.317 95% CI 11.047-3.586). In the presence of the other independent variables, number of previous concussions did not significantly predict performance on any other HCST outcome. These results suggest that number of previous concussions sustained does not negatively influence players' HCST performance scores. Additionally, in the presence of the other independent variables, the time since a players most recent concussion was not a

significant independent variable of any HCST component. This suggests that there are no performance differences between a concussion that happened more recently compared to a concussion that happened longer ago. Finally, in the presence of the other independent variables, time of recovery following most recent concussion significantly predicted performance on the HCST components: forward agility weave without and with the puck, transition agility without the puck, and backward speed without and with the puck. For each of these components, for every day of recovery following a concussion a players time is expected to get faster. It is surprising to have results where participants with more prolonged recovery had better performance. Based on the coefficients calculated from the models, for every 1-day increase in time lost due to concussion a players score is expected to get faster by 0.083 seconds (95% CI 0.131-0.036) on forward agility without the puck, 0.107 seconds (95% CI 0.160-0.055) on forward agility with the puck, 0.01 seconds (0.018-0.004) on transition agility without the puck, 0.05 seconds (0.074-0.026) on backward speed without the puck, and 0.06 seconds (0.097-0.032) on backward speed with the puck. In context, compared to a player that did not require any days of recovery following their most recent concussion, a player that had a concussion that required 10 days of recovery is expected to score approximately 0.8 seconds faster on forward agility without the puck, 1 second faster on forward agility with the puck, 0.1 seconds faster on transition agility without the puck, 0.5 seconds faster on backward speed without the puck, and 0.6 seconds faster on backward speed with the puck.

## **6.5 Strengths**

This is the first study of its kind to examine the test re-test reliability of the HCST, and the association between concussion and sport-specific skill performance in youth ice hockey

players. Previous research in concussion and performance has mainly focused on sports other than ice hockey, and in adult populations.<sup>11-13</sup>

The test-retest analysis employed was statistically rigorous by using Bland Altman LOA and ICCs for comparisons to other commonly used assessment tools. These reliability coefficients in conjunction show that the HCST is a very reliable way to measure on-ice sport specific skill performance, and will facilitate standardized interpretation of the HCST in clinical practice. Further, the HCST is a sport-specific test protocol and is an ideal way to measure performance in this population. This study was unique in that it investigated previous concussion in a multitude of unique ways by examining history, number, time since most recent, and severity of most recent concussion. This study will serve to deepen the knowledge of concussion in youth and performance, and will create a base that will serve to inform future research.

## **6.6 Limitations**

This study is the first of its kind, and contributes novel information to our understanding of concussion, but it is not without its limitations. It is a cross-sectional design; therefore, temporality could not be determined. As a result, causality between concussion and performance could not be evaluated. Future studies using a design where temporality could be established (e.g., prospective cohort) should be used to determine causality. This may be useful in determining if skill performance scores are a risk factor for injury. As described in Chapter 3, twenty-six players were represented in more than one year in the study. Although they were treated as independent subjects, this remains a limitation of the study.

There is the potential for survival bias in the present study, as players that completed HCST had essentially survived and continued in sport up until completing testing. There may be

players that suffered a concussion, and as a result of that concussion stopped playing ice hockey. It is not known how many players have stopped playing because of this reason, or if they were to continue playing, how their on-ice performance would influence the results of this study.

Measurement bias is also another issue in the present study. The baseline questionnaires relied on self-report which is subject to self-report bias, recall bias and non-differential error from missing data. Players (and their parents) may have had different understandings of the word/phrases concussion, “knocked out”, and “bell rung”. The different interpretations could lead to differences in whether players report a previous history of concussion. By nature of the way the question is asked, there is the potential for misclassification bias if players are more likely report saying yes to a previous history of concussion even if they truly didn’t. If these false positives were more likely to be faster on the tests, then this would lead to an underestimation of the true association.

Recall bias is also likely to have occurred if those players that suffered a concussion more recently were more likely to report a previous concussion than those that occurred more in the past. If the false negatives were slower on HCST then this would lead to an underestimation of the true association.

The baseline questionnaire used in 2012-2013 and 2013-2014 seasons only had enough room to report a maximum of 3 previous concussions. This question was modified for the 2014-2015 season cohort to allow a reporting of five previous concussions. Though only three players reported 3 previous concussions over the 2012-2014 seasons, it is possible that these players may have actually reported more if allowed. However, even if these three players all reported 4 or more previous concussions, it would still be too small to include in the exploratory analysis.

Although the HCST is designed with standardized measurements for the different components, the 6-repeat endurance skate uses the entire length of ice for the test. Different arenas have different lengths of ice, which may have impacted the players' scores for this one test. Teams may have completed testing on a shorter length of ice which may have decreased their 6-repeat drop-off time. It is unlikely that those with a previous history were more or less likely to be tested on a shorter rink, so therefore this would lead to a non-differential misclassification bias. This would lead to dilution of the true association towards the null. Additionally, different arenas have differences in lighting, ambient noise, temperature, and other factors. It is unknown how these differences may influence the times of the players.

Handheld stopwatches were used to measure players' performances. Although we are assuming there was high consistency among the timing personnel, a limitation from using the hand stopwatches is basic human reaction time may influence the times of the players. This may be especially true when measuring quick duration tests such as the components forward/backward speed skate, where the times are approximately 6-7 seconds. Although hand stopwatches are not the ideal way to measure time on these components, they are easy to use and practical for use on-ice. Since timing personnel were blinded to who had a previous history of concussion, any errors from the timing personnel would lead to a non-differential misclassification bias. This is because the errors would be similar for concussed and non-concussed players, which would lead to a dilution of the association towards the null.

Repeated skating over the same area of ice may lead to ruts being formed which may have negatively affected the times of participants who skated later in the group, as the ice surface would not be as clean. Although we have tried to prevent this as best as possible by rotating the

drills on the rink, this remains a limitation in this study. Because players were typically divided into groups alphabetically, there is no cause to believe either concussed or non-concussed players were more likely to be the later skaters. Therefore, this would be a non-differential misclassification bias, which would shift the association towards the null.

The HCST data was collected over the entire 2013-2014 and 2014-2015 playing seasons; thus, some teams completed the testing protocol much earlier in the season than others. It is likely that teams will have had a different number of practices, games, and/or overall training sessions before they complete the HCST, which were not controlled for in this study.

The original sample size of 518 (259 with a history of concussion and 259 without), which was estimated to detect a difference of approximately 12% in the proportion in the upper 25<sup>th</sup> percentile between those with and without a concussion, was not achieved as too few players with a history of concussion were recruited. Although 596 participants completed testing and were included in final analysis, only 202 reported a previous history of concussion. This study was not powered on a multivariate analysis and thus these analyses were exploratory. A larger sample size with a history of concussion, particularly in females would have enabled further comparisons and analysis. Clustering effects were taken into account for the analyses as 65 different teams participated with different numbers and demographics. Sample size calculations can be found in Appendix A.

