Concussion in Youth Ice Hockey Players:
Approaches to Identification, Assessment and Management

by

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A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy
Graduate Department of Rehabilitation Science
University of Toronto

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Abstract

Despite the numerous benefits of sport participation, involvement in ice hockey can expose youth to an increased risk of injury, including concussions. With over 500,000 youth registered to play hockey in Canada in 2011-2012 and concussion being one of the most common injuries in the sport, many youth are at risk. The combination of symptoms following a concussion can greatly influence one's ability to safely engage in meaningful activities (e.g., sport, school etc.).

Despite the popularity of ice hockey amongst Canadian youth, the risk of concussion within this population and the implications for functional performance, to date, little research has been conducted specific to concussion in youth ice hockey players. This thesis is comprised of three studies and one commentary focused on the identification, assessment and management of concussion in youth ice hockey players. The first study identifies the player and game characteristics associated with head impacts of greater severity and frequency within female youth ice hockey players. The second and third studies respectively assess the influence of concussion on the strength and cognitive performance of youth ice hockey players. These studies use novel approaches to understanding the influence of concussion on the physical and cognitive abilities of youth athletes and act as a foundation to further develop more accurate indices of readiness to return to play following a concussive event. Finally, a commentary on the
use of occupational therapy to assist in the management of concussion and the promotion of improved outcomes both inside and outside of the sport context for youth is presented. Overall, the direction of this research is to minimize concussion-related impairment within youth athletes, more specifically youth ice hockey players, and act as a preliminary evidence base for future study and the development of youth specific post-concussion rehabilitation treatment protocols.
Acknowledgments

"Five players on the floor functioning as one single unit: team, team, team - no one more important that the other."

~ Coach Norman Dale, Hoosiers

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# Table of Contents

Abstract .................................................................................................................................................. ii
Acknowledgments .................................................................................................................................. iv
Table of Contents ................................................................................................................................... vi
List of Tables ......................................................................................................................................... x
List of Figures ....................................................................................................................................... xii
List of Appendices ................................................................................................................................. xiii

Chapter 1: Introduction ............................................................................................................................ 1
  1.1 Problem .......................................................................................................................................... 1
  1.2 Conceptual framework ..................................................................................................................... 5
  1.3 Purpose and objectives .................................................................................................................... 7
  1.4 Thesis organization and relation to conceptual framework ......................................................... 8
  1.5 Relevance ...................................................................................................................................... 11
  1.6 References .................................................................................................................................... 13

Chapter 2: An investigation of the influence of player and game characteristics on head impacts in female youth ice hockey players: A descriptive study ......................................................... 18
  2.1 Abstract ......................................................................................................................................... 18
  2.2 Introduction .................................................................................................................................... 19
  2.3 Methods .......................................................................................................................................... 24
    2.3.1 Participants ................................................................................................................................. 24
    2.3.2 Instrumentation .......................................................................................................................... 25
      2.3.2.1 Sustained head impacts ........................................................................................................ 25
      2.3.2.2 Exposure to head impacts .................................................................................................... 26
    2.3.3 Procedure .................................................................................................................................. 27
    2.3.4 Data analysis .............................................................................................................................. 29
  2.4 Results ............................................................................................................................................ 30
    2.4.1 Factors associated with the severity of head impacts ............................................................... 31
    2.4.2 Factors associated with the number of head impacts .............................................................. 32
  2.5 Discussion ....................................................................................................................................... 33
    2.5.1 Study limitations ....................................................................................................................... 41
  2.6 Conclusion .................................................................................................................................... 42
4.3.3 Outcome measures ........................................................................ 91
  4.3.3.1 Response reaction time ............................................................ 91
  4.3.3.2 Cognitive dual task cost ........................................................... 91
  4.3.3.3 Response errors ......................................................................... 92
4.3.4 Data analysis .................................................................................. 92
4.4 Results ............................................................................................... 93
  4.4.1 Cognitive dual task results ............................................................. 93
  4.4.2 Response error results ................................................................... 94
4.5 Discussion ........................................................................................... 97
  4.5.1 Influence of condition on cognitive performance ............................. 98
  4.5.2 Influence of time since injury on cognitive performance ................. 99
  4.5.3 Study limitations ........................................................................... 100
4.6 Conclusion .......................................................................................... 102
4.7 References .......................................................................................... 103

Chapter 5: Sport-related concussion and occupational therapy: Expanding the scope of practice ........................................................................................................ 107
5.1 Introduction .......................................................................................... 107
5.2 Role of occupational therapy in youth sport-related concussion ............ 108
  5.2.1 Development of client-centred rehabilitation goals ............................ 108
  5.2.2 Energy conservation ....................................................................... 109
  5.2.3 Return to play ............................................................................... 109
  5.2.4 Return to school ............................................................................ 110
  5.2.5 Cognitive function .......................................................................... 113
  5.2.6 Retirement from sport/exploring alternative occupations ................ 114
5.3 Conclusion ........................................................................................... 114
5.4 References .......................................................................................... 115

Chapter 6: Summary and general discussion .................................................. 119
6.1 Introduction .......................................................................................... 119
6.2 Summary of findings ............................................................................. 120
6.3 Contributions ....................................................................................... 123
  6.3.1 Identification ............................................................................... 124
  6.3.2 Assessment ............................................................................... 125
6.3.3 Management ........................................................................................................ 128
6.4 Suggestions for future study .................................................................................. 129
6.5 Concluding remarks .............................................................................................. 131
6.6 References ............................................................................................................ 135
Appendices ................................................................................................................ 138
List of Tables

Table 1.1: Typical post-concussion symptoms ................................................................. 2

Table 2.1: Final multiple regression model of linear acceleration ............................... 34
Table 2.2: Final multiple regression model of rotational acceleration ...................... 35
Table 2.3: Final multiple regression model of HITsp and head impacts ....................... 36
Table 2.4: Final multiple regression model of head impacts per game ...................... 36
Table 2.5: Literature reporting biomechanical head impact characteristics in youth ice hockey players .................................................................................................................. 37
Table 3.1: Participant characteristics at annual baseline ............................................. 54
Table 3.2: Concussed participant characteristics at time of injury ............................. 55
Table 3.3: Administration schedule of outcome measures .......................................... 61
Table 3.4: Post-concussion symptom and strength performance according to assessment session across all participants .............................................................. 63
Table 3.5: Summary of average effects of concussion occurrence on baseline strength performance ........................................................................................................ 64
Table 3.6: Summary average effects of post-concussion stage of recovery (symptomatic and asymptomatic) on strength performance when considering post-concussion symptom severity .......................................................................................................................... 65
Table 4.1: Gradual return to play protocol .................................................................. 81
Table 4.2: Participant characteristics .......................................................................... 86
Table 4.3: Task protocol conditions ............................................................................ 87
Table 4.4: Cognitive performance (cDTC) of concussed participants compared to non-injured controls ................................................................. 95

Table 4.5: Cognitive performance (response errors) of concussed participants compared to non-injured controls ................................................................. 96

Table 5.1: Gradual return to play protocol ........................................................................................................ 111

Table 6.1: Study testing schedule .................................................................................................................. 134
List of Figures

Figure 1.1: Person-Environment-Occupation (PEO) Model. Overlap between person, environment and occupation factors indicates improved occupational performance ............... 6

Figure 2.1: Touch screen data collection interface for time on task computing utility ............ 28

Figure 3.1: Leg maximal voluntary contraction apparatus .................................................. 58

Figure 4.1: Experimental set-up on standard ice hockey rink ............................................. 90

Figure 6.1: Person-Environment-Occupation (PEO) Model. Overlap between person, environment and occupation factors indicates improved occupational performance .......... 120

Figure 6.2: Study design ..................................................................................................... 133
List of Appendices

Appendix A: Ethics approval to collect head impacts data ...................................................... 138

Appendix B: Consent to collect head impacts data ................................................................. 139

Appendix C: Assent to collect head impacts data ................................................................. 147

Appendix D: Form to collect strength performance and post-concussion symptom data ........ 153

Appendix E: Ethics approval to collect strength performance data ....................................... 156

Appendix F: Consent to collect strength performance data .................................................... 157

Appendix G: Assent to collect strength performance data ..................................................... 163

Appendix H: Ethics approval to collect concurrent cognitive and ice hockey skill performance data ................................................................................................................. 166

Appendix I: Consent to collect concurrent cognitive and ice hockey skill performance data .. 167

Appendix J: Assent to collect concurrent cognitive and ice hockey skill performance data .... 172
Chapter 1

1 Introduction

1.1 Problem

In Canada, sport participation is a common activity for many youth. In 2005, 51% of children aged 5 to 14 years regularly participated in sports (Clark, 2008) and it has been estimated that 43% of young adolescents (12 to 15 years) participate in organized sports at least once a week (Sport Canada, 2003). Physical activity, such as sport participation, can result in improved physical and psychosocial health (Strong et al., 2005), and has been reported to help make youth feel better about themselves, make friends, do better in school and be more active with their family (Sport Canada, 2003). Of particular interest to Canadian youth is the sport of ice hockey. Recognized as Canada's national winter sport (Heritage, 2009), ice hockey is played by 11% of all youth (5 to 14 years) who regularly take part in organized sport, third only to soccer and swimming (Clark, 2008). Further, recent registration statistics report that during the 2011-2012 ice hockey season, over 500,000 Canadian youth (under 18 years) were registered to play organized ice hockey (Hockey Canada, 2012), where it can be expected that even more young athletes participate in ice hockey at a recreational level. Based on these statistics alone, sport participation, and more specifically, ice hockey participation, can be viewed as a popular and meaningful activity amongst Canadian youth.

Despite the numerous benefits of sport participation, involvement in sport activity exposes youth to the increased risk of sport injury. It has been reported that in Canada, sport injury is the leading cause of injury in youth (King, Pickett, & King, 1998; Mummery, Spence, Vincenten, & Voaklander, 1998). More specifically, concussion is one of the most common sports injuries reported in children and youth, where a child is six times more likely to suffer a concussion during organized sport participation that during other physical leisure activities (Browne & Lam, 2006). Specific to the sport of ice hockey, concussions have been reported as the most common specific injury amongst youth (Emery & Meeuwisse, 2006). The reported incidence of concussion in youth hockey players ranges from 12% (Gerberich et al., 1987) to 15% (Brust, Leonard, Pheley, & Roberts, 1992) of all injuries. Further, it is
understood that concussion in youth ice hockey is considerably under reported by players and team personnel (Williamson & Goodman, 2006).

Concussion can be defined as “a complex pathophysiologic process affecting the brain, induced by traumatic biomechanical forces” (McCrory et al., 2009, p. 407). Similar to adults, youth can experience a range of neurobehavioural deficits following concussion that can include combinations of somatic symptoms (e.g. headache, nausea, fatigue, dizziness, balance deficits, sensitivity to light/noise etc.), cognitive symptoms (e.g. reduced processing speed, poor attention/concentration, problem solving/planning difficulties, memory deficits etc.), and emotional/behavioural symptoms (e.g. irritability, feeling more emotional, anxiety, depression etc.) (Kirkwood, Yeates, & Wilson, 2006). These symptoms are generally referred to as post-concussion symptoms. Twenty one common symptoms are traditionally assessed following a concussion (Chen, Johnston, Collie, McCrory, & Ptito, 2007; Collins et al., 1999; Lovell & Collins, 1998; Lovell, Collins, Iverson, Johnston, & Bradley, 2004; Piland, Motl, Ferrara, & Peterson, 2003) and are presented within Table 1.1. Functionally, a combination of these post-concussion symptoms can have a great impact on how youth function during daily activities or during activities of importance and meaning (e.g., sport, school, family and social activities etc.).

**Table 1.1: Typical post-concussion symptoms**

<table>
<thead>
<tr>
<th>Symptom Type</th>
<th>Symptom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somatic</td>
<td>headache, nausea, vomiting, balance problems, dizziness, fatigue, drowsiness, numbness or tingling, feeling slowed down, sensitivity to light, sensitivity to noise</td>
</tr>
<tr>
<td>Cognitive</td>
<td>difficulty concentrating, difficulty remembering, feeling mentally foggy</td>
</tr>
<tr>
<td>Emotional/Behavioural</td>
<td>irritability, sadness, nervousness, feeling more emotional, trouble falling asleep, sleeping more than usual, sleeping less than usual</td>
</tr>
</tbody>
</table>

Although it has been suggested that athletes typically recover within one to two weeks following a concussion (Lovell et al., 2003; McCrea et al., 2003), symptoms and related
performance deficits persisting for several weeks to months post-injury have been reported in both adult (Leddy et al., 2010; Willer & Leddy, 2006) and youth (Gagnon, Galli, Friedman, Grilli, & Iverson, 2009) athletes. Furthermore, it is thought that the developing brain of children and youth may be more vulnerable to concussion (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2001; McCrory, Collie, Anderson, & Davis, 2004), resulting in delayed recovery (McCrory et al., 2009) and the potential for persisting functional deficits. Traditionally, the physiology and plasticity of the pediatric brain was thought to limit severity and increase recovery following a brain injury (Browne & Lam, 2006; Kirkwood et al., 2006; Satz, 1993). However, more recent literature has shown that the immature brain is in fact more vulnerable and in turn, at a greater risk for functional deficits following brain injury (Kirkwood et al., 2006; McCrory et al., 2004).

Both animal and human studies of brain injury suggest that the age at which the injury occurs contributes greatly to eventual outcome (Goldstrohm & Arffa, 2005), with the effect of traumatic brain injury in younger children leading to more persistent physical and cognitive deficits than in older children or adolescence (Ewing-Cobbs, Prasad, Kramer, & Landry, 1999). Furthermore, studies of brain maturation suggest that adolescence is a time of dramatic neural reorganization (Hudspeth & Pribram, 1992) and the concept of critical periods related to cognitive development. It is suggested that if an injury to the brain occurs during one of these critical periods, the potential for permanent impairment of the processes responsible for the development of a particular function or skill is high (Freund, Hayter, MacDonald, Neary, & Wiseman-Hakes, 1994). Despite these findings, very little is known about the effects of sustaining a concussion or repeated brain injuries during late childhood/early adolescence.

With respect to the identification of concussion during sport participation, subjective observation by team medical staff or self-reporting by the athlete are often relied upon to relate a head impact to the possibility of sustaining a concussion, where these methods of reporting often leave a number of sustained concussions unnoticed (Duma et al., 2005; Williamson & Goodman, 2006). However, by using telemetric technology via accelerometer sensors implanted into the helmets of hockey players, the magnitude of acceleration and
location of all head impacts sustained during hockey game situations can be objectively detected in order to inform the need for assessment. The effective use of telemetry in order to record sport-related head impacts has been reported (e.g., Broglio et al., 2009; Broglio et al., 2010; Brolinson et al., 2006; Crisco et al., 2010; Duma et al., 2005; Greenwald, Gwin, Chu, & Crisco, 2008; Manoogian, McNeely, Duma, Brolinson, & Greenwald, 2006; Mihalik, Bell, Marshall, & Guskiewicz, 2007; Rowson, Brolinson, Goforth, Dietter, & Duma, 2009; Schnebel, Gwin, Anderson, & Gatlin, 2007). Despite this increased use of telemetric technology to examine sport-related head impacts, limited research has focused specifically on the sport of ice hockey or youth ice hockey players (Mihalik, Guskiewicz, Jeffires, Greenwald, & Marshall, 2008; Mihalik et al., 2010; Reed et al., 2010), and no studies have examined the head impacts sustained by female youth ice hockey players. This information can help to inform the risks associated with sustaining head impacts of higher frequency and severity during ice hockey competition, some of which may lead to concussion.

With regards to the assessment and management of sport-related concussion, a variety of guidelines currently exist (Aubry et al., 2002; Kirkwood et al., 2006; McCrory et al., 2005; McCrory et al., 2009). Alarmingly, of the numerous concussion management guidelines currently available, none are based upon sport-related concussion research specific to the pediatric population. This gap in appropriate management protocols for children puts many youth participating in ice hockey and other sports at risk for exacerbating their symptoms following premature return to activity, and significant long-term effects after sustaining a second or third head impact following return-to-play while still symptomatic (Collins et al., 2002; Gaetz, Goodman, & Weinberg, 2000; Iverson, Gaetz, Lovell, & Collins, 2004). As a result, the development of evidence-based and age-appropriate sport-related concussion management and rehabilitation protocols is needed. Research specific to how youth recover across domains (e.g., physical and cognitive) and the use of novel approaches to most appropriately assess and manage performance deficiencies (which if ignored may put youth athletes at risk for repeated injury and poorer outcomes) is paramount.

A conceptual framework, the Person-Environment-Occupation (PEO) Model (Law et al., 1996) (see Figure 1.1) was used to guide inquiry throughout this thesis. This framework was
selected in order to identify previously unexplored gaps in research specific to sport-related concussion in youth ice hockey players and to do so while considering the influence of a variety of factors (person, environment and occupation) on the ability of youth ice hockey players to engage in activities that provide meaning and importance in their lives. This approach to inquiry is used in order to explore concussion in youth ice hockey players from a perspective that extends outside of the individual, and related cognitive or physical deficits, and considers the influence of what these youth athletes need or want to do in their lives, along with the environmental context in which they live and compete. By using the PEO Model (Law et al., 1996) to guide the studies presented within this thesis, it is hoped that the consideration of one’s abilities, the activities one engages in and the environment in which these activities take place, can lead to a broader understanding of concussion in youth ice hockey players and in turn, improved identification, assessment and management of this injury. The PEO Model (Law et al., 1996) is explained in greater detail, along with its relation to the individual studies that make up this thesis, in the remaining sections of this chapter.

1.2 Conceptual framework

The PEO Model (Law et al., 1996) (see Figure 1.1) was used as a conceptual framework to guide the inquiry undertaken within this research. The PEO Model is a traditional occupational therapy model that posits that that an individual’s ability to perform an occupation (e.g., a task or activity of meaning and importance) is influenced by the relationship (or fit) between factors specific to the person, the environment and the occupation. Person factors represent an individual’s attributes related to self-concept, personality, cultural background and personal competencies including skills and abilities related to motor and cognitive performance (Law et al., 1996). It is these skills and abilities that individuals utilize in order to perform the occupations that make up their lives. Environment factors represent the cultural, socio-economic, institutional, social and physical aspects of the context within which an occupation is performed, where the environment in which an occupation is performed can have great influence on its performance (Law et al., 1996). Finally, occupation factors represent the functional tasks and activities that an individual has to, needs to or wants to engage in as a means to meet their needs (Law et al.,
According this model, the outcome of the relationship between person, environment and occupation factors is deemed *occupational performance* or the “experience of a person engaged in purposeful activities and tasks within an environment” (Law et al., 1996, p. 16).

The overarching assumption of the PEO Model is that the level at which an individual is able to perform important and meaningful activities in life is dependant upon the interaction between personal, environmental and occupational factors, where optimal performance is a result of how harmoniously each factor fits with the other. Just as this model speaks to the importance of considering multiple factors when exploring occupational performance, this same framework can be used to guide a comprehensive approach to exploring the identification, assessment and management of health-related conditions, such as concussion in youth, and can contribute to a broader understanding of all associated factors. Using the PEO Model as a conceptual framework to guide inquiry, this thesis aims to address a range of phenomena specific to concussion in youth ice hockey players from the perspective that many factors can contribute to this injury, along with its identification, assessment and management. Due to the paucity of research specific to the exploration of concussion in youth athletes, the use of the PEO Model as a guiding conceptual framework allows for the broad exploration of this injury within this population with the hope of generating a comprehensive starting point for further research and improved clinical care and outcomes for youth following concussion.

![Figure 1.1: Person-Environment-Occupation (PEO) Model. Overlap between person, environment and occupation factors indicates improved occupational performance (modified from Law et al., 1996).](image-url)
1.3 Purpose and objectives

Participation in the sport of ice hockey is an occupation of great meaning and importance to many Canadian youth. Despite the numerous benefits, involvement in sport activity such as ice hockey exposes youth to the increased risk of injury, including concussion. Despite growing public interest in sport-related concussion, including its associated symptoms and related functional deficits, there is an absence of knowledge specific to concussion in youth athletes. According to the most recent international consensus statement on concussion in sport (McCrory et al., 2009), there is a need for further study specific to youth concussion and management paradigms. This dissertation begins to address this need. This research uses the PEO Model (Law et al., 1996) as a guide to consider a variety of factors when exploring concussion in youth ice hockey players. Person factors (related to being female, body size or having declined strength abilities), environment factors (related to the type of ice hockey game played, time spent in active ice hockey participation or the multiple cognitive and motor demands inherent to ice hockey contexts), and occupation factors (related to participating in the sport of ice hockey and all related tasks and activities) all have the potential to contribute to our understanding how to best identify, assess and manage concussion in youth ice hockey players, and to date, have not been explored. Overall, the direction of this research is to use the PEO Model (Law et al., 1996) to minimize concussion-related impairments within the youth ice hockey player population and initiate a preliminary evidence-base for future youth sport-related concussion studies and rehabilitation treatment protocols.

The objectives of this research, based on the need to explore concussion in youth ice hockey players while considering the influence of person, environment and occupation factors, are:

1. To describe the number and biomechanical characteristics of head impacts sustained by female youth ice hockey players
2. To explore the influence of player and game characteristics on head impacts sustained by female youth ice hockey players
3. To explore the effect of baseline strength performance on future concussion occurrence, as well as the influence of concussion occurrence on post-injury strength performance, in male and female youth ice hockey players

4. To explore the effect of concussion on cognitive performance in male youth ice hockey players when completing concurrent ice hockey specific skills

5. To describe the use of occupational therapy as an approach to providing clinical care following sport-related concussion

1.4 Thesis organization and relation to conceptual framework

This thesis has been compiled in manuscript format. In addition to this introductory chapter, this thesis is comprised of six chapters. Preceding each chapter is a brief summary of the chapter's contents, a description of the chapter's relation to the conceptual framework used to guide the approach to inquiry (presented in Figure 1.1), as well as a statement highlighting the chapter's current stage of publication.

Chapter 2, entitled 'An investigation of the influence of player and game characteristics on head impacts in female youth ice hockey players: A descriptive study', presents, for the first time, a description of the head impacts sustained during female youth ice hockey competition. This study satisfies objectives 1) to describe the number and biomechanical characteristics of head impacts sustained by female youth ice hockey players, and 2) to explore the influence of player and game characteristics on head impacts sustained by female youth ice hockey players, of this thesis. As forces applied to the head are the prominent cause of concussion (McCrory et al., 2009), exploring the prevalence and nature of head impacts sustained by youth ice hockey players can help inform a greater understanding of what factors may lead to concussion within the youth population. Previous study has explored the head impacts sustained by male youth ice hockey players (Cubos et al., 2009; Mihalik et al., 2008; Mihalik et al., 2010; Mihalik at al., 2012; Reed et al., 2011), however despite reports that rates of concussion amongst female ice hockey players are higher than males (Agel and Harvey, 2010), prior to this dissertation, the head impacts sustained by
female youth ice hockey players had yet to be explored. According to the PEO Model used as a conceptual framework to guide inquiry, this chapter explores the identification of the head impacts sustained amongst female youth ice hockey players through the consideration of person factors (e.g., player position, body size), environment factors (e.g., the context of female youth ice hockey, how much time players are on the ice in a given game) and occupation factors (e.g., engaging in ice hockey participation). It is possible that a variety of factors related to the person, environment and occupation may influence the frequency and severity of head impacts sustained by youth ice hockey players. Considering each of these factors can contribute to a broader understanding of this phenomenon in this population.

Chapter 3, entitled 'Concussion and strength performance in youth ice hockey players', describes a three-year longitudinal investigation of pre- and post-concussion strength performance amongst male and female youth ice hockey players. This chapter addresses this thesis' third objective, to explore both the effect of baseline strength performance on future concussion occurrence, as well as the influence of concussion occurrence on post-concussion strength performance, in male and female youth ice hockey players, and contributes to addressing the need for focused investigation specific to the assessment of abilities following concussion. To date, strength deficits following sport-related concussion have not been explored, however if present, these deficits could have significant functional implications for youth ice hockey players. Following the PEO Model, the strength of a youth ice hockey player can be considered a person factor, where if deficient as a result of a concussion, can obstruct the fit between person, environment and occupation factors (e.g., no longer having the strength required to skate quickly enough to avoid contact from an opponent within the competitive ice hockey environment) and result in impaired occupational performance (e.g., hockey playing ability). It is possible that if a youth ice hockey player is no longer able to play ice hockey at their optimal level, this deficient occupational performance could put them at risk for further injury, including concussion. The assessment of strength performance in youth ice hockey players explored within this chapter could allow for the ability to ensure that the person factors of a youth athlete are intact and that the ability to perform the tasks required of them during ice hockey participation are optimal.
Chapter 4, entitled 'Concussion and concurrent cognitive and sport-specific performance in youth ice hockey players: A pilot study', presents the preliminary use of a novel, sport-specific assessment protocol to compare the cognitive performance of concussed male youth ice hockey players to that of a non-injured control group during the concurrent completion of a visual interference task and combinations of ice hockey skills. This chapter addresses the fourth objective of this thesis, to explore the effect of concussion on cognitive performance in male youth ice hockey players when completing concurrent ice hockey specific skills, with a larger aim of working towards the provision of a more accurate index of readiness to return to play following concussion. Like Chapter 3, this chapter contributes to addressing the need for inquiry specific to the assessment of performance following concussion. The approach to assessment of functional performance following concussion explored within this chapter is novel and described for the first time in relation to youth ice hockey players following concussion. Much like the assessment of strength performance described in Chapter 3, using the PEO Model as a conceptual guide, the approach to assessment described in Chapter 4 of this thesis is unique as it incorporates factors from the person, environment and occupation in order to better inform return to play decisions following concussion. Exploring how youth ice hockey players perform ice hockey specific skills within an ice hockey specific environment provides the opportunity to work towards the provision of a more accurate index of how youth ice hockey players can perform the occupation of playing ice hockey following a concussion and in turn, can promote improved outcomes within this population.

Chapter 5 provides a commentary on the inclusion of occupational therapy, a rehabilitation profession that traditionally is not involved in the management of post-concussion care specific to athletes, as a method to improve post-concussion care and to promote successful return to activities of importance and meaning. Entitled 'Sport-related concussion and occupational therapy: Expanding the scope of practice', this chapter addresses the fifth and final objective of this thesis, to describe the role of occupational therapy in providing clinical care following sport-related concussion, and attempts to satisfy the need for improved information on the management of concussion in youth athletes. The approach to concussion management presented within this chapter is consistent with this dissertation’s conceptual framework, where the consideration of the relationship between person, environment and
occupation factors are paramount in enabling improved occupational performance inside and outside of the sport context for youth athletes following concussion.

Chapter 6 acts as the concluding chapter of this thesis and provides a summary of this research's findings, discussion specific to the contributions and implications of this work, suggestions for future study, as well as closing remarks.

### 1.5 Relevance

The research included within this thesis was designed in order to be relevant to three primary groups: 1) sport concussion researchers; 2) clinicians who include the management of concussion in youth within their practice; and, 3) the youth ice hockey community. Due to the paucity of information specific to concussion in youth athletes and in response to the international recommendations for further study of pediatric concussion injury and management protocols (McCrory et al., 2009), it is hoped that the findings of this research can ignite further interest and exploration of research questions specific to youth amongst concussion researchers across the world. The replication of the methods employed within the work presented in this thesis, along with the use of these methods as starting points for related exploration, will contribute to a greater understanding of concussion in youth athletes and can act as a foundation to inform improved clinical care and management protocols.

Although preliminary, the findings of this research can be used to provide clinicians who are involved in providing post-concussion treatment to youth athletes with additional guidance during the delivery of care. In today's health care system, the use of evidence-based practice is paramount (Rosenberg & Sackett, 1996). Rather than base clinical opinions and decisions on evidence generated in adult athlete populations, the information presented within this thesis can be viewed as providing an initial step towards providing clinicians with evidence specific to how the youth brain responds to concussion and what practices are most appropriate to promote improved outcomes during the recovery stages.

Finally, this research is relevant to those who make up the youth ice hockey community. From youth ice hockey organizations and associations, to coaches and team personnel, to
parents and players, the information presented within this thesis is designed to provide those directly affected by ice hockey-related concussion with additional insight into the risks associated with head impacts, what domains of function are influenced, what measures are most appropriate to use when assessing these domains of function and how can this injury be managed in order to promote improved outcomes for youth both inside and outside of the sport context.

Overall, it is hoped that the generation of the knowledge presented within this thesis can provide all involved in sport-related concussion (e.g., researchers, clinicians, youth ice hockey community) with additional resources that can be used to make informed decisions related to sport participation, recovery and injury management following a concussion and that outcomes for youth athletes following this injury can be improved.
1.6 References


Chapter 2

2 An investigation of the influence of player and game characteristics on head impacts in female youth ice hockey players: A descriptive study

This chapter presents a description of the biomechanical characteristics of the head impacts sustained during female youth ice hockey competition, along with the exploration of the influence of both player and game characteristics on these impacts. This chapter aims to address the need for improved identification of concussion in youth athletes by way of exploring the impacts that lead could lead to this injury from a person (female gender, playing position), environment (game type, time spent on ice) and occupation (female youth ice hockey participation) factor perspective. This chapter will be prepared for submission to the International Journal of Sports Medicine. This journal provides a forum for dissemination of basic and applied information specific to sports medicine and exercise science, including topics related to biomechanics and testing.

2.1 Abstract

Introduction: Despite the growing popularity of ice hockey amongst female youth and interest in the biomechanical mechanisms of head impacts in sport, the head impacts sustained by female youth ice hockey players have yet to be characterized. The purpose of this study was to: 1) describe the number and biomechanical characteristics of and exposure to head impacts in female youth ice hockey players during competition; and, 2) explore the influence of and interaction between player and game characteristics on head impacts.

Methods: Twenty seven female youth ice hockey players (age: 12.5 ± 0.52 years) wore instrumented ice hockey helmets from which biomechanical measures of head impacts were computed across 66 ice hockey games. Data specific to player, game and biomechanical head impact characteristics were recorded. Multiple regression was used to determine the factors most associated with head impacts of greater severity and frequency. Results: A four-way interaction revealed that in older players who had a greater BMI and spent more
time in active hockey participation (time on ice), playing the forward position significantly predicted greater linear acceleration of head impacts (Estimate = 1.00; SE = 1.00; \( t = 2.80; P = 0.008 \)). A three-way interaction revealed that in older players who had a greater BMI, playing the forward position significantly predicted greater rotational acceleration of head impacts (Estimate = 26.01; SE = 2.82; \( t = 3.03; P = 0.008 \)). A two-way interaction revealed that during tournament games, increased ice time significantly predicted increased severity of head impacts (Estimate = 0.004; SE = 0.002; \( t = 2.28; P = 0.03 \)). A main effect revealed that having a higher BMI significantly predicted a higher number of head impacts sustained per game (Estimate = 0.90; SE = 1.04; \( t = -2.73; P = 0.008 \)). **Conclusion:** This study presents for the first time a description of the biomechanical characteristics of head impacts occurring during youth female ice hockey competition, along with the influence of player and game characteristics on these impacts.

### 2.2 Introduction

Inherent to the sport of ice hockey is the potential for head impacts. High rates of speed combined with a variety of obstacles and hard surfaces (e.g. other players, ice, boards, etc.) increase the likelihood of collisions and contact to both the body and head. According to the most recent International Consensus Statement on Concussion in Sport (McCrory et al., 2009), a concussion is caused by a direct blow to the head or elsewhere on the body where an impulsive force is transmitted to the head. Of late, the issue of sport-related concussion has been a topic of great interest and study in adults and more recently in youth. However, to date there exists a paucity of research that specifically examines head impacts or concussion sustained in youth female ice hockey players. In order to further understand the phenomenon of concussion within this population, it is helpful to first gain a greater understanding of the number and nature of head impacts sustained by female youth ice hockey players and the related risk factors for these impacts.

In North America, the popularity of ice hockey amongst female youth has grown exponentially. In Canada, over 500,000 youth (under 18 years) were registered to play minor ice hockey during the 2009-2010 ice hockey season, with close to 70,000 of these registrants being females (Hockey Canada, 2011). In the United States, the number of registered youth
female players has grown from 5,068 in 1990-1991 to 48,781 in 2010-2011 (USA Hockey, 2012.). Although much the same as male ice hockey with regards to rules of play, a significant difference in female ice hockey is that intentional body checking is prohibited at all levels of play. Despite this, collisions do occur and have been reported to account for 50% of all injuries (Agel, Dick, Nelson, Marshall, & Dompier, 2007). Research examining differences in injury rates between male (body checking permitted) and female (no body checking permitted) collegiate ice hockey players found that injury rates between genders did not differ significantly (Schick & Meeuwisse, 2003) and that rates of concussion were higher in females (Agel & Harvey, 2010). Despite the lack of intentional body checking, injuries and concussions remain a significant part of female ice hockey participation, indicating that impacts to the body and head are taking place.

Much research exploring head impact biomechanics during sport participation uses the Head Impact Telemetry (HIT) System (Simbex; Lebanon, NH). The HIT System equips commercially available sport helmets with accelerometers designed to measure the number and biomechanical characteristics of head impacts sustained during sport participation. Although the majority of this research has examined head impacts in high school and collegiate male football (Broglio et al., 2009; Broglio et al., 2010; Brolinson et al., 2006; Crisco et al., 2010; Duma et al., 2005; Greenwald, Gwin, Chu, & Crisco, 2008; Mihalik, Bell, Marshall, & Guskwewicz, 2007; Rowson, Brolinson, Goforth, Dietter, & Duma, 2009; Schnebel, Gwin, Anderson, & Gatlin, 2007) this technology has been used to report head impacts sustained in male youth ice hockey players participating in leagues where intentional body checking is permitted (Cubos et al., 2009; Mihalik, Guskwewicz, Jeffires, Greenwald, & Marshall, 2008; Mihalik et al., 2010; Mihalik et al., 2012; Reed et al., 2010). These studies report the characteristics of head impacts sustained in male youth ice hockey players specific to the number of impacts (Cubos et al., 2009; Mihalik et al., 2008; Mihalik et al., 2010; Mihalik et al., 2012; Reed et al., 2010) and the severity of impacts, including linear acceleration (Cubos et al., 2009; Mihalik et al., 2008; Mihalik et al., 2010; Mihalik et al., 2012; Reed et al., 2010), rotational acceleration (Mihalik et al., 2010; Mihalik et al., 2012; Reed et al., 2010) and measures of injury tolerance (Gadd Severity Index [GSI] and Head Injury Criterion [HIC], Reed et al., 2010; Head Impact Technology Severity Profile [HITsp],
Mihalik et al., 2010; Mihalik et al., 2012), along with the influence of exposure to injury (time on ice, Cubos et al., 2009), event type (Mihalik et al., 2008; Mihalik et al., 2012; Reed et al., 2010), player position (Mihalik et al., 2008; Mihalik et al., 2012; Reed et al., 2010) and both body collision type and level of collision anticipation (Mihalik et al., 2010) on these impacts. Despite the rise in popularity of female ice hockey and the growing interest in the biomechanical characteristics of head impacts sustained during youth ice hockey participation, the head impacts sustained by female youth ice hockey players have yet to be explored.