Finally, there are limitations to the generalizability of this study that are important to consider. The HCST was only tested in youth hockey players in Calgary, Alberta, and therefore, the results of this study should only be generalized to that population. Although goalies were included in testing, the HCST components employed in this study are based on endurance, speed,

and agility skating with and without a puck, which are not skills typically utilized by goaltenders. This suggests that goalies may need to be looked at separately, and possibly using performance measures more related to their position. Different countries (and leagues/age groups, etc.) play different styles of hockey with different focuses on skill performance; they may also utilize different return to play and concussion management programs, which may affect subsequent performance post-injury. The population used in this study is limited to youth ice hockey players in Calgary, Alberta, and therefore, the generalizability to other provinces, countries, adult populations, or other leagues is unknown.

## Chapter Seven: Conclusion

### 7.1 Summary of Findings

This is the first study to examine the association between a history of concussion and sport-specific skill performance in youth ice hockey players. A total of 596 youth participated in this study, with two hundred two (34%) reporting a previous history of concussion and three hundred ninety-four (66%) reporting no previous history of concussion.

Examination of univariate odds ratios suggests those with a history of concussion were not more likely to be the slowest players. It was actually found that players with a previous history of concussion were more likely to be faster on the components forward agility weave without the puck and backward speed with the puck. However, once adjusted for other covariates as well as controlling for clustering by team, these differences were no longer statistically significant. There were also no statistically significant differences in the mean scores between those with and without a previous history of concussion players for either sex, which is similar to the finding in a previous study.<sup>45</sup>

The multiple linear regression models were exploratory in nature. Relative age, position, level of play, previous MSK injury within the last year, sex, and whether the player was elite or not were all variables entered into the regression models. Effect modification was assessed by relative age and sex for all outcomes. There were no differences in all performance outcomes between those with and without a previous history of concussion. Due to the small number of players reporting three previous concussions (n=5), these players were combined with those reporting two previous concussions. Differences between the number of previous concussion and performance were seen on the component forward agility weave with the puck. Specifically,

those with 2+ concussions were found to be significantly faster than those with no history (7.317 seconds; 95% CI 11.047-3.586). Time since most recent concussion was not a statistically significant independent variable of time on any HCST component.

Time of recovery following most recent concussion was statistically significant in predicting time on the HCST components forward agility weave without and with the puck, transition agility without the puck, and backward speed without and with the puck. Based on the calculated coefficients, for every 1-day increase in time lost due to concussion a players score is expected to get faster by 0.083 seconds (95% CI 0.131-0.036) on forward agility without the puck, 0.107 seconds (95% CI 0.160-0.055) on forward agility with the puck, 0.01 seconds (0.018-0.004) on transition agility without the puck, 0.05 seconds (0.074-0.026) on backward speed without the puck, and 0.06 seconds (0.097-0.032) on backward speed with the puck.

The components of the Hockey Canada Skills Test measure one aspect of player performance. This aspect is the technical product or outcome and is measured under ideal practice conditions. Overall player performance, particularly in team sports, is a combination of many factors and should be measured during real game play. The relation between HCST and in-game performance is unknown, and remains an area for future research.

## **7.2 Public Health Implications**

Concussion is a significant problem in youth ice hockey. It has the highest concussion incidence rate in male high school team sports and is the most common specific injury type for youth ice hockey players.<sup>5,6</sup> Players with a history of concussion are at an increased risk of incurring a future concussion.<sup>6,7,9,10</sup> There is a paucity of research examining the association between injury, specifically concussion, and sport-specific performance outcomes. This study is

the first to examine previous history of concussion and sport-specific skill performance. The findings indicate that there are few differences between those with and without a previous history of concussion on various performance skills tests. This information may help to better inform future injury prevention and concussion management strategies.

### **7.3 Recommendations for Future Research**

Future investigations of concussion and performance should employ stronger research study designs such as a prospective cohort study, in order to determine temporality for the few differences found in this study. A prospective cohort study would also allow for the assessment of performance score and risk of injury and concussion. In addition to having a large sample size, it is important that future studies focus on female recruitment. This will facilitate multiple linear regression analyses to examine associations between concussion and skill performance. The increase in sample size must be mindful of potential clustering effects by team and possible effect modification by sex and relative age. Finally, future studies would be wise to recruit from teams in different communities, cities, and levels of play. Doing so will allow for greater generalization of any study results.

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## **APPENDIX A: SAMPLE SIZE CALCULATION**

This sample size calculation was determined using Professor Rollin Brant's online calculator at: <http://stat.ubc.ca/~rollin/stats/ssize/index.html>. Calculations were based on comparing proportions for two independent samples.

Our sample size will be powered on the proportion of those with and without a previous history of concussion that fall in the highest 25<sup>th</sup> percentile (the slowest players) on the HCST component forward agility weave without the puck. This component was chosen as it demonstrates fundamental skating skills.

Using an alpha set at 0.05 and a power of 0.80.

Proportion in sample 1 (no history of concussion): 0.342105263157

Proportion in sample 2 (history of concussion): 0.462686567164

The sample size (for each sample separately) is 259 participants ( $n = 259$ ;  $N = 518$ ).

The calculations are the customary ones based on the normal approximation to the binomial distribution.

**APPENDIX B: HOCKEY CANADA SKILLS TESTING RECORDING SHEETS**



# HOCKEY CANADA

## NATIONAL SKILLS STANDARDS & TESTING



### Skills Testing - Data Recording Sheet

PERSONAL INFORMATION			TEST RESULTS										GOALTENDER TEST RESULTS					
Name	Position	Gender	Passing Accuracy		Fwd Agility Weave w/ Puck	Fwd Agility Weave w/o Puck	Shooting Accuracy	Figure 8's	Transition Agility w/o Puck	Transition Agility w/ Puck	Fwd Speed w/o Puck	Fwd Speed w/ Puck	Bwd Speed w/o Puck	Bwd Speed w/ Puck	Re-bound Control	Iron Cross		Lateral Movement
			(/5) Fh	(/5) Bh												(/30) Fh	(/30) Bh	
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		
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12																		
13																		
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15																		
16																		
17																		
18																		
19																		
20																		
21																		

Team Name: \_\_\_\_\_  
 Age Division: \_\_\_\_\_  
 Date of Test: \_\_\_\_\_

Coach: \_\_\_\_\_  
 Level: \_\_\_\_\_  
 Test #: \_\_\_\_\_

Phone: \_\_\_\_\_  
 Email: \_\_\_\_\_  
 Signature #1: \_\_\_\_\_  
 Signature #2: \_\_\_\_\_

NOTE: (Bh=backhand, Fh=forehand)

## **APPENDIX C: COMPONENTS OF THE HOCKEY CANADA SKILLS TEST**



# **National Skills Standards & Testing Program**

## **Handbook**





## National Skills Standards & Testing Program

### Testing Your Players

#### Introduction

During the 1999 Molson **Open Ice Summit on Player Development** in Canada, delegates close to the game at the grassroots level recommended that Hockey Canada investigate ways to celebrate skill development in hockey. In Canada today there is no nationally organized program that tests or recognizes skill acquisition and skill improvement within the Canadian hockey system. In Canadian minor hockey, coaches should be encouraged to foster the development of the fundamental skills required to play the game at the minor levels by measuring and providing positive individual feedback on skill development. It is essential that minor hockey associations and parents have a method of measuring success beyond wins and losses.

Hockey Canada created the **National Skills Standards and Testing Program (NSST)** for minor hockey aged players in Canada. This program is based on the fundamental philosophy that skill development should be fun and challenging and at the same time accessible to all players in the Canadian minor hockey system. Hockey Canada believes in celebrating skill achievement.