The severity and frequency of head impacts sustained during ice hockey participation are likely influenced by some combination of several factors. Of these factors, it is possible that characteristics specific to the player, such as time spent in active hockey participation, position played, age and body size, may play a role.

Cubos et al. (2009) used a time-on-task computing utility to track active ice hockey participation in male youth ice hockey players and correlated this information with head impact characteristics. Total time on ice (in seconds) was correlated with head impact frequency and force within 13 male youth ice hockey players across 17 ice hockey games. Although no relationship between time on ice and head impacts (frequency or severity) was found within this single male youth ice hockey team, the ability to provide a more accurate measure of exposure to head impacts that is specific to each athlete’s level of active ice hockey participation warrants further use of this tool. The use of the same time-on-task computing utility within the present study will provide, for the first time, the opportunity to explore the influence of each individual player’s exposure (time on ice) to head impacts on the nature of head impacts sustained in female youth ice hockey players.

In the sport of ice hockey, playing position can dictate specific roles and responsibilities performed by the player during competition. Forward position players tend to play closer to their opponent’s goal and are generally responsible for offensive play and goal scoring, while defense position players tend to play closer to their own goal and are generally responsible for preventing their opponents from scoring. It is possible that the roles and responsibilities
inherent to player positions may influence the head impacts sustained. When examining head impacts sustained by male youth ice hockey players, Reed et al. (2010) found that forwards playing the wing position sustained significantly more head impacts than forwards playing the centre position and defensive players, suggesting that increased play in the offensive zone along the boards and in the corners inherent to the forward wing position may have influenced this finding. A similar relationship between player position and head impacts in female youth hockey players has yet to be explored.

When considering age, it seems intuitive that with increased age comes increased size, speed and strength, where these characteristics may result in head impacts of greater number and severity. When comparing the head impacts sustained in high school and collegiate football players, the older college-aged athletes demonstrated more impacts and impacts of higher accelerations (Schnebel et al., 2007). To date, a similar comparison of head impacts in ice hockey according to age has yet to occur, however it has been suggested that increased age of youth ice hockey players leads to a greater risk for injury (Emery & Meeuwisse, 2006; Wattie et al., 2007; Wattie et al., 2010). Related, it has been suggested that significant body size differences can exist among youth participating in sports (Wattie et al., 2007) and that variability in physical size may result in increased injury among youth ice hockey players (Brust, Leonard, Pheley, & Roberts, 1992; Wattie et al., 2010). Specific to concussion, Schulz et al. (2004) found that lower body mass index (BMI) in 15,802 male and female youth athletes predicted an increased risk of concussion. Despite the large sample, no ice hockey players were included. Although not all head impacts will result in injury, it is possible that similar influences of age and body size on the head impacts sustained by youth ice hockey players exist. To date, only one study has directly examined the influence of body size (height, weight and BMI) on head impact characteristics in youth ice hockey players (Reed et al., 2010). Here, it was found that there was no influence of body size on the head impacts sustained by a single male youth ice hockey team. It was suggested that this finding may have been a result of the lack of variability in body size across study participants and that this lack of variability may have been due to a small sample size (N = 13) and a limited range in participant chronological age (all participants were born in the same year and 10 of 13 participants were born within six months of each other). It is likely
that this male youth ice hockey team was not representative of all youth hockey teams, where in general, adolescence can be considered a time of dramatic physical variability and the potential for body size differences among youth participating in sports is significant (Wattie et al., 2007). Specific to female ice hockey players, many leagues have players born in two consecutive calendar years compete with and against each other within a single age category. This participation structure may contribute to greater variance in age, and in turn body size, warranting further exploration of the influence of age and body size on the head impacts sustained specific to the female youth ice hockey population.

In addition to player characteristics, the severity and frequency of head impacts sustained by youth hockey players may be influenced by the type of ice hockey game being played. Typically, youth ice hockey games can be recognized as regular season, tournament or playoff games. It has been reported that tournament game play resulted in an injury rate 4-6 times higher than regular season game play for male youth ice hockey players, where 15% of all injuries were concussion (Roberts, Brust, & Leonard, 1999). Further, it was found that tournament game play lead to significantly higher numbers of head impacts per game in male youth ice hockey players (Reed et al., 2010). Much like their male counterparts, perhaps the type of ice hockey game played dictates more competitive or aggressive play in female youth ice hockey players, where head impacts of increased severity and frequency may result.

Previous study examining head impacts in youth ice hockey competition have examined the influence of a variety of player and game characteristics on head impacts sustained. As it is possible that the severity and number of head impacts sustained during ice hockey participation may be influenced by a combination of several factors, this study aims to build off the main effects presented in previous studies and further explore the interaction between a variety of factors related to youth ice hockey players and the sport of ice hockey. Further, this study aims to, for the first time, explore the head impacts sustained in female youth ice hockey players.

The purpose of this study was to: 1) describe the number and biomechanical characteristics (linear acceleration, rotational acceleration, HITsp) of head impacts, as well as exposure to
head impacts (time on ice) in female youth ice hockey players during competition; and, 2) explore the influence of and interaction between player characteristics (age, playing position, BMI and time on ice per game) and game characteristics (game type: regular season, playoff and tournament games) on head impacts. It is anticipated that understanding the influence of these variables on sustained head impacts will lead to further research and a greater awareness of the factors associated with increased risk of head impacts in female youth ice hockey.

2.3 Methods

2.3.1 Participants

A convenience sample of 27 female youth ice hockey players (age = 12.5 ± 0.52 years; height = 156.5 ± 8.9 cm; weight = 49.0 ± 9.8 kg; BMI = 19.8 ± 2.69 kg/m\(^2\)) across three different representative level ice hockey teams from the Ontario Women’s Ice hockey Association (OWHA) was recruited. Each participating team was followed for one ice hockey season across a three year period. Within the OWHA, female youth representative ice hockey teams participate in different age categories and at different levels of competition. Age categories are comprised of two age cohorts within each category (i.e., Peewee contains 11 and 12 year olds). From least competitive to most competitive, the levels of competition are C, B, BB, A and AA. This study aimed to exclude female youth ice hockey players who did not play representative level ice hockey (e.g. houseleague, select) and who played at either the lowest (C) or highest (AA) levels of competition in order to provide a more accurate representation of the typical female youth ice hockey player. Participant female youth ice hockey players played on either one of two Peewee-aged (11-12 years) A teams (20 players) or one Bantam-aged (13-14 years) BB team (7 players). Of the 27 female youth hockey players, 10 played the defense position and 17 played the forward position. As no instrumented goalie helmets were used, players who played the goalie position were also excluded from the study. Three participants played on more than one of the study’s participating hockey teams. In order to avoid additional influence of individual playing style on potential exposure to head impacts and related biomechanical characteristics on the full
dataset, only data collected from the first ice hockey season enrolled in the study were used for these players.

2.3.2 Instrumentation

2.3.2.1 Sustained head impacts

Sustained head impact data were collected using the HIT system (Simbex; Lebanon, NH). The HIT system equips commercially available approved Easton Stealth S9 ice hockey helmets (Easton-Bell Sports; Van Nuys, CA) with accelerometers designed to continuously measure head impact accelerations during ice hockey participation. The helmet units were approved by the American Standards for Testing and Materials (ASTM) and Canadian Safety Association (CSA). Each helmet unit consisted of six spring-loaded accelerometers embedded into the foam liner of the helmet in order to keep constant contact with the head to ensure accelerations of the head, rather than the helmet, were recorded (Brolinson et al., 2006). The helmet unit also contained a removable battery pack, a wireless transceiver (903-927 MHz) and an onboard memory and data acquisition capabilities (8 bit; 100 Hz/channel) (Duma et al., 2005). For all head impacts with an acceleration greater than 10 g, data was collected for 40 ms (8 ms pre-trigger and 32 ms post-trigger) to ensure the capture of a complete waveform (Brolinson et al., 2006; Schnebel et al., 2007). Head impact biomechanical measures were recorded in real-time, where data was time stamped and wirelessly transmitted through a radiofrequency telemetry link to an off-ice laptop computer. The HIT system is capable of recording the number of sustained head impacts for a full ice hockey team during ice hockey competition. Through the use of a novel algorithm, information specific to impact location and severity (linear acceleration, rotational acceleration, HIC, GSI and HITsp) can be generated. A more complete description of the HIT system and related algorithms (Crisco, Chu, & Greenwald, 2004; Duma et al., 2005) along with its use to measure head impacts sustained during youth contact ice hockey (Mihalik et al., 2008; Mihalik et al., 2010; Mihalik et al., 2012; Reed et al., 2010) can be found elsewhere.

The variables of interest within the present study specific to sustained head impacts collected using the HIT system were: (1) the number of head impacts sustained by each participant
during each ice hockey game played; and (2) impact severity, as measured by linear acceleration, rotational acceleration and HITsp. Within this study, linear acceleration refers to the velocity of the estimated centre of gravity of the head resulting from an impact and is measured in g, while rotational acceleration refers to the angular velocity of the head in a given direction following an impact with the estimated centre of gravity of the head acting as the origin and is measured in rad/s². HITsp can be considered a measure of head impact injury tolerance used to better predict the incidence of concussion (Greenwald et al., 2008). HITsp was created using Principal Component Analysis (Jolliffe, 2002) in order to transform correlated biomechanical measures of linear acceleration, rotational acceleration, impact location and more traditional measures of head impact injury tolerance, being HIC (Versace, 1971) and GSI (Gadd, 1966), that are more specific to skull fracture and more severe brain injury, into a new uncorrelated composite variable as a means to generate a biomechanical measure most sensitive to the prediction of concussion (Greenwald et al., 2008). Principal Component Analysis yielded the following equation, where sX = (X-mean(X))/(SD(X), LIN = linear acceleration, ROT = rotational acceleration, HIC = head injury criteria, GSI = Gadd severity index and the offset by 2 and scaling by 10 generated a principal component score greater than zero and within the numerical range of the other classic biomechanical measures included in the equation (Greenwald et al., 2008):

\[
\text{HITsp} = 10 \cdot ((0.478 \cdot s_{\text{GSI}} + 0.4742 \cdot s_{\text{HIC}} + 0.4336 \cdot s_{\text{LIN}} + 0.2164 \cdot s_{\text{ROT}}) + 2)
\]  

(1)

In a study examining the biomechanical characteristics of 289,916 head impacts sustained during college and high school football participation, this composite variable was found to be more predictive of concussion compared to linear acceleration, rotational acceleration, HIC and GSI alone (Greenwald et al., 2008). Due to its incorporation of multiple biomechanical head impact variables of injury tolerance (HIC and GSI) and its relevance to concussion, HITsp was used as the sole measure of injury tolerance within the present study.

2.3.2.2 Exposure to head impacts

Data specific to time on ice during ice hockey competition were collected using a computing utility designed to measure time-on-task when examining injury in sport participation
(Montelpare, Baker, Faught, et al., 2007). This computing utility is a stand alone personal computer program that is based on an integration of a web-server application and the scripting features of JavaScript and Perl (Montelpare, Baker, Faught, et al., 2007). Using a touchscreen tablet computer and a start/stop mechanism, this utility allows one to record in real time when each player of a given sports team is involved actively (e.g. on the ice) versus not involved actively (e.g. on the bench) during sport competition. Figure 2.1 illustrates the data collection interface of this time-on-task computing utility. Time on ice data has been collected using this computing program for male atom aged (Montelpare, Baker, Corey, et al., 2007) and male bantam aged (Cubos et al., 2009) youth ice hockey players. For the purposes of the present study, this time-on-task computing utility was used to calculate the total exposure time (time on ice) per game for each participant.

2.3.3 Procedure

Data were collected during the 2008-2009 ice hockey season (January, 18, 2009 to April 10, 2009), the 2009-2010 ice hockey season (November 27, 2009 to April 2, 2010), and the 2010-2011 ice hockey season (October 31, 2010 to April 15, 2011). In total, data specific to time on ice, along with the severity and frequency of head impacts was collected from 27 female youth ice hockey players at 66 ice hockey games (29 regular season, 18 playoff and 19 tournament games). Start and end times for each ice hockey game and individual periods were recorded by the study’s investigators in order to exclude any head impacts occurring outside of ice hockey game play (e.g. before or after the game, between periods) from the data analysis.
As the study investigators were most interested in the characteristics of head impacts sustained during youth female ice hockey competition, real-time head impact data were collected only during game play and not during team practices. Specific to ice hockey, it has been reported that concussions are more likely to occur during game play than during practice (Honey, 1998; Stuart, Smith, Nieva, & Rock, 1995) and when measuring head impacts in youth ice hockey players, a greater number and greater average acceleration of impacts have been found during game play compared to practices (Mihalik et al., 2008; Mihalik et al., 2012).

In order to explore the influence of player characteristics on head impacts sustained during ice hockey competition, time on ice, playing position (forward and defense), age, height, weight and BMI (a measure of an individual’s body mass divided by the square of their height) were recorded. Using the time-on-task computing utility, study investigators
collected exposure data at all ice hockey games by clicking the corresponding ‘start’ button on the program’s interface using a touchscreen enabled pen each time a given participant stepped on the ice during game play. The ‘stop’ button was clicked when the participant stepped off the ice or when play was stopped following a whistle. These data were collected in order to obtain a more accurate representation of head impact exposure and to determine the influence of active hockey participation on the severity and frequency of recorded head impacts. The purpose of recording playing position was to explore the influence that the roles and responsibilities inherent to player positions may have on the head impacts sustained during competition. As the participant sample included an age range from 11.3 to 14.2 years, age was included within the analyses in order to explore the effect of being at the lower or upper limits of this age range on head impact characteristics. Height, weight and BMI were recorded to explore the potential influence of body size on the characteristics of head impacts sustained during ice hockey competition. Further, all ice hockey games were coded according to game type as regular season, playoff or tournament games to allow for influence of game type on head impacts sustained to be explored.

Due to comfort issues and personal helmet brand preferences, not all participants wore their instrumented ice hockey helmet during all games played. To account for this, as well as any games not played by a particular participant (e.g. illness, injury etc.), a log of which participants were both playing and wearing their instrumented helmets was recorded for each ice hockey game. Both head impact and exposure data were only collected from participants wearing an instrumented helmet within a given ice hockey game.

Ethics approval was obtained from the University of Toronto Health Science Research Ethics Board (see Appendix A). Informed consent was obtained from all participants’ legal guardian and assent was obtained from all participants prior to data collection (see Appendix B and C).

2.3.4 Data analysis
Descriptive statistics for sustained head impacts data and exposure to injury data were calculated for each participant. In order to account for differences in the number of ice
hockey games at which data was collected between participants, all data was normalized by analyzing data for each player per game. The effects and interactions between player and game characteristics on head impacts were analyzed using multiple regression. To avoid the influence of correlated predictor variables on the final regression models (multicollinearity), a correlation matrix containing bivariate correlation coefficient values for all continuous predictor variables was generated. Results showed strong positive correlations between the body size variables of height and weight ($r = 0.76$, $p = <.001$) and weight and BMI ($r = 0.84$, $p = <.001$). By including predictor variables that are highly correlated with a regression model, the information these variables provide to the model can be considered partially redundant (Portney & Watkins, 2000). By asking the model to estimate an additional parameter without supplying additional information, regression findings can include inflated standard errors and misleading results. One method of addressing multicollinearity is to combine two or more correlated predictor variables into a single composite variable (Berry & Feldman, 1985). As BMI is a composite variable of height and weight ($\text{BMI} = \text{kg/m}^2$), BMI alone was used to denote body size in place of height and weight within the final regression models. Separate regression models were created for mean linear acceleration, rotational acceleration, HITsp and number of head impacts sustained per game as the criterion variables. In all models, player position, player age, player BMI, time on ice per game and game type acted as the predictor variables. For all models, the predictor variables were entered simultaneously and the model was simplified by removing the least significant term and ensuring that this deletion resulted in an insignificant increase in deviance. This process was followed until all remaining factors were statistically significant ($p < 0.05$). Linear acceleration and impacts sustained per game values were log transformed, while rotational acceleration values were square root transformed, due to skew. Descriptive statistics and multiple regression analyses were carried out using the statistical programming environment R (R Development Core Team, 2010). The threshold for statistical significance was set at $p < 0.05$. Averages are reported as means ± standard deviation (SD).

2.4 Results

Over the course of 66 total ice hockey games across the three-year study duration, 27 female youth ice hockey players sustained 436 head impacts during 415,436 seconds (115.4 hours)
of active ice hockey participation (time on ice). On average, participants spent 863± 134 seconds (range, 526-1067 seconds) (14.4 minutes) on the ice per game and sustained 0.9 ± 0.6 (range, 0-2.06) head impacts per game. For all head impacts recorded across all participants, the mean linear acceleration was 16.6g ± 7.3 (range, 10-61g), where 94.1% of all impacts were less than 30g and the mean rotational acceleration was 1329.4 ± 870.6 rad/s² (range, 234.7-5872.1 rad/s²), where 84.3% of all impacts were less than 2000 rad/s². The mean HITsp was 12.5 ± 3.9 (range, 5.7-31.3). The distribution for HITsp values was also skewed towards lower values with 80.0% of all impacts having HITsp values below 15.

Multiple regression analyses were used to determine factors associated with head impacts (severity and frequency) sustained in female youth hockey players. Separate models were created for each criterion variable (linear acceleration, rotational acceleration, HITsp and number of head impacts per game). Player position, player age, player BMI, time on ice per game and game type were included as predictor variables in each model. The highest order effects (main effects or interactions) for each independent variable specific to severity and frequency of head impacts sustained are presented below.

2.4.1 Factors associated with the severity of head impacts

Linear acceleration, rotational acceleration and HITsp were collected as variables of head impact severity. When exploring the effect of player and game characteristics on the linear acceleration of head impacts, a significant final model emerged, accounting for 29% of the variance (adjusted $R^2 = 0.29$, $F_{23, 46} = 2.25$, $P = 0.01$). A four-way interaction between player position, time on ice per game, age and BMI revealed that in older players who had a greater BMI and spent more time in active hockey participation (time on ice), playing the forward position significantly predicted greater linear acceleration of head impacts (Estimate = 1.00; SE = 1.00; $t = 2.80$; $P = 0.008$). As well, three-way interactions between game type, player position and age revealed that in older players who played the defense position, playing in regular season games significantly predicted greater linear acceleration of head impacts (Estimate = 1.57; SE = 1.22; $t = 2.28$; $P = 0.027$) and that in older players who played the defense position, playing in tournament games significantly predicted greater linear acceleration of head impacts (Estimate = 1.34; SE = 1.10; $t = 2.04$; $P = 0.046$).
acceleration of impacts (Estimate = 1.54; SE = 1.19; t = 2.39; P = 0.021). All significant main effects and interactions specific to linear acceleration are presented in Table 2.1.

When exploring the effect of player and game characteristics on the rotational acceleration of head impacts, a highly significant final model emerged, accounting for 41% of the variance (adjusted $R^2 = 0.41$, $F_{15, 54} = 4.17$, $P < 0.001$). When examining the highest order significant interaction for each independent variable, a three-way interaction between player position, age and BMI revealed that in older players who had a greater BMI, playing the forward position significantly predicted greater rotational acceleration of head impacts (Estimate = 26.01; SE = 2.82; $t = 3.03; P = 0.004$). An additional three-way interaction between time on ice, age and BMI revealed that in older players who had a greater BMI, more time spent in active hockey participation (time on ice) significantly predicted greater rotational acceleration of head impacts (Estimate = 0.004; SE = 2.5E-5; $t = 4.66; P < 0.001$). Furthermore, a two-way interaction between game type and BMI revealed that for players with a greater BMI, playing in regular season games significantly predicted higher rotational acceleration of head impacts (Estimate = 1.66; SE = 0.38; $t = -2.08; P = 0.04$). All significant main effects and interactions specific to rotational acceleration are presented in Table 2.2.

When exploring the effect of the independent variables on the HITsp of head impacts, a significant final model emerged accounting for 16% of the variance (adjusted $R^2 = 0.16$, $F_{4, 65} = 4.20$, $P = 0.004$). With respect to HITsp, a significant two-way interaction between game type and time spent in active hockey participation (time on ice) revealed that during tournament games, increased ice time significantly predicted increased HITsp (Estimate = 0.004; SE = 0.002; $t = 2.28; P = 0.03$). Further, a significant main effect for age was found (Estimate = 0.95; SE = 0.29; $t = 3.24; P = 0.002$), where an increase in age significantly predicted an increase in HITsp. All significant main effects and interactions specific to head impact HITsp are presented in Table 2.3.

### 2.4.2 Factors associated with the number of head impacts
When exploring the effect of the independent variables on the number of head impacts sustained per hockey game, a significant final model emerged accounting for 9% of the variance (adjusted $R^2 = 0.09$, $F_{1,68} = 7.44$, $P = 0.008$). A significant main effect for BMI (Estimate = 0.90; SE = 1.04; $t = -2.73$; $P = 0.008$) was found, where having a higher BMI significantly predicted a higher number of head impacts sustained per game. No significant interactions were found (see Table 2.4).

2.5 Discussion

This study was conducted in order to gain a greater understanding of head impacts sustained during female youth ice hockey competition. To the best of our knowledge, this study was the first to measure the biomechanical characteristics of head impacts in female youth ice hockey players and to examine the effects of, and interactions between, player characteristics (player position, age, BMI and time on ice per game) and game characteristics (game type).

In our study, in order to account for differences between participants in the number of ice hockey games at which data was collected, and the potential influence on the total number of head impacts sustained, data was normalized and reported as head impacts per player per game. The mean number of head impacts recorded per player per game across all participants was less than one impact per game ($0.85 \pm 0.12$) and was considerably lower than the $5.19 \pm 0.62$ head impacts per player per game reported previously in male Bantam aged AAA ice hockey players for whom intentional body checking was permitted (Reed et al., 2010). The head impacts sustained by the female youth ice hockey players within the present study were also of a lower severity (e.g., lower linear acceleration, rotational acceleration and HITsp values) than those reported previously within youth male ice hockey players in all but one study (see Table 2.5).
**Table 2.1: Final multiple regression model of linear acceleration**

<table>
<thead>
<tr>
<th></th>
<th>Log Estimate (SE)</th>
<th>Back Transformed Estimate (SE)</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GameTypeRegular</td>
<td>-5.19 (2.40)</td>
<td>0.01 (11.02)</td>
<td>-2.12</td>
<td>0.036</td>
</tr>
<tr>
<td>GameTypeTourney</td>
<td>-5.21 (2.21)</td>
<td>0.01 (9.12)</td>
<td>-2.36</td>
<td>0.027</td>
</tr>
<tr>
<td>PositionForward</td>
<td>-241.80 (103.40)</td>
<td>9.72E-106 (8.06E+44)</td>
<td>-2.34</td>
<td>0.024</td>
</tr>
<tr>
<td><strong>Two-way Interactions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GameTypeRegular:PositionForward</td>
<td>6.22 (2.91)</td>
<td>502.70 (18.37)</td>
<td>2.14</td>
<td>0.038</td>
</tr>
<tr>
<td>GameTypeTourney:PositionForward</td>
<td>5.88 (2.54)</td>
<td>357.81 (12.68)</td>
<td>2.31</td>
<td>0.025</td>
</tr>
<tr>
<td>PositionForward:TimeOnIcePerGame</td>
<td>0.27 (0.10)</td>
<td>1.31 (1.11)</td>
<td>2.81</td>
<td>0.007</td>
</tr>
<tr>
<td>PositionForward:Age</td>
<td>15.79 (5.74)</td>
<td>7.20E+6 (311.06)</td>
<td>2.75</td>
<td>0.009</td>
</tr>
<tr>
<td>PositionForward:BMI</td>
<td>10.59 (3.92)</td>
<td>3.97E+4 (50.40)</td>
<td>2.70</td>
<td>0.010</td>
</tr>
<tr>
<td><strong>Three-way Interactions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GameTypeRegular:PositionDefense:Age</td>
<td>0.45 (0.20)</td>
<td>1.57 (1.22)</td>
<td>2.28</td>
<td>0.027</td>
</tr>
<tr>
<td>GameTypeTourney:PositionDefense:Age</td>
<td>0.43 (0.18)</td>
<td>1.54 (1.19)</td>
<td>2.39</td>
<td>0.021</td>
</tr>
<tr>
<td>PositionForward:TimeOnIcePerGame:Age</td>
<td>-0.02 (0.008)</td>
<td>0.98 (1.01)</td>
<td>-2.83</td>
<td>0.007</td>
</tr>
<tr>
<td>PositionForward:TimeOnIcePerGame:BMI</td>
<td>-0.01 (0.005)</td>
<td>0.99 (1.01)</td>
<td>-2.77</td>
<td>0.008</td>
</tr>
<tr>
<td>PositionForward:Age:BMI</td>
<td>-0.84 (0.31)</td>
<td>0.43 (1.36)</td>
<td>2.73</td>
<td>0.009</td>
</tr>
<tr>
<td><strong>Four-way Interactions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PositionForward:TimeOnIcePerGame:Age:BMI</td>
<td>0.001 (0.0004)</td>
<td>1.00 (1.00)</td>
<td>2.80</td>
<td>0.008</td>
</tr>
</tbody>
</table>
Table 2.2: Final multiple regression model of rotational acceleration

<table>
<thead>
<tr>
<th></th>
<th>Square Root Estimate (SE)</th>
<th>Back Transformed Estimate (SE)</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GameTypeRegular</td>
<td>26.63 (12.31)</td>
<td>709.16 (151.54)</td>
<td>2.16</td>
<td>0.035</td>
</tr>
<tr>
<td>PositionForward</td>
<td>1241.00 (421.70)</td>
<td>1.5E+6 (1.8E+5)</td>
<td>2.94</td>
<td>0.005</td>
</tr>
<tr>
<td>TimeOnIcePerGame</td>
<td>5.83 (1.32)</td>
<td>33.99 (1.74)</td>
<td>4.40</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Age</td>
<td>426.00 (103.90)</td>
<td>1.8E+5 (1.1E+4)</td>
<td>4.10</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>BMI</td>
<td>291.6 (70.07)</td>
<td>8.5E+4 (4.9E+3)</td>
<td>4.16</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td><strong>Two-way Interactions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PositionForward:Age</td>
<td>-94.69 (32.39)</td>
<td>8966.20 (1049.11)</td>
<td>-2.92</td>
<td>0.005</td>
</tr>
<tr>
<td>TimeOnIcePerGame:Age</td>
<td>-0.46 (0.10)</td>
<td>10.21 (0.01)</td>
<td>-4.48</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>GameTypeRegular:BMI</td>
<td>-1.29 (0.62)</td>
<td>1.66 (0.38)</td>
<td>-2.08</td>
<td>0.042</td>
</tr>
<tr>
<td>PositionForward:BMI</td>
<td>-66.91 (21.96)</td>
<td>4477.00 (482.24)</td>
<td>-3.05</td>
<td>0.004</td>
</tr>
<tr>
<td>TimeOnIcePerGame:BMI</td>
<td>-0.31 (0.07)</td>
<td>0.16 (0.01)</td>
<td>-4.57</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Age:BMI</td>
<td>-22.63 (5.34)</td>
<td>512.12 (28.52)</td>
<td>-4.24</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td><strong>Three-way Interactions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PositionForward:Age:BMI</td>
<td>5.10 (1.68)</td>
<td>26.01 (2.82)</td>
<td>3.03</td>
<td>0.004</td>
</tr>
<tr>
<td>TimeOnIcePerGame:Age:BMI</td>
<td>0.02 (0.01)</td>
<td>0.0004 (2.5E-5)</td>
<td>4.66</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>
Table 2.3: Final multiple regression model of HITsp

<table>
<thead>
<tr>
<th>HITsp</th>
<th>Estimate (SE)</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Effects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>0.95 (0.29)</td>
<td>3.24</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>Two-way Interactions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GameTypeTourney:TimeOnIcePerGame</td>
<td>0.004 (0.002)</td>
<td>2.28</td>
<td>0.026</td>
</tr>
</tbody>
</table>

Table 2.4: Final multiple regression model of head impacts per game

<table>
<thead>
<tr>
<th>Head Impacts per Game</th>
<th>Log Estimate (SE)</th>
<th>Back Transformed Estimate (SE)</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td>-0.10 (0.04)</td>
<td>0.90 (1.04)</td>
<td>-2.73</td>
<td>0.008</td>
</tr>
</tbody>
</table>

With respect to head impact distribution, the current study recorded an even higher percentage of impacts of a low linear acceleration (94.1% below 30g) compared to previous findings reported in male youth hockey players (83.1% below 30g) (Reed et al., 2010). A recent study by Brainard et al. (2011) examining gender differences in head impacts sustained by collegiate ice hockey players demonstrated a similar trend when comparing females to males. The authors found that female collegiate ice hockey players experienced fewer head impacts per athlete exposure and that these impacts were of a lower severity. It is important to note that all levels of female ice hockey prohibit bodychecking and that all previous studies examining the head impacts sustained by male youth and college-aged ice hockey players have included participants from ice hockey leagues in which bodychecking was permitted. As a result, it is possible that the differences in the number and severity of head impacts seen between males and females are influenced by the permissibility of bodychecking. However, further research that incorporates larger sample sizes of both male and female ice hockey players is needed in order to improve our understanding of this possibility, in addition to the influence of other factors that may be gender specific (e.g. body size, strength, speed, nature of play etc.), more directly.
Of the six regression models created, the most predictive was for rotational acceleration, where the player and game characteristic predictor variables included within the study accounted for 41% of the variance. Here, it was found that for players who played the forward position and for players who spent more time on ice, being older and having a higher BMI was significantly predictive of head impacts with higher rotational accelerations. It has been suggested that rotational accelerations of the head are a primary mechanism for diffuse brain injury, including concussion (Ommaya & Gennarelli, 1974) and specific to sport participation, rotational accelerations following head impacts sustained in male collegiate football players were found to be the primary predictor of concussion (Broglio et al., 2010).

Table 2.5: Literature reporting biomechanical head impact characteristics in youth ice hockey players

<table>
<thead>
<tr>
<th>Study</th>
<th>Population</th>
<th>Mean linear acceleration (g)</th>
<th>Mean rotational acceleration (rad/s²)</th>
<th>Mean HITsp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current study</td>
<td>Female youth hockey players (N=27; age=11-14 years)</td>
<td>16.6</td>
<td>1329.4</td>
<td>12.5</td>
</tr>
<tr>
<td>Mihalik et al. (2008)</td>
<td>Male youth hockey players (N=14; age=13 years)</td>
<td>Forwardsº</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18.8 (+12%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Defense</td>
<td>18.4 (+10%)</td>
<td>-</td>
</tr>
<tr>
<td>Cubos et al. (2009)</td>
<td>Male youth hockey players (N=13; age=13-14 years)</td>
<td>15.8 (-5%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Reed et al. (2010)</td>
<td>Male youth hockey players (N=13; age=13-14 years)</td>
<td>22.1 (+25%)</td>
<td>1557.4 (+15%)</td>
<td>-</td>
</tr>
<tr>
<td>Mihalik et al. (2010)</td>
<td>Male youth hockey players (N=16; age=14 years)</td>
<td>21.5 (+23%)</td>
<td>1441.1 (+8%)</td>
<td>15.8 (+21%)</td>
</tr>
<tr>
<td>Mihalik et al. (2012)</td>
<td>Male youth hockey players (N=52; age=13-16 years)</td>
<td>18.4 (+10%)</td>
<td>1464.5 (+9%)</td>
<td>14.1 (+11%)</td>
</tr>
</tbody>
</table>

º: No combined mean linear acceleration (Forwards + Defense) reported
- : Value not reported
Percent difference from current study is reported in parentheses
Further, Rowson et al. (2012) found that within male collegiate football players, average subconcussive head impacts had a rotational acceleration of 1230 rad/s² and average concussive head impacts had a rotational acceleration of 5022 rad/s², indicating a higher likelihood of experiencing a concussive injury with impacts of greater rotational acceleration. Although a concussive injury threshold for head rotational acceleration has yet to be reported specific to ice hockey or youth ice hockey, a similar relationship between impacts of higher rotational acceleration and concussion is likely.

Although a concussive event did not occur as a result of the head impacts sustained during our study, the possible link between head impacts of greater rotational acceleration and concussion, along with the player and game characteristic predictor variables included in our study accounting for a large portion of the variance in rotational acceleration recorded, our findings may be used to better prevent impacts of higher rotational acceleration in female youth ice hockey players who may be at a higher risk for these types of impacts (e.g., older players with higher BMI who either spend more time on ice or play the forward position). Although our study did not explore the specific behaviours performed by youth female hockey players that may lead to head impacts of higher rotational acceleration and further study exploring these behaviours is required, Mihalik et al. (2010) reported that in male youth ice hockey players, head impacts of increased rotational acceleration were a result of impacts that were unanticipated. It was suggested that during unanticipated impacts, cervical musculature is not contracted and in turn, less able to mitigate acceleration forces of the head (Mihalik et al., 2010). A unique aspect of female ice hockey is that intentional bodychecking is prohibited. Due to the rules of the game, many players may not expect contact or head impacts to occur, which in turn may leave them vulnerable to a higher proportion of unanticipated impacts and the potential for impacts of higher rotational acceleration. Further study that directly explores the level of anticipation for contact amongst youth female ice hockey players and the relationship between anticipation of contact, body mechanics and head impact characteristics is needed. This additional study may help inform coaching and training strategies specific to situational awareness when on the ice, expecting contact during game play and how to prepare the body to effectively receive contact as a means to limit unanticipated impacts of higher rotational.
A critical finding of this study is that player body size was predictive of head impacts of greater linear acceleration, rotational acceleration and frequency. It was found that having a greater BMI, while also being older, spending more time on the ice and playing the forward position, significantly predicted head impacts of a higher linear acceleration, and having a higher BMI, while also being older and playing the forward position, significantly predicted head impacts of a higher rotational acceleration. Further, a main effect revealed that having a higher BMI predicted a higher number of head impacts sustained per game. Body size as a predictive factor for head impacts is important in youth ice hockey as it has been suggested that body size differences both exist and may result in increased injury amongst youth ice hockey players (Wattie et al., 2007; Wattie et al., 2010).