#### **PROGRAM GOAL**

*"Raise awareness of the importance of skill development and establish a system to measure and celebrate skills."*

#### Accessible To:

- Any Hockey Canada member team has access to the program.
- Coaches can collect the test data and keep it within the team or the testing results can be centralized through the use of the Hockey Canada national web site database at [www.hockeycanada.ca](http://www.hockeycanada.ca).

A series of 6 individual skill tests have been designed to measure the skill level of players. These tests can be administered by team coaches requiring very little equipment, expense and set up time.

It is ideal to test players 2 times per season, but if ice time is available it is recommended that players be tested 3 times per season. Testing 2 or 3 times in a season will help to establish performance levels and demonstrate the amount of improvement that takes place. It is very important that the testing environment is set up in the same manner each time to ensure that the comparisons of test results from each session are meaningful and accurate.





### **National Skills Standards & Testing Program**

If testing were to take place 3 times throughout the season, the best times would be:

1. The beginning of the season: sets a baseline for each player and the team
2. Mid – season: demonstrates the amount of skill improvement of each player and the team
3. End of season: demonstrates improvement from the start of the season to the end of the season

#### **Conducting the Test**

With the right number of assistants (6) on the ice, the 6 station test can be administered during one ice session with all stations active simultaneously. A second option would be to incorporate the test into a series of practices by setting up and executing one or two stations over several ice sessions.

Equipment required:

- ❖ (30) Pucks
- ❖ (1) Tape Measure – 100 feet
- ❖ (1) Spray paint
- ❖ (3) Stop watches
- ❖ (10) Pylons
- ❖ Shooter Tutor
- ❖ (6) Clipboards / pens

Personnel required:

- ❖ (1) Lead Tester – to coordinate all on ice activities
- ❖ (6) Assistant Testers – to lead individual testing stations
- ❖ (6) Recorders – optional (can assist with recording scores at each station)

#### **Standards**

- Over time (beginning November 2004) a set of age division standards will accumulate in the database of test results. Players and teams will be able to compare scores and judge strengths, weaknesses and areas in need of improvement.

#### **Education**

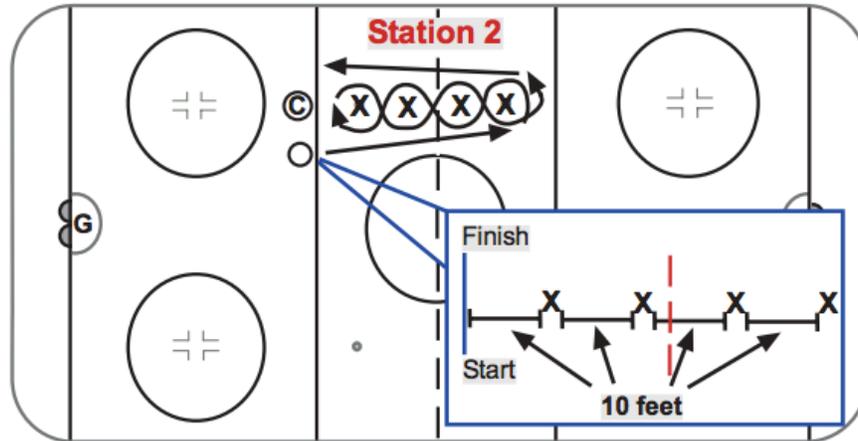
- One of the most important aspects of the NSST program is that once coaches have tested their players and the results have been uploaded on to the NSST website, coaches will receive a series of drills designed to help improve weaknesses of the team as a whole, or individual player weaknesses.





**National Skills Standards & Testing Program**

**STATION TWO: Forward Weave Agility Skate**

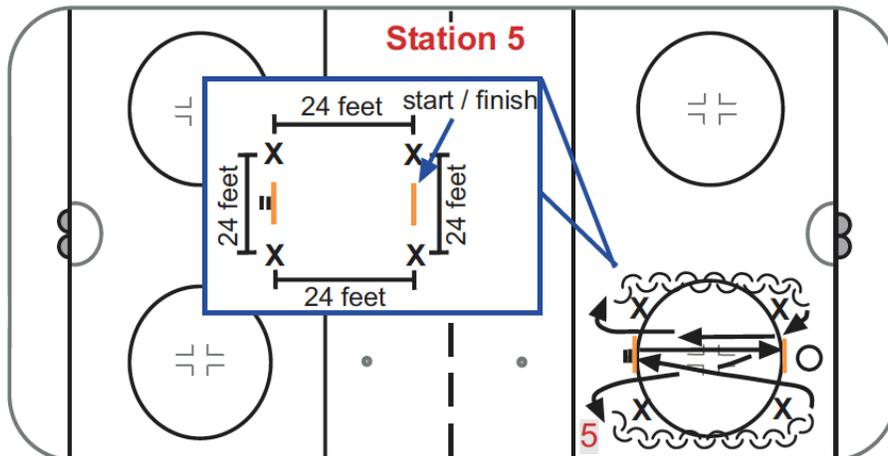


Time	Description
6 MIN	Forward Weave Agility Skate
<ul style="list-style-type: none"> <li>❖ Start at the blue line, skate forward towards the far pylon and make a tight turn around first pylon. Weave back through the pylons, making a tight turn around the last pylon (closest to start line), and weave back through the pylons, making a tight turn around the last one. Sprint back to the blue line which is both the start and finish line.</li> <li>❖ The first pylon is 10 feet from blue line. (Starting point)</li> <li>❖ Pylons are set 10 feet apart.</li> </ul>	
Key Execution Points (KEP)	
<ul style="list-style-type: none"> <li>❖ This is a timed drill.</li> <li>❖ Do the test without a puck first, then repeat the test with a puck.</li> <li>❖ Measure distances for pylon placement and use spray paint to mark the spot. Place a pylon over top of each spray painted dots. This ensures that if a pylon gets knocked off down, it will be easy to replace it to the exact spot.</li> </ul>	



**National Skills Standards & Testing Program**

**STATION FIVE: Transition - Agility Skate**

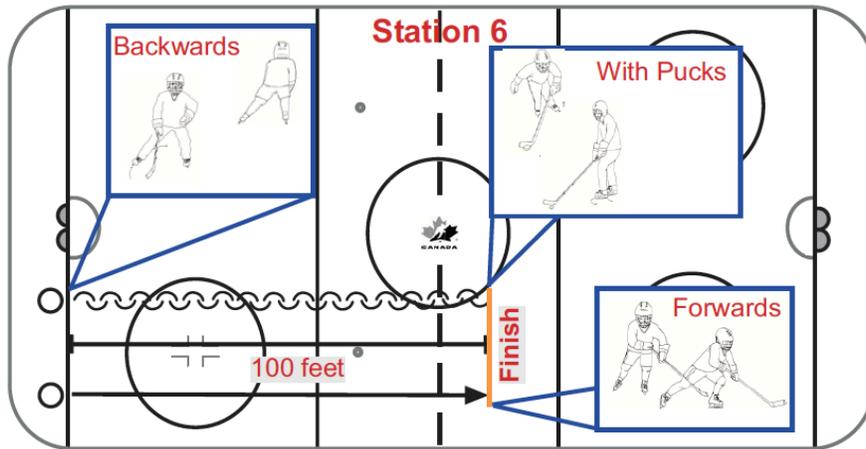


Time	Description
8 MIN	Transition - Agility Skate
<ul style="list-style-type: none"> <li>❖ Each player starts on line at the bottom of circle. The player skates forward to far right side pylon, pivots and skates backwards to lower right side pylon.</li> <li>❖ The player then pivots and skates forward to far left side pylon, pivots and skates backwards to lower left side pylon.</li> <li>❖ The player then pivots and skates forward to designated line, stops, and then skates forward back to starting line.</li> <li>❖ Complete the test without a puck. Then complete the test with a puck.</li> </ul>	
Key Execution Points (KEP)	
<ul style="list-style-type: none"> <li>❖ Players must transition from forward to backward and forward to backward at the pylons.</li> <li>❖ Measure distances, and use spray paint to mark the spot. Place a pylon over top of each spray painted dot. This will ensure accurate placement of the pylon without having to re-measure when pylons are knocked over.</li> </ul>	



**National Skills Standards & Testing Program**

**STATION SIX: Forward / Backward - Speed Skate**



Time	Description
8 MIN	Forward / Backward - Speed Skate
	<ul style="list-style-type: none"> <li>❖ Players skate as fast as they can straight ahead, first forwards and then backwards.</li> <li>❖ The distance is 100 feet.</li> <li>❖ Measure 100 feet starting at the goal line. Use spray paint to draw a line to indicate the finish line.</li> <li>❖ Complete first without a puck. Then add a puck for the second trial.</li> </ul>
Key Execution Points (KEP)	
	<ul style="list-style-type: none"> <li>❖ Complete forward skating without a puck then add a puck. Repeat the test backwards first without a puck and then with a puck.</li> <li>❖ Encourage players to skate through finish line (discourage players from stopping at the finish line).</li> </ul>



## **APPENDIX D: BASELINE QUESTIONNAIRE**



# HOCKEY STUDY

## PRE-SEASON BASELINE QUESTIONNAIRE



SSID #: \_\_\_\_\_ \*OFFICE USE ONLY

<b>Name:</b> _____		<b>Today's Date:</b> ____ / ____ / ____ Day Month Year	
<b>Gender:</b> <input type="checkbox"/> Male <input type="checkbox"/> Female			
<b>Age:</b> _____	<b>City:</b> _____	<b>Player's Phone No:</b> ( ) _____	
<b>Height:</b> ____ feet ____ inches <b>or</b> ____ cm		<b>Date of Birth:</b> ____ / ____ / ____ Day Month Year	
<b>Weight:</b> _____ (lbs) <b>or</b> _____ (kg)		<b>Level of Play:</b> <input type="checkbox"/> Pee Wee <input type="checkbox"/> Bantam <input type="checkbox"/> Midget	
<b>Dominant Hand (for writing):</b> <input type="checkbox"/> Right <input type="checkbox"/> Left			
<b>Division:</b> <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6 <input type="checkbox"/> 7 <input type="checkbox"/> 8 <input type="checkbox"/> 9 <input type="checkbox"/> 10 <input type="checkbox"/> 11 <input type="checkbox"/> 12 <input type="checkbox"/> AA <input type="checkbox"/> AAA			
<b>Position:</b> <input type="checkbox"/> Forward <input type="checkbox"/> Defense <input type="checkbox"/> Goalie		<b>Team Name:</b> _____	
<b>Please check off how many years of organized hockey you have played prior to this season (check only one):</b>			
<input type="checkbox"/> 0 years <input type="checkbox"/> 4 years <input type="checkbox"/> 8 years <input type="checkbox"/> 12 years <input type="checkbox"/> 1 year <input type="checkbox"/> 5 years <input type="checkbox"/> 9 years <input type="checkbox"/> 13 years <input type="checkbox"/> 2 years <input type="checkbox"/> 6 years <input type="checkbox"/> 10 years <input type="checkbox"/> 14 years <input type="checkbox"/> 3 years <input type="checkbox"/> 7 years <input type="checkbox"/> 11 years <input type="checkbox"/> Other _____			
<b>Have you ever participated in a University of Calgary hockey research study?</b> <input type="checkbox"/> yes <input type="checkbox"/> no <i>If "Yes", what year?</i> _____			
<b>EQUIPMENT (check all that apply):</b>			
<b>a) Mouthguard:</b>			
<b>At games:</b> <input type="checkbox"/> always <input type="checkbox"/> less than 75% <input type="checkbox"/> never		<b>At practices:</b> <input type="checkbox"/> always <input type="checkbox"/> less than 75% <input type="checkbox"/> never	
<b>Type of mouthguard worn:</b> <input type="checkbox"/> dentist custom-fit <input type="checkbox"/> off the shelf			
<b>b) Helmet:</b>			
<b>Make:</b> <input type="checkbox"/> Bauer <input type="checkbox"/> CCM <input type="checkbox"/> Itech <input type="checkbox"/> Jofa <input type="checkbox"/> Mission <input type="checkbox"/> Nike <input type="checkbox"/> RBK <input type="checkbox"/> Other: _____			
<b>Type:</b> <input type="checkbox"/> full clear visor <input type="checkbox"/> full wire cage <input type="checkbox"/> combination visor/cage			
<b>Age:</b> <input type="checkbox"/> new this season <input type="checkbox"/> new last season <input type="checkbox"/> 2-3 years old <input type="checkbox"/> >3 years old			

### INJURY HISTORY:

1. Have you ever had a concussion or been "knocked out" or had your "bell rung"?  
 Yes  No

*if "Yes", please list below:*

Date: <i>eg. (DD/MM/YY)</i>	Activity of the time <i>hockey, skateboarding, etc.</i>	Time unconscious		Memory loss (yes or no) <i>no</i>	Time loss before FULL return to sport <i>1 day, 10 days, etc</i>
		<i>0min</i>	<i>30sec</i>		

If you answered **yes** to Question 1, please indicate whether you have any persistent problems with:

- |              |                              |                             |
|--------------|------------------------------|-----------------------------|
| a) memory    | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| b) dizziness | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| c) headaches | <input type="checkbox"/> Yes | <input type="checkbox"/> No |

2. In addition to any injury described in question 1, have you had any other injury requiring medical attention OR at least 1 day of missed participation from sport or physical activity in the past **12 MONTHS**?

Yes  No

*If "Yes", please describe this injury/these injuries to the best of your ability below:*

Injury Date <i>eg. (DD/MM/YY)</i>	Injury type <i>sprain, bruise, etc.</i>	Body part <i>knee, nose, etc.</i>	Sport of occurrence <i>soccer, wakeboarding, etc.</i>	Treatment description <i>first aid, physio, etc.</i>	Time loss before FULL return to sport <i>1 day, 3 weeks, etc.</i>

3a. Do you have any incompletely healed injuries?

Yes  No

*If yes, describe this injury to the best of your ability:* \_\_\_\_\_

3b. Are you currently receiving treatment for this injury/these injuries?