In addition to the intuitive belief that with increased age, and in turn age category of ice hockey participation, comes the potential for increased body size amongst youth ice hockey players, specific to female youth ice hockey, it is important to consider that these size differences may also occur within a given age category of ice hockey participation. As was the case for the female youth ice hockey teams involved in our study, many female youth ice hockey leagues are comprised of age categories that consist of two age cohorts or constituent years (e.g., the Peewee age category consists of both 11 and 12 year olds etc.). With two age cohorts playing within a single age category, there is a greater potential for variability in developmental and maturational characteristics amongst these youth athletes, including body size. A study by Reed et al. (2010) examining head impacts sustained in male youth ice hockey players found no influence of body size on the linear or rotational accelerations of head impacts. However, it is important to consider that the single male youth ice hockey team included within this study participated in a league where age categories are made up of only one age cohort. It is possible that if this team was comprised of athletes across two age cohorts, more variability in body size may have existed, and in turn, the influence of body size on head impacts may have differed. With a greater potential for players of higher BMI playing alongside players of lower BMI, and with higher BMI being predictive of head impacts of a higher severity, body size may be an important factor for female youth ice hockey players when considering exposure to head impacts of high severity and frequency, and the potential for concussive injuries. Further study on how the specific behaviours
performed by youth female ice hockey players (e.g. intentional vs. unintentional body contact, receiving vs. delivering contact, contact with opponents, teammates or other surfaces etc.) influence head impact biomechanics will help contribute to our understanding of why increased BMI may predict impacts of higher severity in this population. Further, strategies aimed at decreasing the variability in player size within female youth ice hockey, such as limiting age category participation to a single age cohort (similar to the male youth ice hockey team mentioned above), may prove effective when attempting to limit head impact risk.

The four-way and three-way interactions found specific to linear and rotational acceleration, along with the two-way interaction specific to HITsp suggest a complex relationship between player and game characteristics and exposure to head impacts of high severity. Considering player and game characteristics in relation to each other and when looking across all head impact variables collected, it was found that age, BMI, playing position, time on ice, and game type all had some influence on the severity and/or frequency of head impacts sustained during female youth ice hockey participation. A greater understanding of this information may contribute to modified coaching methods or playing styles in order to reduce the risk of head impact exposure for female youth ice hockey players who may otherwise be at a greater risk for impacts of increased severity and frequency based on player characteristics (e.g. forward position, increased age, increased BMI, increased time on ice) or the type of game that is being played (e.g. regular season, playoff or tournament).

Of these factors, it is important to consider which we can most readily control in order to promote safer ice hockey participation for female youth. For obvious reasons, the age of the athlete cannot be changed. Changes in body size and position played are possible, however may require extensive training and practice on the part of the athlete and those around them in order to modify body composition as well as playing abilities and skills inherent to a given playing position. Further, the type of games played (e.g., regular season, playoff and tournament) are universally engrained into the sport of ice hockey and would require significant changes at the organizational and cultural level in order to modify. In contrast, the amount of time a player spends on the ice during ice hockey competition is a factor that,
by way of coaching strategy and increased awareness of how long individual players are on the ice, can be modified. In our study, either as a main effect or an interaction, time spent on ice was found to significantly predict higher values of linear acceleration, rotational acceleration and HITsp. By more appropriately managing ice time across female youth ice hockey participation, it is possible that these athletes can avoid increased risk of head impacts of greater severity. Further, the promotion of greater parity across players specific to playing time can contribute to greater opportunities for development and enjoyment for all players. Judging by the large numbers of female youth participating in ice hockey, it is an activity of great meaning and importance to many. As a result, it is important that strategies aimed at allowing female athletes of all ages, sized and abilities continue to play the sport of ice hockey, and do so in a safer manner, be explore and implemented across the ice hockey community.

2.5.1 Study limitations

Several limitations of the current study must be addressed. First, the instrumented helmets proved to be uncomfortable to wear for several of the study participants. As a result, some participants chose not to wear the helmet in all or some of their team’s games during the ice hockey season, limiting the amount of data collected. Future research would benefit from the use of a more adjustable helmet that can be modified to accommodate persisting comfort issues. Another limitation relates to the period of data collection. Due to recruitment delays during year 1 of the study, data was not collected from participants until three months after the start of the team’s ice hockey season. Although the number of games at which data was collected did not differ greatly from the other years of data collection (Year 1 = 20 games; Year 2 = 21 games; Year 3 = 25 games), it is possible that if included within the data analysis, the head impacts sustained during the games at which data was not collected may have influenced the mean exposure and head impact data values. Further, the lack of variety with respect to age categories across the study’s participating ice hockey teams can be seen as a limitation of this study. Out of the three participating teams, two were Peewee aged (11-12 years) and one was Bantam aged (13-14 years). A broader representation of different age categories have provided a better opportunity to explore the influence of age on the head impacts sustained in youth female ice hockey. Furthermore, there was little variability in the
level of competition played by the participant teams (two A teams and one BB team). It is possible that level of competition played may influence the nature of head impacts sustained. By examining teams who participate in a wide range of competition levels (C through AA), a more direct examination of the effect of competition level could be completed. Future studies would benefit from a more targeted approach to recruitment.

2.6 Conclusion

This study presents for the first time a description of the biomechanical characteristics of head impacts occurring in female youth ice hockey players. The data suggests that, although at a lower level of frequency and severity, head impacts are occurring in female ice hockey despite the lack of intentional body checking. It is recommended that those involved in the female youth ice hockey community consider the potential risk factors for head impacts of greater severity and frequency related to player position, age, BMI, time on ice and game type in order to avoid unnecessary risk for injury during ice hockey participation. This study acts as an initial step towards further exploration of head impacts sustained in youth female ice hockey players. The replication of similar methodology in future studies across genders, age groups and a variety of sports, as well as the capture of the biomechanical characteristics of head impacts resulting in concussion, will further contribute to our understanding of the risk factors specific to head impacts and concussion in youth athletes.
2.7 References


Chapter 3

3 Concussion and strength performance in youth ice hockey players

This chapter highlights the prospective longitudinal exploration of strength performance in youth ice hockey players before and after a concussion. According to this thesis’ conceptual framework, the aim of this chapter is to address the need for improved assessment following concussion in youth ice hockey players by exploring the influence of concussion on the person (strength performance). This chapter will be prepared for submission to Medicine and Science in Sport and Exercise, a leading journal in the field of sports medicine and science with a large readership made up of individuals from a variety of sport-related allied health fields involved in the delivery of post-concussion care.

3.1 Abstract

Introduction: Concussions are common during youth ice hockey participation, in which persisting functional deficits can result. Despite growing public interest in sport-related concussion, what remains to be explored is the relationship between strength and concussion in youth athletes. The need for upper and lower body strength is inherent to ice hockey participation. It is possible that concussion occurrence may influence post-injury strength performance. The purpose of this study was to explore both the effect of baseline strength performance on future concussion occurrence, as well as the influence of concussion occurrence on post-injury strength performance, within youth ice hockey players. Methods: This study used a three-year prospective longitudinal research design. The participant group was made up of 178 unique male and female ice hockey players (ages 8 to 14 years). Twenty two total concussive events were sustained during the study duration. Baseline and post-concussion data on leg maximal voluntary contraction, jump test and hand grip strength were collected. Results: Using a linear mixed-effects model, interaction and linear models reporting effects of sustaining a concussion on post-concussion strength performance were explored. No significant differences were found when comparing the baseline strength performance of individuals who went on to experience a concussion and those who did not.
When accounting for severity of post-concussive symptoms, significant average effects were found for jump height (squat jump: Estimate = -0.05; SE = 0.02; t = -2.51; P = 0.0186; countermovement jump: Estimate = -0.03; SE = 0.02; t = -2.20; P = 0.0371) and hand grip strength (non-dominant hand: Estimate = -0.03; SE = 0.02; t = -2.01; P = 0.05) during the symptomatic stage post-concussion and for leg maximal voluntary contraction (Estimate = -1.05; SE = 0.47; t = -2.27; P = 0.0421) during the asymptomatic stage post-concussion, indicating decreased strength performance following concussion. **Conclusions:** This study acts as an initial step towards better understanding concussion-related strength performance deficits that may limit the on and off ice performance of youth ice hockey players and in turn, can act as a foundation for future sport-related concussion research and rehabilitation protocols.

### 3.2 Introduction

Concussion has been reported as the most common specific injury type in youth hockey participation (Emery & Meeuwisse, 2006). Youth involved in organized sports, such as competitive hockey, are nearly six times more likely to suffer a severe concussion compared to children involved in other physical leisure activities (Browne & Lam, 2006). In North America alone, 515,073 Canadian youth (Hockey Canada, 2011) and 339,610 American youth (USA Hockey, 2011) were registered to play minor hockey during the 2009-2010 season. The high incidence of concussion inherent to hockey participation, combined with the growing popularity of the sport, puts a large number of youth at risk for concussion and related functional deficits. According to Cook et al. (2003), the potential for long-term deficits due to hockey-related concussions is significant among sport-related public health issues.

According to the most recent international consensus statement developed following the 3rd International Conference on Concussion in Sport (McCrory et al., 2009), sport-related concussion can result in one or more of the following: Physical signs (e.g., loss of coconsciousness, amnesia); clinical symptoms (e.g., somatic, cognitive and/or emotional); cognitive impairments (e.g., reaction time, attention); behavioural changes (e.g., irritability, depression); and, sleep disturbances. In order to reduce the risk of re-injury and prolonged
recovery, it is important to assess the clinical symptoms and abilities of the youth athlete following concussion prior to them returning to sport participation. It is recommended that athletes abstain from physical or cognitive activity until symptom free, at which time one can gradually return to activity in a step-wise fashion (McCrory et al., 2009). Furthermore, the use of neuropsychological and balance assessment are reported as beneficial when evaluating the injury and informing return to play decisions (McCrory et al., 2009).

To date, the majority of studies examining sport-related concussion have been limited to the college-aged and adult population, and have focused heavily on the male athlete. Furthermore, much of the previous literature specific to sport-related concussion has been limited to examining short-term outcomes and has typically opted to examine change over time by comparing group data rather than considering change at an individual level and the heterogeneity of pre and post-concussion performance. The investigation of pediatric concussion, the effects of gender on outcome and the investigation of long-term outcomes following concussion have all been recognized internationally as key areas for future research (McCrory et al., 2009). This study attempts to address these identified areas of further investigation within the field of sport-related concussion.

A key element in determining recovery following a concussion is the presence and severity of post-concussion symptoms (Chen, Johnston, Collie, McCrory, & Ptito, 2007), where return to sport participation should not occur until the injured athlete is asymptomatic (McCrory et al., 2009). The number of post-concussion symptoms has been reported to be useful when measuring severity of a concussive event and when making return to play decisions (McCrory, Ariens, & Berkovic, 2000). Due to the multifaceted and heterogeneous nature of concussion, no measure alone is sufficient to determine severity of injury and recovery from concussion (McCrory et al., 2005). The assessment of post-concussion symptoms can contribute to a comprehensive approach to management following a concussion. Chen at al. (2007) explored an association between post-concussion symptom scores and both neuropsychological function and levels of brain activation (measured using blood oxygen level dependent functional magnetic resonance imaging) in adult athletes post-concussion where elevated post-concussion symptoms were found to be associated with
declined cognitive performance and reduced brain activation levels. Furthermore, the link between post-concussion symptom scores and cognitive impairment has been reported elsewhere within the youth sport-related concussion population (Collins et al., 2003; Lovell, Collins, Iverson, Johnston, & Bradley, 2004). What remains to be explored is the influence of post-concussion symptoms on strength performance in athletes, more specifically, youth ice hockey players.

Muscle weakness is considered a common symptom following brain injury (Killington, Mackintosh, & Ayres, 2010), where deficits in strength following traumatic brain injury in children have been reported (Chaplin, Deitz, & Jaffe, 1993; Katz-Leurer, Rotem, Keren, & Meyer, 2009; Katz-Leurer, Rotem, Keren, & Meyer, 2010). Functionally, returning to play with undetected strength impairments may result in decreased sport performance, and more specifically, may lead to increased fatigue and decreased ability to navigate away from injurious on-ice situations, putting the youth athlete at risk for repeated concussion. For similar reasons (e.g., fatigue, decreased ability to avoid injurious situations etc.), it is also possible that already deficient strength (not due to a concussive event) in comparison to one's teammates and/or opponents may put youth ice hockey players at risk for concussion. It has been suggested that significant body size differences can exist among youth participating in sports (Wattie et al., 2007) and that variability in physical size may result in injury among youth ice hockey players (Brust, Leonard, Pheley, & Roberts, 1992; Wattie et al., 2010). One possible explanation for this trend is that variability in physical size may result in smaller and potentially weaker athletes competing against larger and potentially stronger athletes. As a result, it is possible that having less physical strength compared to one's peers may put youth ice hockey players at risk for injury and possibly concussion. Despite the potential functional implications of strength deficits in youth ice hockey players either prior to or following concussion, much remains unknown regarding the relationship between concussion and strength performance, and if concussion occurrence can contribute to decreased upper and lower body strength.

Given the paucity of information regarding concussion and strength performance in youth athletes, along with the deficiencies recognized in previous sport-related concussion research, this study was designed to use a prospective, longitudinal pre-post design to monitor male
and female youth ice hockey players over the course of a three-year period. The study provided the rare opportunity to obtain annual pre-injury strength performance data and compare to outcome post-injury. Furthermore, a mixed-effects modeling approach to analysis was used in order to consider the individual effects of baseline strength performance on future concussion occurrence, as well as concussion occurrence on post-concussion strength performance across time for each participant. This study intended to address the following questions: 1) Does baseline upper and lower body strength performance influence concussion occurrence in youth ice hockey players?; and, 2) Does concussion occurrence, when considering post-concussion symptom severity, influence post-concussion upper and lower body strength performance in youth ice hockey players?

3.3 Methods
3.3.1 Participants
A convenience sample of 177 youth ice hockey players (ages 8 to 14 years) from the Greater Toronto Hockey League (GTHL), Mississauga Hockey League (MHL) and the Ontario Women’s Hockey Association (OWHA) was recruited across three years of this longitudinal study. Data specific to strength performance was collected as part of a larger test battery that included neurocognitive assessment. Rather than recruit participants individually, youth ice hockey teams were recruited where individual players on each participating youth ice hockey team were asked to participate. Across the three-year study duration, a total of 11 youth ice hockey teams participated within the study (7 male and 4 female). In order to account for attrition from the study, attrition from the sport of ice hockey and youth ice hockey team player turnover from year to year, recruitment was continuous across the three years. As a result, participants who enrolled in the study in year one had the opportunity to be in the study for three years, while participants who enrolled in the study in years two and three had the opportunity to be in the study for two years and one year respectively. In addition to the participants from the 11 youth ice hockey teams, six additional youth ice hockey players participated in the study. These additional participants were not recruited, however contacted the researchers directly to participate in the study (informed via word of mouth by other participants). Participants were included within the study if they were youth ice hockey
players between the ages of 8 and 14 years and were excluded if they experienced a musculoskeletal or neuromuscular condition that would influence their ability to perform the strength-related tasks included within the study protocol. Although the study was designed to recruit equal numbers of male and female youth ice hockey players, it proved more difficult to recruit female participants, particularly in year one of the study where no females were enrolled. The aim was to recruit youth ice hockey players of younger ages due to the paucity of literature in this population, as well as to attempt to capture the athlete's first concussive event as a means to obtain a more accurate representation of recovery and the influence of concussion on strength performance (e.g., less influence of previous concussions and the potential for lingering or compounded deficits etc.). Baseline data was collected for each participant each year that they were enrolled in the study. Participant characteristics at baseline for each of the three years of the study are presented in Table 3.1. Additionally, of the 177 unique participants, 18 participants experienced a concussion while enrolled in the study (15 male and 3 female), while two participants had two concussions and one participant had three concussions for a total of 22 concussive events. Concussed participant characteristics at the time of injury are presented in Table 3.2.

3.3.2 Outcome measures
Dependant variables included measures of upper and lower body strength performance, along with the assessment of post-concussion symptoms. Upper body strength was recorded by measuring hand grip strength for both dominant and non-dominant hands, lower body strength was recorded by measuring maximal leg voluntary contraction and jump height during a squat and countermovement jump and post-concussion symptoms were measured by self report (see Appendix D for data collection form).