Yes  No

*If yes, describe this injury to the best of your ability:* \_\_\_\_\_

**MEDICAL HISTORY**

1. Do you take any medications (asthma inhaler, Advil, Tylenol, etc.) on a regular basis ?

Yes  No

*If yes, please list:* \_\_\_\_\_

2. Are you currently taking any supplements (vitamins, minerals, protein powder, etc.) ?

Yes  No

*If yes, please list:* \_\_\_\_\_

3. Have you been diagnosed by a physician with a bone fracture, arthritis, or other muscle or bone related condition?

Yes  No

*If yes, describe your condition(s) to the best of your ability:* \_\_\_\_\_

Year of diagnosis: \_\_\_\_\_

4. Have you been diagnosed by a physician with a systemic disease (e.g., cancer, thyroid disease, heart disease)?

Yes  No

*If yes, describe your condition(s) to the best of your ability:* \_\_\_\_\_

Year of diagnosis: \_\_\_\_\_

5. Have you ever been diagnosed by a physician with a circulation or heart-related problem (e.g., heart murmur, irregular heart beat, congenital deformity of the heart)?

Yes  No

*If yes, describe your condition(s) to the best of your ability:* \_\_\_\_\_

Year of diagnosis: \_\_\_\_\_

6. Have you been diagnosed by a physician with a neurological disorder (e.g., brain injury, cerebral palsy, pinched nerve, "stinger", multiple sclerosis, etc.)?

Yes  No

*If yes, describe your condition(s) to the best of your ability:* \_\_\_\_\_

Year of diagnosis: \_\_\_\_\_

*questionnaire continues*

7a. Have you ever experienced headaches?  
 Yes  No

7b. If yes, are they associated with (please check all that apply):  
 Nausea  
 Vomiting  
 Sensitivity to Light  
 Sensitivity to Noise

7c. Does anyone else in your family experience headaches?  
 Yes  No  
 If **yes**, please list which family members: \_\_\_\_\_

7d. Have you ever been diagnosed with migraines?  
 Yes  No Year of diagnosis: \_\_\_\_\_

8a. Have you ever been concerned that you have an attention or learning issue?  
 Yes  No  
 If **yes**, please describe to the best of your ability: \_\_\_\_\_

8b. Have you ever been formally diagnosed by a health care professional (physician, psychologist, etc.) as having an attention or learning issue?  
 Yes  No  
 If **yes**, please describe to the best of your ability: \_\_\_\_\_ Year of diagnosis: \_\_\_\_\_

8c. Have you ever been formally diagnosed by a health care professional (physician, psychologist, etc.) with any of the following: (check all that apply)

<input type="checkbox"/> Cognitive Delay	<input type="checkbox"/> Disruptive Behaviour Disorder
<input type="checkbox"/> Communication Disorder	<input type="checkbox"/> Oppositional Defiant Disorder
<input type="checkbox"/> Pervasive Developmental Disorder	<input type="checkbox"/> Conduct Disorder
<input type="checkbox"/> ADHD	<input type="checkbox"/> Mood Disorder
<input type="checkbox"/> Learning Disability	<input type="checkbox"/> Depression
<input type="checkbox"/> Anxiety Disorder	<input type="checkbox"/> BI-Polar
<input type="checkbox"/> Other: _____	

The following questions ask about your thoughts on body checking and how you use body checking in hockey. We ask that you answer as honestly as possible, without any influence from other people.  
 Please circle the number that best matches your answer.

	Strongly disagree ☹	Disagree a little	Neither ☺	Agree a little	Strongly agree ☺
	1	2	3	4	5
1) I like body checking.	1	2	3	4	5
2) I like to be body checked.	1	2	3	4	5
3) My coach encourages me to body check.	1	2	3	4	5
4) My parents encourage me to body check.	1	2	3	4	5
5) My teammates encourage me to body check.	1	2	3	4	5
6) I could be seriously injured by a body check.	1	2	3	4	5
7) I could seriously injure someone else with a body check.	1	2	3	4	5
8) I think body checking increases my teams' chances of winning.	1	2	3	4	5
9) I would try to harm an opponent with a body check if it would increase my team's chance of winning.	1	2	3	4	5
10) I think body checking should be allowed in Pee Wee hockey.	1	2	3	4	5
11) I would body check another player even if I knew it would injure them.	1	2	3	4	5

## ACTIVITY HISTORY QUESTIONNAIRE

1. In **THE LAST SIX WEEKS**, how many weeks and how many hours per week (on average) did you participate in PE class?  
 \_\_\_\_\_ hours per week      \_\_\_\_\_ number of weeks

2. In **THE LAST SIX WEEKS**, did you participate in any sports (**NOT including PE class**)? Yes  No   
 If **yes**, please estimate the average number of hours per week you participated in each sport:

SPORT	HOURS PER WEEK	NUMBER OF WEEKS		SPORT	HOURS PER WEEK	NUMBER OF WEEKS
Aerobics				Lacrosse		
Alpine skiing				Martial arts		
Badminton				Rock climbing		
Baseball				Rollerblading		
Basketball				Rugby		
Boxing (incl. kick)				Running		
Cross-country skiing				Skateboarding		
Cycling (road or mtn)				Snowboarding		
Dance				Soccer		
Dirt biking				Squash		
Diving				Speed skating		
Field hockey				Swimming		
Figure skating				Tennis		
Floor hockey				Track and field		
Football				Volleyball		
Golf				Waterpolo		
Gymnastics				Weight training		
Hiking/ Scrambling				Wrestling		
Hockey				Other (please describe):		
Horse riding						

3. In **THE LAST SIX WEEKS**, how many **HOURS A WEEK (on average)** do you spend on sport-related preparation (e.g. reading and reviewing scouting reports, watching game tape/film sessions, studying playbooks)?  
 \_\_\_\_\_ hours per week      \_\_\_\_\_ number of weeks

4. How many classes have you taking **THIS SEMESTER**?      1   2   3   4   5   6  
 How many hours (on average) do you spend in class in one week? \_\_\_\_\_  
 How many hours (on average) do you spend on homework in one week? \_\_\_\_\_  
 How many hours (on average) do you spend studying for a test in your hardest class? \_\_\_\_\_  
 How many hours (on average) do you spend studying for a test in your easiest class? \_\_\_\_\_  
 How many hours (on average) do you use a computer for school? \_\_\_\_\_  
 How many hours (on average) do you spend tutoring or being tutored? \_\_\_\_\_

5. On average, how many texts messages/BBMs do you send or receive a day? \_\_\_\_\_

6. Please answer the following question based on the **LAST SIX WEEKS**:

On, average, how many **HOURS A DAY** do you spend on the following:

- Reading (non-academic material such as novels, magazines, comics) \_\_\_\_\_
- Playing Non-Computer Games (e.g., chess, checkers, board games) \_\_\_\_\_
- Playing Games (on gaming systems, computer or phone) \_\_\_\_\_
- Playing Card Games \_\_\_\_\_
- Doing Word/Number Puzzles (e.g., Sudoku, Crosswords, Search-A-Word) \_\_\_\_\_
- Completing Puzzles \_\_\_\_\_
- Watching TV \_\_\_\_\_
- Talking on the Phone \_\_\_\_\_
- Watching Movies \_\_\_\_\_
- Using the Internet \_\_\_\_\_
- Email \_\_\_\_\_
- Social media (Facebook, Twitter, MySpace) \_\_\_\_\_
- Blogging \_\_\_\_\_
- Surfing/Searching \_\_\_\_\_
- Chores (e.g. making bed, doing dishes, mopping, taking out garbage) \_\_\_\_\_

7a. In **THE LAST SIX WEEKS**, have you been employed? Yes  No

If yes:

7b. What is your job title (e.g. coach, general labourer, server, office assistant): \_\_\_\_\_

7c. In **THE LAST SIX WEEKS**, how many weeks and how many hours per week (on average) did you work?  
 \_\_\_\_\_ hours per week      \_\_\_\_\_ number of weeks

**Thank you for your effort and time in completing this questionnaire. Please ensure this form given to the research staff as soon as possible.**

**APPENDIX E: PLAYER ASSENT FORM**

## Assent Form for Players

**TITLE:** SAFE TO PLAY: A longitudinal research program to establish best practice in the prevention, early diagnosis and treatment of sport-related concussion in youth ice hockey players.

**INVESTIGATORS:** Dr. Carolyn Emery, Dr. Willem Meeuwisse

### What is a research study?

- A research study is a way to learn new information about something. Children 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 concussions, which are a kind of brain injury, and are the most common injury type in youth ice hockey. We are asking you to be in the study because your hockey coach has agreed to let you decide if you want to be in this study or not. About 1000 children will be in this study.

### If you agree to join this study, what will you have to do?

- We will need you to do some tests at the start of each ice hockey season. These will take about 1.5-2 hours total. Some tests will ask you questions about whether or not you think you have had a head injury, others will ask about head injuries and safety, or what kinds of food you eat. Other tests will be on the computer or use a robotic test and some will require you to work with a physiotherapist to evaluate your balance and your neck. With your team, you will also complete an on-ice Hockey Canada Skills Assessment. These tests will allow us to see any changes that happen after a concussion and during recovery.
- If you get a hockey injury while you are playing or practicing, a parent on your team will collect some information about the injury and how it happened. The adult will ask you questions about the injury, such as how it happened or if you went to see a doctor or other medical person for treatment.
- If you, your parent/guardian or coach thinks you might have a concussion, you will be able to see a Sport Medicine doctor who will decide if you have a concussion and what you should do to recover from it fully before going back to playing hockey or other sports. You will then repeat the tests you did at the beginning of the season, along with a questionnaire used for concussion injuries. You will also be asked to get a blood test. You will be monitored until you return to playing hockey, at which time you will again repeat the tests, as well as after 3 months. You will get another blood test after 3 months and after 6 months. If you keep having symptoms of concussion after this, blood will also be drawn 1 and 2 years after your concussion.
- If you get another type of injury from ice hockey that keeps you out for more than a week you will be able to see a physiotherapist or athletic therapist who will tell you what type of injury you have and what you should do to recover from it fully before going back to playing ice hockey or other sports.
- You may be in the study for four years if you choose.

### Will any part of the study hurt?

- The testing done at the start of the season will not hurt. 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. The testing typically does not cause any discomfort but 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.
- If you get a concussion and are asked to go for a blood test, the blood draw might hurt a little bit and you may get a bruise. The nurse doing the test will explain this to you at the time.



## Assent Form for Players

**PROJECT TITLE:** Evaluating the effect of body-checking policy change in youth ice hockey players

**INVESTIGATOR:** Carolyn Emery

### What is a research study?

- A research study is a way to learn new information about something. Children 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 injuries that children get when they play ice hockey with different rules. We are asking you to be in the study because your hockey coach has agreed to let you decide if you want to be in this study or not. About 2000 children will be in this study.

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

- We will be followed in the study for the full 2014/2015 ice hockey season (unless you change your mind).
- We will need you to do a special concussion test at the start of the ice hockey season called a SCAT3 that will last about 15 minutes. This is test that can be done at the hockey arena before a hockey practice. We will test your memory, concentration, balance and coordination by asking you some simple questions and getting you to do some simple tasks. We will also ask you to go through a checklist about how you are feeling when you do the test. Your parent/guardian or coach can be in the room if you want them to be.
- We will ask you to complete two short questionnaires. One is about your experience playing hockey and other sports, and the other is about injuries and body contact in hockey. Your answers will be kept secret.
- If you get a hockey injury while you are playing or practicing, a parent on your team will collect some information about the injury and how it happened. The adult will ask you for some information about the injury, how it happened or if you went to see a doctor or other medical person for treatment.
- If you, your parent/guardian or coach thinks you might have a concussion from ice hockey, you will be able to see a Sport Medicine doctor who will decide if you have a concussion and what you should do to recover from it fully before going back to playing ice hockey or other sports.
- If you get another type of injury from ice hockey that keeps you out for more than a week you will be able to see a physiotherapist or athletic therapist who will tell you what type of injury you have and what you should do to recover from it fully before going back to playing ice hockey or other sports.
- You will do an on-ice skills session with your team during one of your ice times.
- Some hockey games will be video recorded, you may be playing in some of these games, but no one will know it was you.

### Will any part of the study hurt?

- The tests that we do will not hurt. By being part of this study, you will not have a higher chance of getting hurt than if you decide not to be part of this study.

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**Will the study help you or help others?**

- If you do get an injury while playing ice hockey, you will be able to see a Sport Medicine doctor within a week. Sometimes, it can take much longer than that.
- This study might find out things that will help other children who play ice hockey lower their chances of getting hurt by making sure the rules are safe.

**Do your parents know about this study?**

- Your parents will get information about your participation in 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 will be kept safely locked up. Nobody will know it except the people doing the research. The information about you will not be given to your parents, except for the concussion test results if your parents want to know. The researchers will not tell your friends or anyone else.

**What do you get for being in the study?**

- You do not get any money or gifts for being in the study.

**Do you have to be in the study?**

- You do not 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 this 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 talk about it more with your parents if you like. If you start the study and then change your mind, you can decide not to take part anymore, just tell your parents and the researchers.
- There are other ways to help your injury or concussion if you don't want to be in this study. Examples are to not continue to play ice hockey until you see a doctor for their advice and to rest from all activities that might make you feel worse.
- This study is separate from hockey, so if you don't want to take part, nothing else about your ice hockey will change.

**What if you have any questions?**

- You can ask any questions that you may have about the study. If you have questions later, either you can call or have your parents call the people organizing the study, at 403-220-6336 or [hockey@ucalgary.ca](mailto:hockey@ucalgary.ca)

**Assent:**

**Would you like to take part in this study?**

Please put and "x" next to your choice.

\_\_\_\_\_ Yes, I will be in this research study. \_\_\_\_\_ No, I don't want to be in this study.

\_\_\_\_\_  
Child's name (Print)

\_\_\_\_\_  
Signature of the child

\_\_\_\_\_  
Date

\_\_\_\_\_  
Name of Parent or Legal Guardian (Print)

\_\_\_\_\_  
Person obtaining assent – investigator (Print)

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date

Evaluating the effect of body-checking policy change in youth ice hockey players

**APPENDIX F: PARENT CONSENT FORM**

## Consent Form for Parents/Guardians

**TITLE:** SAFE TO PLAY: A longitudinal research program to establish best practice in the prevention, early diagnosis and treatment of sport-related concussion in youth ice hockey players.