3.3.2.1 Hand grip strength
Hand grip strength data was collected using a Smedley’s hand grip dynamometer (TTM, Japan). While in an upright standing position with arm in full extension at side of body, participants were asked to squeeze the hand grip dynamometer with maximal effort for approximately five seconds. The task was completed three times with both the dominant and
Table 3.1: Participant characteristics at annual baseline

<table>
<thead>
<tr>
<th>Variable</th>
<th>Year 1 (N = 58)</th>
<th>Year 2 (N = 103)</th>
<th>Year 3 (N =100)</th>
<th>Total (N =261)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD) age, y</td>
<td>11.05 (0.64)</td>
<td>11.31 (0.89)</td>
<td>11.86 (1.28)</td>
<td>11.46 (1.06)</td>
</tr>
<tr>
<td>Gender: Male, N</td>
<td>58</td>
<td>78</td>
<td>64</td>
<td>200</td>
</tr>
<tr>
<td>Female, N</td>
<td>0</td>
<td>25</td>
<td>36</td>
<td>61</td>
</tr>
<tr>
<td>Level: Male, N</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>16</td>
<td>46</td>
<td>27</td>
<td>89</td>
</tr>
<tr>
<td>AA</td>
<td>42</td>
<td>30</td>
<td>36</td>
<td>108</td>
</tr>
<tr>
<td>AAA</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Select</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Female, N</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BB</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>0</td>
<td>25</td>
<td>24</td>
<td>49</td>
</tr>
<tr>
<td>AA</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Dominant Hand: Right, N</td>
<td>52</td>
<td>94</td>
<td>92</td>
<td>238</td>
</tr>
<tr>
<td>Left, N</td>
<td>6</td>
<td>9</td>
<td>8</td>
<td>23</td>
</tr>
<tr>
<td>Mean (SD) Height, m</td>
<td>1.46 (0.09)</td>
<td>1.48 (0.09)</td>
<td>1.53 (0.11)</td>
<td>1.50 (0.10)</td>
</tr>
<tr>
<td>Mean (SD) Weight, kg</td>
<td>39.35 (6.34)</td>
<td>41.10 (8.66)</td>
<td>45.88 (9.58)</td>
<td>42.54 (8.97)</td>
</tr>
</tbody>
</table>

*Value includes repeated annual baseline testing for participants enrolled in study for multiple years across the three year study duration (177 unique participants).
Table 3.2: Concussed participant characteristics at time of injury

<table>
<thead>
<tr>
<th>Variable</th>
<th>Number of Concussions (N = 22)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD) age, y</td>
<td>11.67 (0.70)</td>
</tr>
<tr>
<td>Gender: Male, N</td>
<td>19</td>
</tr>
<tr>
<td>Female, N</td>
<td>3</td>
</tr>
<tr>
<td>Level: Male, N</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>2</td>
</tr>
<tr>
<td>AA</td>
<td>16</td>
</tr>
<tr>
<td>AAA</td>
<td>1</td>
</tr>
<tr>
<td>Select</td>
<td>0</td>
</tr>
<tr>
<td>Female, N</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
</tr>
<tr>
<td>BB</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>3</td>
</tr>
<tr>
<td>AA</td>
<td>0</td>
</tr>
<tr>
<td>Dominant Hand: Right, N</td>
<td>20</td>
</tr>
<tr>
<td>Left, N</td>
<td>2</td>
</tr>
<tr>
<td>Mean (SD) Height, m</td>
<td>1.52 (7.88)**</td>
</tr>
<tr>
<td>Mean (SD) Weight, kg</td>
<td>42.68 (8.31)**</td>
</tr>
<tr>
<td>Mean (SD) Head Circumference</td>
<td>55.10 (1.70)**</td>
</tr>
</tbody>
</table>

* 18 unique participants experienced concussions; two participants sustained two concussions and one participant sustained three concussions
** Mean and SD calculated for 21 concussions (data missing for 1 concussion)
*** Mean and SD calculated for 20 concussions (data missing for 2 concussions)
non-dominant hand, with the maximum hand grip strength for each hand being recorded in kilograms. A systematic review by Castro-Pinero et al. (2010) designed to formulate an evidence-based proposal of the most valid field-based fitness tests in youth reported the hand grip strength test as the most strongly supported measure of musculoskeletal fitness in youth. Further, specific to ice hockey performance, strength in the hand, wrist and forearm is important for skills such as shooting, passing, puck control and being able to contain opponents physically (Twist, 2007).

3.3.2.2 Jump height
Jump height data was collected using an Axon Jump Mat (Vacumed, USA). With feet shoulder width and hands on their hips, participants performed both a squat jump (begin in 90° flexion at knees and extend knees to jump off ground) and a countermovement jump (begin in upright standing and in one motion flex at knees to 90° and extend knees to jump off ground). Participants were asked to complete three squat jumps and three countermovement jumps with maximal effort. The maximum height for each type of jump task across trials was recorded in centimetres. Explosive muscle power has been reported as the main determinant of performance in many individual and team sports (Newton & Kramer, 1994). The sport of ice hockey is widely recognized for its speed of play, along with the inherent need for explosive leg power to allow for quick acceleration and overall skating speed (Bracko, 2001; Mascaro, Seaver, & Swanson, 1992). Vertical jump testing is considered one of the most used field assessments when measuring anaerobic leg power, where squat jump and countermovement jump vertical jump testing are reported to be the most reliable field tests for the estimation of explosive power of the lower limbs (Markovic, Dizdar, Jukic, & Cardinale, 2004). Further, specific to the sport of ice hockey, vertical jump testing has been reported as a strong predictor of skating speed and performance amongst ice hockey players (Mascaro et al., 1992).

3.3.2.3 Leg maximal voluntary contraction
Leg maximal voluntary contraction was collected using an AccuGait Portable Gait and Balance Platform (AMTI, USA) and a strength bar fabricated by the researchers using a 31” titanium lacrosse handle, two 40” utility chains, a 24” x 26” plywood platform, two dock ring
fasteners and two U-bolts (1” width) (see Figure 3.1). With feet shoulder width apart and the strength bar adjusted to rest on the participant’s lap while in a squat position (90° angle at the knees), participants were asked to push up against the stationary bar (attempt to achieve upright standing position) with maximal effort for approximately 5-10 seconds. The maximum force generated (Fz) across three trials was recorded in newtons. Isometric strength performance (such as that performed during the leg maximal voluntary contraction testing) has been used extensively in exercise science to assess strength performance, demonstrating high reliability in single and multijoint test protocols (Wilson & Murphy, 1996). With respect to the relevance of isometric strength assessment to functional sport performance, contrasting findings have been reported. A review conducted by Wilson and Murphy (1996) questions the ability of isometric strength assessment to predict or correlate with dynamic activity performance due to both neural and mechanical differences. In contrast, a review by Juneja, Verma and Khanna (2010) reports the strong potential for isometric strength assessment to predict performance in dynamic activities, more particularly in activities involving large amounts of force and explosive power (e.g., ice hockey skill performance etc.). Regardless of the direct functional implications of assessing leg maximal voluntary contraction, the isometric strength assessment of the lower limbs provides an additional measure of strength that can be examined with respect to change according to age, gender and following a concussive event.

3.3.2.4 Post-concussion symptoms

Post-concussion symptoms, along with their severity, were recorded using the Post-concussion Scale Revised (Lovell & Collins, 1998), a 22-item checklist that asks the athlete to report common post-concussion symptoms on a 7-point likert scale denoting severity (‘0’ = no symptom through ‘6’ = severe symptom). A total composite score is calculated. Chen et al. (2007) report a total post-concussion symptoms score of 0 to 5 as normal, 6 to 21 as low, 22 to 84 as mild and 85 to 132 as severe. Participants were asked to report and rate only the symptoms that they were feeling at the time of assessment. Despite being a subjective measure and containing items (symptoms) that are not always specific to concussion, the assessment of post-concussion symptoms is recommended internationally during the diagnosis and management of sport-related concussion (McCrory et al., 2009). Further, by
Figure 3.1: Leg maximal voluntary contraction apparatus

way of identifying the association between post-concussion symptoms and both ongoing cerebral haemodynamic abnormality and mild cognitive impairment, the use of the Post-concussion Scale Revised during assessment and recovery management following concussion is supported (Chen et al., 2007). Additionally, debate within the clinical community exists with respect to the ability of youth to reliably self report symptoms following injury. According to a study completed by Hajek et al. (2011), post-concussion symptoms can be reliably assessed based on child self report and although parent and child report of symptoms display moderate agreement, children self report higher mean levels post-concussion symptoms compared to proxy reports made by their parents.
3.3.3 Procedure

All participants completed an annual baseline assessment for each year enrolled in the three-year study. Each baseline assessment included the completion of all five strength tasks (hand grip—dominant hand and non-dominant hand; jump test—squat jump and countermovement jump; and, leg maximal voluntary contraction) along with a rating of post-concussion symptoms. If participants experienced a concussion while enrolled in the study, follow-up assessment on the same measures was completed on an accelerated schedule. Post-injury follow-up assessment for hand grip and jump measures was completed at approximately day one, day five and upon post-concussion symptom resolution in order to capture any changes in performance during recovery. To avoid significant physical exertion in the presence of post-concussion symptoms (Majerske et al., 2008; McCrory et al., 2009), leg maximal voluntary contraction was only completed once post-concussion symptoms had resolved. Additionally, if symptoms were exacerbated when completing the strength-related outcome measures, the assessment was stopped and the participant was monitored. In order to track post-concussion symptom resolution, a post-concussion symptom rating was obtained each day from days one to seven post injury and then weekly if symptoms persisted after the first seven days. If post-concussion symptoms had resolved at days one or five post-injury, all follow-up measures were completed on that day and no further follow-up testing was completed until the participant’s next annual baseline assessment. The planned administration schedule of all outcome measures for all subjects (baseline and follow-up assessments) is presented in Table 3.3. It must be noted that although post-concussion assessment was planned to take place as per the administration schedule presented, the number of days post-concussion at which assessments occurred varied based on participant availability. In total, 261 baseline assessments for 177 unique study participants and 43 post-concussion follow-up assessments for 18 unique participants were completed over the three-year study duration. Ethics approval was obtained from the University of Toronto Health Science Research Ethics Board (see Appendix E). Informed consent was obtained from all participants’ legal guardian and assent was obtained from all participants prior to data collection (see Appendix F and G).
3.3.4 Data analysis
To explore the question of whether concussion occurrence predicted upper and lower body strength performance in youth ice hockey players, a longitudinal mixed-effect modeling approach to analysis was used. Traditionally, longitudinal data has been analyzed using repeated measures multivariate analysis of variance (MANOVA). Limitations to this approach include the need for complete and balanced data for all participants (all participants have same number of measurements made at approximately the same time) (Chu et al., 2007), where participants with missing data are excluded from the analysis (Christensen et al., 2008). In addition to modeling heterogeneity in outcome, mixed-effects modeling can accommodate for missing and variable data (Chu et al., 2007), a scenario common to longitudinal research. As the recovery from concussion can be different between individuals (e.g. rate of recovery, symptoms, functional impairments etc.) and because the assessment schedule was variable across the study sample (e.g. number and timing of baseline and post-concussion assessment sessions), mixed-effects modeling best represents the phenomenon explored and the data collected within this study. Average effects of concussion occurrence on baseline upper and lower body strength outcome measures were generated to determine the influence of baseline strength performance on the future occurrence of concussion during the study duration, while average effects of concussion occurrence on post-concussion upper and lower body strength outcome measures were generated to determine the influence of concussion occurrence on post-concussion strength performance.

In order to explore the influence of post-concussion symptom severity on strength performance post-concussion, the maximum post-concussion symptom score collected at any point post-concussion was used to account for relative severity of the concussive event. Estimates for the ‘PCSmax:Symptomatic’ and ‘PCSmax:Asymptomatic’ parameters reflect the average effect of one unit increase in maximum post-concussion symptoms on strength performance at either symptomatic or asymptomatic follow-up testing sessions respectively. All statistical analyses were carried out using the statistical programming environment R (R Development Core Team, 2010) and its ‘nlme’ package. The threshold for statistical significance was set at \( p \leq 0.05 \).
Table 3.3: Administration schedule of outcome measures

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Post-concussion Symptoms</th>
<th>Hand Grip Strength (dominant and non-dominant hand)</th>
<th>Jump Test (squat jump and countermovement jump)</th>
<th>Leg Maximal Voluntary Contraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Pre-season Baseline</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Post-concussion Day 1*</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Post-concussion Day 2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-concussion Day 3</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-concussion Day 4</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-concussion Day 5*</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Post-concussion Day 6</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-concussion Day 7</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekly after Post-concussion Day 7</td>
<td>X</td>
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</tr>
<tr>
<td>Post-concussive Symptom Resolution*</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Annual Pre-season Baseline</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

*Post-concussion assessment sessions

Note: ‘X’ represents completion of measure. Participants complete an annual baseline for each year enrolled in the three year study. If participant’s post-concussive symptoms resolve at days 1 or 5 post-injury, all measures are completed at that time and no additional follow-up testing is completed. To avoid significant physical exertion in the presence of post-concussive symptoms, leg maximal voluntary contraction was only completed once post-concussive symptoms had resolved. Additionally, if post-concussive symptoms were exacerbated when completing the strength-related outcome measures, the assessment was stopped and the participant was monitored.
3.4 Results

3.4.1 Descriptive results

Descriptive results (mean and standard deviation) of strength performance and post-concussion symptoms according to assessment session (baseline, symptomatic and asymptomatic) are presented in Table 3.4.

3.4.2 Baseline data

No significant differences in baseline strength performance were found between participants who went on to experience a concussion and those who did not. Summary data on the average effects of concussion occurrence on baseline performance are presented in Table 3.5.

3.4.3 Post-concussion (follow-up) data

Using mixed-effects modeling and when accounting for severity of post-concussion symptoms, significant average effects were found for squat jump height (Estimate = \(-0.05\); SE = 0.02; \(t = -2.51; P = 0.02\)), countermovement jump height (Estimate = \(-0.03\); SE = 0.02; \(t = -2.20; P = 0.04\)) and hand grip strength for the non-dominant hand (Estimate = \(-0.03\); SE = 0.02; \(t = -2.01; P = 0.05\)) during the symptomatic stage post-concussion, indicating decreased jump height and hand grip (non-dominant hand) performance following concussion when symptomatic. According to the study’s protocol, leg maximal voluntary contraction was only assessed once the participants’ post-concussion symptoms were resolved as a means to avoid significant physical exertion while symptomatic (McCrory et al., 2009). Significant average effects during the asymptomatic stage post-concussion were found for leg maximal voluntary contraction (Estimate = \(-1.05\); SE = 0.47; \(t = -2.27; P = 0.04\)), indicating decreased performance following concussion. No additional significant average effects were found during the asymptomatic stage post-concussion. Summary data on the average effects of maximum post-concussion symptoms on outcomes during symptomatic and asymptomatic stages post-concussion are presented in Table 3.6.
Table 3.4: Post-concussion symptom and strength performance according to assessment session across all participants

<table>
<thead>
<tr>
<th>Domain</th>
<th>Assessment</th>
<th>Baseline</th>
<th>Symptomatic</th>
<th>Asymptomatic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (SD)</td>
<td>N</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Post-concussion Symptoms (n)</td>
<td>261</td>
<td>4.3 (4.9)</td>
<td>21</td>
<td>28.1 (18.0)</td>
</tr>
<tr>
<td>Hand Grip Strength (dominant hand) (kg)</td>
<td>261</td>
<td>23.8 (4.5)</td>
<td>20</td>
<td>22.1 (3.7)</td>
</tr>
<tr>
<td>Hand Grip Strength (non-dominant hand) (kg)</td>
<td>261</td>
<td>22.8 (4.5)</td>
<td>20</td>
<td>20.0 (4.3)</td>
</tr>
<tr>
<td>Squat Jump Height (cm)</td>
<td>258</td>
<td>24.3 (4.7)</td>
<td>12</td>
<td>22.0 (7.1)</td>
</tr>
<tr>
<td>Counter-movement Jump Height (cm)</td>
<td>258</td>
<td>25.6 (5.0)</td>
<td>11</td>
<td>25.2 (8.5)</td>
</tr>
<tr>
<td>Leg Maximal Voluntary Contraction (N)</td>
<td>242</td>
<td>396.9 (120.8)</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 3.5: Summary average effects of concussion occurrence on baseline strength performance

<table>
<thead>
<tr>
<th>Domain</th>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Grip Strength (Dominant Hand)</td>
<td>Concussion</td>
<td>-1.35</td>
<td>0.90</td>
<td>-1.50</td>
<td>0.14</td>
</tr>
<tr>
<td>Hand Grip Strength (Non-dominant Hand)</td>
<td>Concussion</td>
<td>-1.60</td>
<td>0.94</td>
<td>-1.71</td>
<td>0.09</td>
</tr>
<tr>
<td>Squat Jump Height</td>
<td>Concussion</td>
<td>-1.12</td>
<td>1.09</td>
<td>-1.03</td>
<td>0.31</td>
</tr>
<tr>
<td>Countermovement Jump Height</td>
<td>Concussion</td>
<td>-0.94</td>
<td>1.10</td>
<td>-0.86</td>
<td>0.39</td>
</tr>
<tr>
<td>Leg Maximal Voluntary Contraction</td>
<td>Concussion</td>
<td>-25.37</td>
<td>27.19</td>
<td>-0.93</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Note: Estimates for the ‘Concussion’ parameter represent the average effect of going on to experience a concussion during the study duration on baseline (pre-injury) strength performance.
Table 3.6: Summary average effects of post-concussion stage of recovery (symptomatic and asymptomatic) on strength performance when considering post-concussion symptom severity

<table>
<thead>
<tr>
<th>Domain</th>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Grip Strength (Dominant Hand) (kg)</td>
<td>PCSmax:Symptomatic</td>
<td>-0.02</td>
<td>0.02</td>
<td>-1.38</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>PCSmax:Asymptomatic</td>
<td>0.01</td>
<td>0.02</td>
<td>0.23</td>
<td>0.82</td>
</tr>
<tr>
<td>Hand Grip Strength (Non-dominant Hand) (kg)</td>
<td>PCSmax:Symptomatic</td>
<td>-0.03</td>
<td>0.02</td>
<td>-2.01</td>
<td>0.05*</td>
</tr>
<tr>
<td></td>
<td>PCSmax:Asymptomatic</td>
<td>0.01</td>
<td>0.02</td>
<td>0.70</td>
<td>0.49</td>
</tr>
<tr>
<td>Squat Jump Height (cm)</td>
<td>PCSmax:Symptomatic</td>
<td>-0.05</td>
<td>0.02</td>
<td>-2.51</td>
<td>0.02*</td>
</tr>
<tr>
<td></td>
<td>PCSmax:Asymptomatic</td>
<td>-0.001</td>
<td>0.02</td>
<td>-0.05</td>
<td>0.96</td>
</tr>
<tr>
<td>Countermovement Jump Height (cm)</td>
<td>PCSmax:Asymptomatic</td>
<td>0.003</td>
<td>0.01</td>
<td>0.26</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>PCSmax:Symptomatic</td>
<td>-0.03</td>
<td>0.02</td>
<td>-2.20</td>
<td>0.04*</td>
</tr>
<tr>
<td>Leg Maximal Voluntary Contraction (N)</td>
<td>PCSmax:Asymptomatic</td>
<td>-1.05</td>
<td>0.47</td>
<td>-2.27</td>
<td>0.04*</td>
</tr>
</tbody>
</table>

* indicates significance (p < .05);

Note: Estimates represent the average effect of one unit increase in maximum post-concussive symptoms (PCSmax)
3.5 Discussion

The present study examined the effects of concussion occurrence specific to baseline strength performance data collected at 261 baseline testing sessions for 177 unique participants over a three year period. No significant differences were found when comparing the baseline strength performance of participants who went on to experience a concussion while enrolled within the study to those who did not. Although not found to be significant, negative estimates were found for all outcomes variables when exploring the average effect of going on to experience a concussion on baseline strength performance, indicating a general trend in poorer baseline strength performance for participants who went on to experience a concussion during the study duration. It is possible that with a large sample of concussed participants, this trend in poorer baseline strength performance for youth athletes who go on to experience a concussion may continue. With further study, a greater understanding of whether decreased upper and lower body strength at baseline can put a youth athlete at a greater risk for concussion can be garnered.

The present study illustrates for the first time strength deficits following concussion in youth ice hockey players. The finding of a significant negative average effect of maximum post-concussion symptoms when symptomatic on jump test performance and hand grip (non-dominant hand) performance following concussion illustrates that on average, when considering post-concussion symptom severity, jump height and hand grip strength were impaired after concussion. It is important to note that due to exacerbated symptoms in some participant’s during post-concussion assessment, squat jump data was not collected during 12 and countermovement jump data was not collected during 11 of the total 43 follow-up sessions across all concussed participants. Considering data was only not collected in the most symptomatic participants, it is possible that this dataset does not include symptomatic post-concussion strength performance data from some of the most impaired participants and deficits specific to jump test performance could be even more significant than presented within this paper. These findings of lower and upper body strength impairment when in the symptomatic stage post-concussion further support international sport concussion consensus recommendations of abstaining from sport participation until all post-concussion symptoms
have resolved (McCrory et al., 2009). Furthermore, as similar significant average effects were not found on jump test or hand grip performance during the asymptomatic stage post-concussion, avoiding exertion (both cognitive and physical) in order to avoid prolonged post-concussion symptoms may lead to quicker symptom resolution at which point strength deficits appear to no longer exist.

The finding of declined average maximal leg voluntary contraction performance during the asymptomatic stage post-concussion warrants further attention. Again, referring to the most recent sport concussion consensus statement (McCrory et al., 2009), the return to play process can occur once an athlete is considered to be asymptomatic (no longer reporting post-concussion symptoms). In the present study, although no longer symptomatic, on average, these athletes were still presenting with impaired leg strength. In most cases, where strength assessment is not traditionally used to inform return to play decisions, these youth athletes would begin the return to play process despite persisting strength deficits and the related functional implications of these deficits. Other studies have reported persisting performance deficits despite post-concussion symptom resolution in athletes when completing cognitive (Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Field, Collins, Lovell, & Maroon, 2003; Lovell et al., 2003; Peterson, Ferrara, Mrazik, Piland, & Elliott, 2003) and balance (Peterson et al., 2003) tasks. A study performed by Fait et al. (2009) explored concurrent locomotor navigation and cognitive performance in a single hockey player before and after a concussion. It was reported that despite symptom resolution and a return to pre-injury neurocognitive performance, locomotor, planning and attentional abilities remained impaired up to 30 days post-concussion. Similarly, the present study illustrates that although seemingly recovered, tasks of greater difficulty or complexity (e.g., more exertion required for maximal leg voluntary contraction than hand grip strength or jump test) may remain impaired.

The generation of muscular strength is dependent on both muscular (the muscle fibre size and force generating capacity) and neural (the nervous system's ability to recruit and stimulate motor units) contributions (Spiering & Kraemer, 2008). Specific to youth, it has been reported that both gains and decrements in strength performance are predominantly a result
of neural changes during motor unit recruitment and activation, rather than changes in muscle size (Blimkie & Bar-Or, 2008; Guy & Micheli, 2001). As concussion results in impairment in neurologic function (McCrory et al., 2009), it is possible that the strength deficits found within youth ice hockey players following concussion were a result of concussion induced impairment in neurologic function causing disruptions in the recruitment and activation of motor neurons responsible for strength production. In order to gain a greater understanding of the cause of strength deficits following concussion, further study is needed. According to Lieber (2002), it is possible to attribute strength changes to neural or muscular factors by using electromyography (EMG) to measure the electrical activity produced by skeletal muscle during muscle activation. In future research, recording EMG values during baseline and post-concussion strength performance would allow for the individual comparison of muscular electrical activity before and after a concussive event. Here, if strength changes post-concussion are due to decreased neural activation, pre to post injury strength changes will be directly proportional to pre to post concussion changes in EMG, however if strength changes are due to muscular contributions, strength deficits will occur in the absence of changes in EMG.

Returning to sport participation with strength deficits has several functional implications. Increased fatigue or inability to use one’s lower body strength in order to avoid injurious on-ice situations may result in a greater risk for repeated concussion. Furthermore, from a capacity theory perspective (Pashler, 1999), in which one can view neural resources as a finite pool, strength deficits post-concussion may result in a greater demand for neural resources when performing strength-related tasks. This competition for limited neural resources may result in the allocation of resources away from cognitive task performance, leaving the youth ice hockey player with a decreased ability to respond to the cognitive demands inherent to hockey. Performance deficits during concurrent motor and cognitive task performance have been reported in college-aged athletes following concussion (Fait et al., 2009; Parker, Osternig, Lee, Donkelaar, & Chou, 2005; Parker, Osternig, Van Donkelaar, & Chou, 2006; Parker, Osternig, van Donkelaar, & Chou, 2007; Parker, Osternig, van Donkelaar, & Chou, 2008) and more recently during concurrent skating, sport-specific motor and cognitive tasks in healthy youth ice hockey players (Fait et al., 2011). Whether a result of
direct strength declines or cognitive resource allocation, the functional deficits associated with decreased strength may put the youth ice hockey player at risk for repeated concussion upon returning to play. The findings presented within the present study suggest strength impairments following concussion in youth ice hockey players, where consideration for the assessment and related training of strength performance prior to return to full sport participation is warranted.

Although this study was designed to collect baseline data across three hockey seasons and post-concussion follow-up data at days one and five post injury, as well as upon symptom resolution, data collection across participants was variable. Specific to baseline data, year one of the study saw 58 baseline testing sessions completed, followed by 103 and 100 in years two and three respectively. Of these baseline data collection sessions, 116 unique participants completed a single annual baseline, 32 unique participants completed two annual baselines and 27 unique participants completed three annual baselines. As new participants were recruited to enter the study during each of the three years, a large number of initial baseline assessments were conducted, however the number of participants who completed multiple annual baseline assessments was smaller. Both attrition and timing of entering into the study contributed to this. In addition to general attrition from the research study from year to year, the number of participants completing multiple annual baseline assessments was also influenced by participant hockey team turnover, as well as dropout from the sport of hockey. As youth hockey teams were targeted as the primary source of recruitment, it was found that if players left a participating hockey team, returning to complete a second or third annual baseline was less likely. Furthermore, if participants entered the study during its second or third years, the opportunity to complete multiple annual baseline assessments was limited. The timing of post-concussion follow-up data collection was also variable. Although the study attempted to assess participants on days one and five post-concussion, satisfying this aim was heavily dependent on the availability of the participant. Furthermore, as no additional post-concussion data collection occurred after the participants’ post-concussion symptoms had resolved and the timing of post-concussion symptom resolution was different for each participant, both the number and timing of assessments post-concussion were different between individuals. Although traditional approaches to the
analysis of longitudinal data (e.g. MANOVA) may consider this variability in data points across participants a major limitation, mixed-effects modeling allows for strength performance trajectories relative to time to be generated using all collected data where the average effect of age, gender or experiencing a concussion on strength performance could be explored. Although used previously to explore longitudinal recovery of cognitive function following traumatic brain injury (Christensen et al., 2008; Chu et al., 2007; Green et al., 2008; Spikman, Timmerman, Zomeren, & Deelman, 1999; Wong, Monette, & Weiner, 2001; Zwaagstra, Schmidt, & Vanier, 1996), the current study effectively uses mixed-effects modeling to explore, for the first time, the recovery of strength performance following concussion and includes pre-injury baseline performance.

The small number of female participants can be considered a limitation of this study. Although this study was designed to explore the influence of concussion occurrence on strength performance in both male and female youth ice hockey players, with respect to both baseline and post-concussion data, there were considerably more males than females. It is possible that the findings of this study may have been different in the presence of more female participants. The limited generalizability of concussion research to female athletes has been reported elsewhere (Collins et al., 2002; Gaetz, Goodman, & Weinberg, 2000; Guskiewicz et al., 2003; Iverson, Brooks, Collins, & Lovell, 2006; Iverson, Gaetz, Lovell, & Collins, 2004; Reed et al., 2010). Although female youth ice hockey players were included within this study, future research with a more balanced sample would further contribute to the understanding of how gender influences outcome following concussion.

Additionally, when considering the functional task of returning to sport participation, it is important to consider ecological validity, or whether performance on an assessment is related to performance in daily life. Although utilized as a starting point to further inform the need to assess strength post-concussion in youth athletes, the outcome measures used to assess strength performance within the current study may not directly reflect functional strength performance within a sport context. In order to further explore the functional implications of post-concussion strength deficits, it is important that future research be conducted where post-concussion strength performance is assessed directly within the sport context and while
performing functional sport-specific strength related tasks (e.g. skating speed on ice rink etc.).

3.6 Conclusion

This study explored, for the first time, the effect of concussion occurrence on strength performance in youth ice hockey players. Using a longitudinal pretest-posttest design, comparison of post-concussion strength performance to baseline or pre-injury strength performance across individuals was possible. Linear mixed-effects modeling was used in order to effectively account for heterogeneity in outcome and to accommodate for missing and variable data, characteristics common to concussion and longitudinal research respectively. In summary, when considering the severity of post-concussion symptoms, declines in strength following concussion were found for upper and lower body strength performance and during both symptomatic and asymptomatic stages post-concussion. Functionally, returning to ice hockey participation with undetected strength performance impairments may put the youth ice hockey player at a greater risk for repeated concussion. This study acts as an initial step towards improved post-concussion management and rehabilitation within youth athletes. When managing sport-related concussion, it is important that all areas of performance affected by the injury are addressed prior to returning to pre-injury levels of activity. The findings presented provide support for the inclusion of strength assessment and treatment within a multi-faceted, systematic approach to rehabilitation post-concussion in order to obtain a more accurate index of readiness to return to sport participation.
3.7 References


Chapter 4

4 Concussion and concurrent cognitive and sport-specific task performance in youth ice hockey players: A pilot study

This chapter presents pilot data specific to the use of a real-world and sport specific assessment of functional performance to determine the cognitive abilities of youth ice hockey players following concussion. Much like the previous chapter, this chapter aims to address the need for improved assessment following concussion in youth ice hockey players by considering the combined influence of person (cognitive deficits), environment (multiple demands inherent to the ice hockey context) and occupation (performing ice hockey skills) factors. This chapter will be prepared for submission to the Journal of Head Trauma and Rehabilitation. This journal specializes in presenting practice-based information on clinical management and rehabilitation of persons with head injury.

4.1 Abstract

Introduction: Concussion is common in the sport of ice hockey and can cause deficits in cognitive function. In most situations, ice hockey participation requires the performance of more than one skill at a time. It has been reported that following concussion in athletes, performance deficits arise when locomotor and cognitive tasks are performed concurrently that may have otherwise gone unnoticed if assessed in isolation of one another. The purpose of this pilot study was to describe if experiencing a concussion within the previous ice hockey season has an effect on cognitive performance when completing concurrent ice hockey specific tasks and to inform the development of an onsite method of functional return to play assessment following ice hockey-related concussion. Methods: This single case pilot study compares the performance of 4 male youth ice hockey players who had experienced a concussion in the previous ice hockey season (mean age = 11.7 ± 0.3 years; mean time since injury = 92.5 ± 49.1 days) to a group of 10 non-injured controls (mean age = 11.8 ± 0.8 years). Participants completed a randomized combination of three ice hockey specific tasks (unobstructed skating, stickhandling and avoiding a fixed obstacle) while concurrently
completing a visual interference task (modified Stroop task). Dependant variables were response reaction time dual task costs and response errors during the visual interference task.

**Results:** Despite reporting no post-concussion symptoms and demonstrating comparable performance to non-inured controls during isolated visual interference task completion, participants who experienced a concussion within the previous ice hockey season and were ≤ 58 days post-injury demonstrated significantly poorer cognitive performance (increased cognitive dual task cost) across all conditions when completing the visual interference task concurrently with ice hockey specific skills (p ≤0.05). **Conclusions:** This study acts as an initial step towards the development of a real-world and sport-specific assessment of functional performance following concussion in youth ice hockey players to help inform safer return to play.

### 4.2 Introduction

According to international consensus (McCrory et al., 2009), concussion is defined as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" (p. 186) and can result in short or long term symptoms (somatic, cognitive and/or emotional), behavioural changes and cognitive impairment. Functionally, these outcomes can make it difficult to participate in activities of meaning and importance. It has been estimated that in the United States alone, up to 3.5 million concussions occur each year as a result of recreation and sport participation (Langlois, Rutland-Brown, & Wald, 2006). Further, it has been suggested that the potential for concussion is greatest in athletic environments where collisions are common (Powell, 2001). For these reasons, concussion is an injury of great prevalence and concern within the sport community. Specific to youth athletes, Browne and Lam (2006) report that youth involved in organized contact sports (such as ice hockey) are six times more likely to suffer a concussion compared to youth involved in other leisure physical activities. Specific to the sport of ice hockey, concussion has been reported as the most common specific injury amongst youth (Emery & Meeuwisse, 2006), where high speed play, environmental hazards (e.g., ice, boards etc.) and frequent body contact have been suggested as contributing factors (Williamson & Goodman, 2006).
Returning to play following a concussion is a priority to many athletes young and old, however caution when reintegrating into full sport participation must be taken. Returning to sport too soon (e.g., prior to recovering from a concussion) can contribute to exacerbated symptoms and delayed recovery from the current injury (McCrory et al., 2009), and more seriously, may contribute to a secondary concussive event. Second-impact Syndrome can occur when an athlete sustains a second concussion prior to the resolution of symptoms as a result of an initial concussion (Cantu, 1998). Although considered rare, this second concussion can lead to catastrophic brain swelling, often resulting in death (McCrory, Davis, & Makdissi, 2012). Further, from a functional perspective, as cognitive deficits, such as slowed reaction time (Covassin, Elbin, & Nakayama, 2010), can be present following concussion, returning to play prior to the resolution of these deficits may limit one's ability to process and respond appropriately to potentially injurious situations (e.g., contact from an opponent during hockey competition), where a secondary concussive event may result. To avoid potential negative outcomes associated with returning to play too soon, appropriate concussion management is recommended (McCrory et al., 2009).

According to the most recent international recommendations specific to sport-related concussion (McCrory et al., 2009), returning to full sport participation after a concussion involves the athlete following a gradual stepwise approach through six rehabilitation stages that involve activities of progressive physical activity and cognitive load (see Table 4.1). Progression through these six rehabilitation stages is dictated by the absence of self-reported post-concussion symptoms (e.g., headache, nausea, slowed thinking, increased irritability etc.) at rest and both during and following the completion of prescribed exercise inherent to each rehabilitation stage. Once able to take part in normal (i.e. full) training/practice activities without the return of post-concussion symptoms, final medical clearance can be provided and athletes can return to play.

A concern with this approach to returning to sport participation following a concussion is its inherent reliance on self-reported post-concussion symptom ratings. Although resolution of post-concussion symptoms dictates progressions through the rehabilitation stages, it has been suggested that post-concussion symptom report can be influenced by several factors, including the collection method (e.g., questionnaire vs. interview), as well as who the
Table 4.1: Gradual return to play protocol

<table>
<thead>
<tr>
<th>Rehabilitation Stage</th>
<th>Activity/Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No activity</td>
<td>Complete rest (cognitive and physical)</td>
</tr>
<tr>
<td>2. Light aerobic exercise</td>
<td>Walking, cycling (stationary) or swimming at &lt;70% maximum predicted heart rate</td>
</tr>
<tr>
<td>3. Sport-specific exercise</td>
<td>Skating drills in hockey, running drills in lacrosse or soccer (no head impact activities)</td>
</tr>
<tr>
<td>4. Non-contact training/practice</td>
<td>More complex training drills (passing drills etc.)</td>
</tr>
<tr>
<td></td>
<td>Light resistance training</td>
</tr>
<tr>
<td>5. Full contact training/practice</td>
<td>Following medical clearance, participate in full training/practice activities</td>
</tr>
<tr>
<td>6. Return to play</td>
<td>Game play</td>
</tr>
</tbody>
</table>

*Modified version of the recommendations presented at the Third International Conference on Concussion in Sport (McCrory et al., 2009).