**Funding:** Alberta Children's Hospital Research Institute, Canadian Institutes for Health Research, International Olympic Committee

### INVESTIGATORS:

Principal Investigators: Dr. Carolyn Emery, Dr. Willem Meeuwisse

Co-Investigators (University of Calgary): Dr. Brent Hagel, Dr. Sean Dukelow, Dr. Brian Benson, Dr. Brian Brooks, Dr. Karen Barlow, Dr. Tish Doyle-Baker, Dr. Jian Kang, Dr. Chantel Debert, Dr. Steve Scott, Dr. Grant Iverson, Dr. Carly McKay, Dr. Shelina Babul, Dr. Alison Macpherson, Dr. Kathryn Schneider, Dr. Raylene Reimer, Dr. Keith Yates, Tracy Blake (PhD (c)), Kirsten Taylor (MSc student), Amanda Black (PhD student), Paul Eliason (MSc student)

Co-Investigators (University of Alberta): Dr. Martin Mrazik, Dr. Connie Lebrun, Andrea Krol (PhD Student)

*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. For further details about this study, or to have your questions addressed please contact us. Please take the time to read this carefully and to understand any accompanying information. If you choose to participate, please keep your copy of this form and return the study copy (signed and witnessed) to your team designate.*

### BACKGROUND

Concussions are the most common injury type in youth ice hockey. Concussions can lead to long-term side effects including prolonged symptoms (i.e., headache, dizziness, neck pain) and neurocognitive deficits. In addition to neurocognitive changes that may occur with concussion, we will also be looking at other changes to functions in the body that may occur with concussion. These include changes in heart rate and heart rate variability, changes in neck function and balance, neuroendocrine changes, changes in function and skill, and behavioural changes. Understanding how concussion affects these functions in the body both in the short and long-term will help us develop best practice for treatment following concussion as well as prevention strategies.

More than 1000 hockey players are expected to participate in this study, from a number of Alberta Pee Wee and Bantam hockey teams will take part in this research project. We would like to invite your child to participate.

### WHAT IS THE PURPOSE OF THE STUDY?

The purpose of this study is to establish a standard of practice for baseline evaluation (pre-concussion), and longitudinally (post-concussion) measure the nature and extent of concussive injuries using neurocognitive (BASC-2, ImPACT, BRIEF, reaction time, memory, concentration, attention and processing speed), clinical (SCAT3, 4C), robotic (KINARM), autonomic, functional, and neuroendocrine techniques.

### WHAT WOULD MY CHILD HAVE TO DO?

We will be recruiting 80 teams in Calgary from Pee Wee and Bantam hockey and following these players for four consecutive years, as well as continuing to follow those Pee Wee players who participated in the 2013-2014 season. Pre-season assessments will be completed at the Sport medicine Centre, University of Calgary each year (this will take approximately 1.5-2 hrs per team). This will provide a baseline to evaluate changes that may occur following a concussion and throughout recovery.

Before the baseline assessment, there will be an information package sent home that includes a consent form, a preseason medical questionnaire and behavioural questionnaires. On the day of the baseline assessment, each participant will complete the Sport Concussion Assessment Tool (SCAT3), the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT), the Behavior Assessment System for Children (BASC-2), the Behavior Rating Inventory of Executive Function (BRIEF), the Concussion Risk Awareness and Beliefs Questionnaires, the Harvard Food Frequency Questionnaire, KINARM robotic assessment, and physical (neurologic/vestibular) examination with a physiotherapist.

These measures will allow researchers to evaluate changes that occur following concussion, many of which have not been evaluated in this cohort of youth ice hockey players previously. With their team, your child will also complete an on-ice Hockey Canada Skills Assessment, which will give the coaches and players a way to measure skill acquisition and skill improvement.

**During the season:**

During the season, 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 the study sport medicine physician at the Sport Medicine Centre at the University of Calgary within a week following the injury. At this time, your child will also repeat the baseline tests, along with the 4C questionnaire used for concussion injuries. Participants will also be asked to get a blood test to assess serum biomarkers. Blood will be drawn by a trained technician at Calgary Laboratory Services. Athletes will be assessed until return to play; as well as 3 and 6 months following concussion for blood draws. If symptoms persist, blood will also be drawn 1 and 2 years post-concussion.

Your child may also be asked to act as a health control, in the event that one of your child's teammates sustains a concussion. This will involve coming into the Sport Medicine Centre and repeating the baseline tests at the same time as your child's teammate.

If your child sustains an injury that causes your child to miss more than one week of hockey practices and/or games, your child will have the opportunity for follow-up assessment with the study therapist at the Sport Medicine Centre at the University of Calgary.

**ARE THERE ANY BENEFITS FOR MY CHILD?**

If you agree to participate in this study there may or may not be a direct medical benefit to your child. His/her injury risk may be decreased during the study but there is no guarantee that this research will help him/her. If your child experiences a suspected concussion during the study duration, or other type of injury which keeps them from participating in hockey for more than 7 days, the player will be assessed by a study physician (concussion only) or therapist (other injuries) at the Sport Medicine Centre at the University of Calgary with recommendations for follow-up treatment and return to play. The information we get from this study may help us to provide better sport injury prevention in future adolescent sport activities.

**DOES MY CHILD HAVE TO PARTICIPATE?**

Participation in this study is voluntary and you may withdraw your child from the study at any time by contacting the Research Coordinators at 403-220-6336 or hockey@ucalgary.ca. Your child's involvement and registration in the club/team will not be affected if you chose not to consent for your child to take part in the study. Continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your child's participation. You will be informed if there is new information available through this study period.

Please note that you or your child (if over 18 years of age) may be contacted in the future for invitation to participate in other research studies that may relate to any injuries that your child may sustain within the duration of this study.

**WILL THERE BE FINANCIAL COMPENSATION, OR WILL THERE BE COSTS FOR THE PARTICIPANT?**

There will be no financial compensation to the child or costs to the child as a participant in this study.

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

All of the information collected from the survey will be anonymous and will remain strictly confidential. Only the investigators responsible for this study, the research assistants who will be doing the baseline assessments, the statistician who will analyze the data and the University of Calgary, Conjoint Health Research Ethics Board will have access to this information. Confidentiality will be protected by using a study identification number in the database. Any results of the study, which are reported, will in no way identify study participants.

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

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

**SIGNATURES**

If you agree to allow your child to participate, we require you to sign and return this form to your designated team study personnel. Two copies of the form are provided. Please keep one for your records.

Your signature on this form indicates that you have understood to your satisfaction, the information regarding participation in this research project and agree to allow your child participate as a subject. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. Your child is free to withdraw from the study at any time without jeopardizing your health care.

If you have further questions concerning matters related to this research, please contact:

Research coordinators 403-220-6336 or hockey@ucalgary.ca

If you have any questions concerning your rights as a possible participant in this research, please contact the Chair of the Conjoint Health Research Ethics Board, University of Calgary, at 403-220-7990.

\_\_\_\_\_  
Parent/Guardian Signature

\_\_\_\_\_  
Witness Signature

\_\_\_\_\_  
Parent/Guardian Name (Print)

\_\_\_\_\_  
Witness Name (Print)

\_\_\_\_\_  
Date

\_\_\_\_\_  
Date

\_\_\_\_\_  
Child's Name (Print)

**Contact information**

**Office use only**

\_\_\_\_\_  
Parental email address

\_\_\_\_\_  
Investigator/Delegate Signature

\_\_\_\_\_  
Phone

\_\_\_\_\_  
Investigator/Delegate Name (Print)

\_\_\_\_\_  
Date

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

**PLEASE SIGN THIS PAGE AND RETURN THE FULL DOCUMENT TO YOUR  
TEAM DESIGNATE OR STUDY PERSONNEL.**

**\*KEEP THE OTHER COPY FOR YOUR RECORDS\***

## Consent Form for Parents/Guardians

**TITLE:** Evaluating the effect of body-checking policy change in youth ice hockey players

**Funding:** Alberta Innovates Health Solutions CRIO, Alberta Children's Hospital Research Institute, Canadian Institutes for Health Research, International Olympic Committee, Max Bell Foundation

### INVESTIGATORS:

Principal Investigators: Carolyn Emery (University of Calgary)

Co-Investigators: Kathryn Schneider (University of Calgary), Jian Kang (University of Calgary), Willem Meeuwisse (University of Calgary), Brian Brooks (University of Calgary), Keith Yeates (University of Calgary), Shelina Babul (University of British Columbia), Brent Hagel (University of Calgary), Carly McKay (University of Calgary), Alberto Nettel-Aguirre (University of Calgary), Gillian Currie (University of Calgary), Deborah Marshall (University of Calgary), Alison Macpherson (York), Martin Mrazik (University of Alberta), Constance Lebrun (University of Alberta), Don Voaklander (University of Alberta), Claude Goulet (Université Laval), Luc Nadeau (Université Laval)

*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. For further details about this study, or to have your questions addressed please contact us. Please take the time to read this carefully and to understand any accompanying information. If you choose to participate, please keep your copy of this form and return the study copy (signed and witnessed) to your team designate.*

### BACKGROUND

In Canada, sports and recreation participation is the leading cause of injury in children and adolescents. An adolescent sport injury will likely reduce future involvement in physical activity, which may also affect the future health of our population. There is a critical need for research that will lead to injury prevention in adolescent sports and recreation. It is essential to have an understanding of sport specific participation and injury rates, risk factors, and current sport safety practices in adolescents. This will allow researchers to target the appropriate groups of adolescents with specific sport injury prevention strategies.

A number of Calgary and Edmonton hockey teams have agreed to take part in this research project, and your child's team has been randomly selected. We would like to invite your child to participate. More than 1000 hockey players are expected to participate in this study each year over a 3-year period.

### WHAT IS THE PURPOSE OF THE STUDY?

The purpose of this study is to compare the risk of injury among youth ice hockey players who are not exposed body checking, with those in similar divisions with rules that do not permit body checking.

**WHAT WOULD MY CHILD HAVE TO DO?**

In the 2014/2015 hockey season, we will be recruiting 70 teams in Calgary and Edmonton from Bantam level youth hockey. Pre-season assessments will be completed by individuals, or at a team practice after the roster has been set, and ideally before regular season games begin. The assessment will consist of the completion of the Standardized Concussion Assessment Tool Version 3 (SCAT3). This will provide a baseline to evaluate changes that may occur following a concussion and throughout recovery. Baseline assessments will take approximately 15 minutes per player.

Before the baseline assessment, you will receive an information package with this consent form, an assent form, a preseason medical questionnaire, and a questionnaire about body contact and injuries in hockey. The assent form and questionnaires are for the player to complete.

**During the season:**

During the season, if you, your child, the coach, team trainer or other team personnel suspects that your child has sustained a concussion, your child will have the opportunity to follow-up with the study sport medicine physician at the Sport Medicine Centre at the University of Calgary, or at the Glen Sather Sports Medicine Clinic at the University of Alberta in Edmonton within a week following the injury. At this time, your child will also repeat the SCAT3 test. Athletes will remain under the care of the study sport physician until they are cleared to return to play.

If your child sustains any other type of injury (other than a concussion) that causes your child to miss more than one week of hockey practices and/or games, your child will have the opportunity for follow-up assessment with the study therapist at the Sport Medicine Centre at the University of Calgary or at the Glen Sather Sports Medicine Clinic at the University of Alberta. The assessing therapist will complete the Injury Report Form that will be initiated by a team volunteer (Team Designate or Team Trainer) on your child's team and make recommendations as to whether further treatment should be sought.

As part of the study, your child will be participating in a 1.5-hour on-ice skills session. In collaboration with Hockey Canada we are offering the National Skills Testing Protocol, administered by our research team during a team ice time. The time of the session will be coordinated through the team manager/designate and the coaches. Players will receive their individual on-ice assessment results.

In addition, the research team will be video recording a random selection of games throughout the season. It is possible that your child will be a participant in one of the recorded games. All video data will be anonymous, as player numbers will not be linked to team rosters. The purpose of the video data is to examine injury events.

**ARE THERE ANY BENEFITS FOR MY CHILD?**

If you agree to participate in this study there may or may not be a direct medical benefit to your child. If your child has a suspected concussion or other injury lasting more than 7 days, they will receive a direct referral to a study physician or therapist. The information we get from this study may help us to provide better sport injury prevention in future adolescent sport activities.

**DOES MY CHILD HAVE TO PARTICIPATE?**

Participation in this study is voluntary and you may withdraw your child from the study at any time by contacting the research team at 403-220-6336 or hockey@ucalgary.ca. Your child's involvement and registration in the hockey association/team will not be affected if you chose not to consent for your child to take part in the study. Continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your child's participation. You will be informed if there is new information available through this study period.

Please note that you or your child (if over 18 years of age) may be contacted in the future for invitation to participate in other research studies that may relate to any injuries that your child may sustain within the duration of this study.

**WILL THERE BE FINANCIAL COMPENSATION, OR WILL THERE BE COSTS FOR THE PARTICIPANT?**

There will be no financial compensation to the child or costs to the child as a participant in this study.

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

All of the information collected from the study will be anonymized during data entry and will remain strictly confidential. Only the investigators responsible for this study, the research assistants who will be doing the baseline assessments, the statistician who will analyze the data and the University of Calgary, Conjoint Health Research Ethics Board will have access to this information. Confidentiality will be protected by using a study identification number in the database. Any results of the study, which are reported, will in no way identify study participants.

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

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

**SIGNATURES**

If you agree to allow your child to participate, we require you to sign and return this form to your Team Designate (volunteer parent) or Team Trainer. Two copies of the form are provided. Please keep one for your records.

Your signature on this form indicates that you have understood to your satisfaction, the information regarding participation in this research project and agree to allow your child participate as a subject. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. Your child is free to withdraw from the study at any time without jeopardizing your health care.

If you have any questions concerning your rights as a possible participant in this research, please contact the Chair of the Conjoint Health Research Ethics Board, University of Calgary, at 403-220-7990.

_____	_____
Parent/Guardian Signature	Witness Signature
_____	_____
Parent/Guardian Name (Print)	Witness Name (Print)
_____	_____
Date	Date
_____	
Child's Name (Print)	
<b>Contact information</b>	<b>Office use only</b>
_____	_____
Parental email address	Investigator/Delegate Signature
_____	_____
Phone	Investigator/Delegate Name (Print)
	_____
	Date

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

**PLEASE SIGN THIS PAGE AND RETURN THE FULL DOCUMENT TO YOUR TEAM DESIGNATE, TRAINER, OR STUDY PERSONEL.**

**\*KEEP THE OTHER COPY FOR YOUR RECORDS\***