Symptoms are being reported to (e.g., parent vs. clinician) (Krol, Mrazik, Naidu, Brooks, & Iverson, 2011). Further, specific to youth ice hockey, concern for players not reporting incidents indicative of concussion and related symptoms has been suggested as a contributor to considerable underreporting of concussions within this population (Williamson & Goodman, 2006). An additional concern with this approach to returning to sport participation following a concussion and its reliance on post-concussion symptom resolution is that all impairments associated with concussion may not resolve in concert with symptoms. When examining cognitive performance amongst 61 concussed athletes, Collie et al. (2006) reported that participants demonstrated deficits in the cognitive domain of divided attention (attending to two tasks at one time) despite no longer reporting post-concussion symptoms, indicating that the recovery of cognitive function can lag behind the resolution of post-concussion symptoms. In sport, the ability to divide attention between several concurrent tasks is often essential, where a decline in one's ability to do so may put an athlete at risk for
a secondary concussive event.

The need for further objective information specific to post-concussion recovery has led to recommendations for the use of neuropsychological assessment in order to determine cognitive recovery (in addition to symptom resolution) and to contribute further to return to play decision making (Echemendia & Cantu, 2003; McCrory et al., 2005; McCrory et al., 2009). However, the isolated and clinical nature of neuropsychological assessments (e.g., assessing a single domain of cognitive performance in the absence of concurrent cognitive and motor demands) may provide only a limited view of whether an athlete is truly ready to return to sport competition. According to Haggard et al. (2000), “most daily living tasks involve concurrent movement and cognition, yet quantitative assessment after brain injury typically treats these functions separately” (p.485). Performance in clinical settings does not necessarily transfer to performance during daily activities in other settings, where differences exist in the demands inherent to a given environment (e.g. obstacles, visual/auditory distractions etc.) (Huang & Mercer, 2001). With isolated clinical evaluation of cognitive performance comes the potential for masking performance deficits that may occur with the multiple demands of dynamic real-world environments.

Thus, an individual who has experienced a concussion may perform adequately on an isolated test of cognition, however, when combined with a motor task to mimic the demands of a real-world task, deficiencies in performance may arise. Recent study has shown that when the performance of concussed athletes is assessed using concurrent real-world cognitive and motor tasks, deficits arise that may have otherwise gone unnoticed (Fait, McFadyen, Swaine, & Cantin, 2009; Fait, Swaine, Cantin, Leblond, & McFadyen, 2012; Parker, Osternig, van Donkelaar, & Chou, 2007) and these deficits remain even once post-concussion symptoms and impaired isolated cognitive performance resolve (Fait et al., 2009; Fait et al., 2012). These findings suggest that in order to generate an accurate index of readiness to return to play following concussion, athletes must be assessed in a manner that is ecologically valid and that provides cognitive and motor challenges comparable to sport participation. One approach towards improved ecological validity and the more accurate assessment of functional ability following concussion is the use of dual-task methodology
and the use of sport-specific skills.

From a general perspective, dual-task methodology involves the performance of two different tasks concurrently (Brauer, Broome, Stone, Clewett, & Herzig, 2004) or more specifically, the use of a testing model that involves the simultaneous performance of cognitive and motor tasks (Broglio, Tomporowski, & Ferrara, 2005). As originally outlined by Abernathy (1988), dual-task methodology examines two tasks performed simultaneously, one task designated as the primary task and the other as the secondary task. This paradigm purports that performance on the primary task is to remain at baseline or single-task level (as would be performed in the absence of the secondary task), while reduced performance on the secondary task during the dual-task condition is what denotes an interference effect (McCulloch, 2007; Woollacott & Shumway-Cook, 2002). Dual-task methodology incorporating the concurrent performance of cognitive and motor tasks has been used previously to demonstrate performance deficits in college-aged athletes following concussion (Parker, Osternig, Lee, van Donkelaar, & Chou, 2005; Parker, Osternig, van Donkelaar, & Chou, 2006; Parker et al., 2007; Parker, Osternig, van Donkelaar, & Chou, 2008), including impairments in cognitive outcomes (Catena, van Donkelaar, & Chou, 2011; Fait et al., 2009; Fait et al., 2012). Further, paradigms involving concurrent performance of sport-specific tasks have been used to demonstrate the influence of increased task complexity on performance in non-injured youth athlete populations (Fait et al., 2011; Leavitt, 1979; Smith & Chamberlin, 1992). However, to date, the influence of concussion on cognitive abilities during concurrent sport-specific task performance in youth has yet to be explored.

Due to the visible and concrete physical demands of sport performance, the contribution of cognitive processes can often be overlooked. Sport performance, including playing ice hockey, can be considered highly cerebral, where cognitive abilities such as attention allocation, planning, reaction time and reaction accuracy can contribute to the differentiation between elite and novice athletes (Mann, Williams, Ward, & Janelle, 2007). Specific to sport-related concussion in youth ice hockey players, it is possible that impaired cognitive abilities, such as a declined ability to respond quickly and appropriately to opponents and navigate away from injurious situations, could put one at risk for injury during ice hockey
competition. Further, it has been reported that functional performance deficits remain in athletes when performing cognitive and motor skills concurrently despite resolution of post-concussion symptoms and deficits on isolated neuropsychological assessment (Fait, Swaine, Cantin, Leblond, & McFadyen, 2012). As a result of the importance of cognitive function in sport and the implications of concussion on ice hockey performance and injury risk, the direct exploration of the influence of concussion on cognitive function during concurrent ice hockey skill performance is warranted.

As a result, the purpose of this single case pilot study was to explore the effect of experiencing a concussion within the previous ice hockey season on the cognitive performance of youth ice hockey players while completing concurrent ice hockey specific tasks. It is anticipated that the findings of this study may be viewed as an initial step towards a greater understanding of the influence of concussion on cognitive performance within a real-world context and inform both further study and the development of sport-specific measures of readiness to return to play for youth ice hockey players.

4.3 Methods

4.3.1 Participants
A convenience sample of 14 competitive youth male ice hockey players from the Greater Toronto Hockey League and the Mississauga Hockey League participated in the study. Participants were divided into two groups: Those who experienced a concussion during the previous ice hockey season (4 concussed participants; mean age = 11.7 ± 0.3 years; mean time since injury = 92.5 ± 49.1 days) and non-injured controls with no reported history of concussion (10 non-injured control participants; mean age = 11.8 ± 0.8 years). Data for 7 of the 10 control participants was collected at an earlier date and has been reported previously (Fait et al., 2011). Within the ice hockey leagues from which the participants were recruited, competitive youth ice hockey teams participate in three divisions based on skill level. These divisions are A, AA and AAA, where A represents the lowest skill level and AAA represents the highest skill level. Only youth ice hockey players who participated on A and AA hockey teams were enrolled in this study to provide a more accurate representation of the typical
youth representative level ice hockey player. All participants were male. Participants were included within the concussed group if they had experienced a concussion during the previous ice hockey season (diagnosed by a medical practitioner), while participants were included within the non-injured control group if they reported no history of concussion. Further, all participants in the concussion group were no longer reporting post-concussion symptoms and had returned to full daily activities including ice hockey participation. Exclusion criteria included any self-reported neurological or musculoskeletal problems or taking medication affecting alertness, cognitive or motor abilities. Participant characteristics are presented in Table 4.2. Ethics approval was obtained from the University of Toronto Health Sciences Research Ethics Board (see Appendix H) and all participants’ legal guardians signed informed consent prior to data collection (see Appendix I). In addition, the study was explained to the youth participants and their assent was obtained in order to proceed with the study protocol (see Appendix J).

4.3.2 Procedure
The protocol used was designed as a replication of previous study specific to concurrent cognitive and motor performance during hockey skill performance in healthy youth ice hockey players (Fait et al., 2011). Participants were asked to complete a series of combined ice hockey related tasks of various complexities along with a visual interference task in order to emulate the real-world and cognitive demands required during ice hockey participation. Three tasks: 1) skating; 2) avoiding a fixed obstacle in skating path (right and left); and, 3) stickhandling an ice hockey puck were completed in combination with each other while concurrently completing a visual interference task (modified Stroop task; Golden, 1978), creating a total of six conditions. All possible task conditions, along with the number of concurrent tasks completed, are presented in Table 4.3.

Participants completed three trials of each possible condition for a total of 18 trials (6 conditions x 3 trials per condition = 18 total trials). Trials were completed in random order with the participant informed by the researchers of which concurrent tasks were to be completed prior to completing each trial. Prior to the completion of the study protocol, all participants completed a warm-up consisting of light skating and stretching, a practice trial of
the visual interference task while standing still and three task protocol practice trials: 1) unobstructed skating; 2) skating while stickhandling and avoiding the obstacle to the left; and, 3) skating, while avoiding the obstacle to the right and completing the visual interference task.

**Table 4.2: Participant Characteristics (n = 14 males)**

<table>
<thead>
<tr>
<th>Participant</th>
<th>Days Post-concussion</th>
<th>Age (years)</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
<th>Stickhandling Side Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concussion Group (n = 4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>44</td>
<td>12.0</td>
<td>1.38</td>
<td>30.4</td>
<td>Right</td>
</tr>
<tr>
<td>2</td>
<td>58</td>
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<td>1.35</td>
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<td>1.53</td>
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<tr>
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<td>0.12</td>
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### Table 4.3: Task protocol conditions

<table>
<thead>
<tr>
<th>Number of Concurrent Tasks</th>
<th>Visual Interference (Stroop)</th>
<th>Skating</th>
<th>Stickhandling Ice Hockey Puck</th>
<th>Obstacle Avoidance Right</th>
<th>Obstacle Avoidance Left</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
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<tr>
<td></td>
<td>x</td>
<td>x</td>
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</tr>
<tr>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>4</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

### 4.3.2.1 Description of tasks

#### 4.3.2.1.1 Skating

During all trials, participants were asked to skate forward at full speed along a 16.50 meter skating path mapped onto a standard ice hockey rink. Figure 4.1 illustrates the experimental set-up, including the orientation and distance of the skating path. From a stationary start position, participants were asked to skate at full speed from start to finish of the skating path without stopping. The start position of the skating path was marked clearly on the ice using heavy permanent marker and the end position was the front of an ice hockey net. As described in the previous study (Fait et al., 2011), full speed skating was used to reduce variability in selected skating speeds across task protocol conditions. Further, two cones approximately 1.50 meters apart were placed at 4.20 meters into the skating path from the start position. From the start position, participants were instructed to skate forward through these cones towards the end position (ice hockey net) in order to decrease variability in the trajectory of the skating path and to help promote forward skating.
4.3.2.1.2 Obstacle avoidance
During trials that included avoiding an obstacle, participants circumvented a fixed cylindrical obstacle placed within the skating path at 8.40 m from the start position (see Figure 4.1). The custom built obstacle (height: 1.45 m, diameter: 0.30 m) was made of a thick cylindrical fabric shell filled with a stack of five inflated beach balls. Sandbags were placed at the bottom of the obstacle to stand them upright. The same obstacle was used previously with healthy youth ice hockey players (Fait et al., 2011) and a similar obstacle has been used previously with adult athletes (Gérin-Lajoie et al., 2007). Prior to each trial that included obstacle avoidance, the participants were provided instruction specific to which direction they were to circumvent the obstacle (left or right). Participants were asked to skate at full speed and to pass through the two cones (placed at the 4.20 metres into the skating path) prior to circumventing the obstacle and arriving at the skating path end position. Again, the cones were used in order to limit the variability in skating path trajectory during the task and to promote both forward skating and explicit obstacle circumvention.

4.3.2.1.3 Stickhandling ice hockey puck
During trials that included stickhandling an ice hockey puck, participants were asked to use their own ice hockey stick to carry a standard ice hockey puck from the start position to the end position of the skating path. Further, once arriving at the end position of the skating path, participants were asked to place the ice hockey puck on a clearly marked 'X' centered at the front of the ice hockey net. This ice hockey puck placement was used during stickhandling trials to keep participants from shooting the puck at the ice hockey net prior to or upon reaching the end position of the skating path in order to both promote consistency when arriving at the skating path end position and to avoid errant ice hockey pucks striking experimental equipment or members of the research team.

4.3.2.1.4 Visual interference
The visual interference task consisted of a modified Strop Color Word Test, Interference Condition (Golden, 1978) projected on a large screen directly in front of the participants at the end of the skating path. A data projector (Epson Powerlite 77c) was placed on a table directly behind the ice hockey net at the end position of the skating path. The large
presentation screen (1.52 m x 1.35 m) was placed at 2.83 meters away from the data projector (see Figure 4.1). The task consisted of the words "red", "green" and "blue" being projected onto the screen in colours either congruent (e.g., word "red" written in red) or incongruent (e.g., word "red" written in blue) with the words lexical meaning. Participants were asked to verbally identify the colour that the word was written in as quickly as possible. Trials were accompanied by a visual and auditory countdown to identify the start of the trial (e.g., when to begin skating towards the end position and when to begin verbally responding to visual stimuli). Visually, this countdown presented the numbers 3, 2, then 1 on individual slides, followed by a separate slide presenting the word "GO". Each slide within the countdown was presented 1 second apart from each other and was paired with an auditory beep. Upon the completion of the countdown, the colour words were projected onto the screen a separate slide for each word was presented at a rate of one word every second. Prior to completing the visual interference task concurrently with the other experimental tasks (e.g., while skating etc.), all participants completed the visual interference task during a static trial (while standing) in order to determine baseline performance. During the static trial, the presentation of word stimuli slides was stopped after five words, while during skating trials the presentation of the word stimuli slides was stopped when the participant reached the end position of the skating path. All visual and auditory stimuli slides were created using PowerPoint 2007 (Microsoft Corporation, Redmond, WA). Verbal responses to the visual stimuli were recorded using a portable voice recorder (Panasonic RR-U360) worn by the participants during all trials and all trials were video recorded to confirm response accuracy and performance.
Figure 4.1: Experimental set-up on standard ice hockey rink

Note: ‘X’ denotes cones placed approximately 1.5 meters apart at the 4.2 meters after the starting position in order to reduce variability in skating path trajectory by participants and promote forward skating.
4.3.3 Outcome measures
Dependant variables included three measures of cognitive performance: 1) response reaction time; 2) cognitive dual task cost; and, 3) cognitive response errors.

4.3.3.1 Response reaction time
Response reaction time measured the speed in which participants reacted to the visual stimuli presented within the visual interference task. Verbal response reaction times were calculated by subtracting the onset of verbal response to a given word stimulus from the onset of the visual stimulus presentation. The onset of the first visual stimulus of a given trial was configured to appear 1.5 seconds after the final beep of the visual and auditory countdown leading into the task, while the interval between consecutive word stimuli during the trial was set to 1 second. As the onset of visual stimuli presentation was standardized across trials, once the verbal response time to a given stimulus was known, the differential between the two could be calculated, indicating reaction time. A custom Matlab 7.7.0.471 (The MathWorks, USA) program was used to calculate reaction time across trials. Response reaction time was used to calculate dual task cost (see below) across all conditions and is only directly reported specific to baseline (static) visual interference task performance in order to differentiate cognitive performance by concussed participants compared to the non-injured control group in the absence of concurrent task performance. Higher response reaction time values indicate poorer cognitive performance.

4.3.3.2 Cognitive dual task cost
Cognitive dual task cost (cDTC) measured decrements in cognitive performance by comparing cognitive performance while completing concurrent tasks compared to cognitive performance while completing the visual interference task alone. cDTC was calculated by comparing verbal response reaction times to the visual interference task stimuli during concurrent task performance trials to verbal response reaction time for the visual interference task stimuli during the baseline (static) trial using the following equation:

\[
cDTC \% = \frac{(\text{Dual Task Response Reaction Time} - \text{Single Task Response Reaction Time})}{\text{Single Task Response Reaction Time}} \times 100 \tag{1}
\]
As this equation allows dual task costs to be interpreted as a percentage, controlling for variable baseline performance amongst participants and allowing for comparison across individuals is possible (McCulloch, 2007). The single task response reaction time value was generated by taking the mean reaction time across verbal responses to each stimulus presented during the baseline (static) trial. The dual task response reaction time was the differential between stimulus onset and verbal response onset for each stimulus presented under a given condition. Individual cDTC values were reported for each condition during which the visual interference tasks was completed concurrently with ice hockey specific skills by calculating the mean cDTC for each stimulus presented across the three trials for that condition. Higher cDTC values indicate poorer cognitive performance.

4.3.3.3 Response errors
Response errors were calculated by summing the number of errors made when responding to the word stimuli of the visual interference task (modified Stroop task). Again, visual interference task consisted of the words "red", "green" and "blue" being projected onto the screen in colours either congruent (e.g., word "red" written in red) or incongruent (e.g., word "red" written in blue) with the words lexical meaning, where participants were asked to verbally identify the colour that the word was written in. When responding to the visual stimuli, both incorrect responses and omissions were counted as errors. Response errors were determined by matching verbal responses recorded using a portable voice recorder to the known sequence of visual stimuli presented during a given trial. Further, each trial was video recorded in order to confirm the number of response errors committed. Response errors were reported across all conditions (baseline and concurrent task performance). A higher number of response errors indicates poorer cognitive performance.

4.3.4 Data analysis
Given the small number of participants and the pilot nature of the study, a single case approach to data analysis was used. The cognitive performance (cDTC and response errors) for individual participants within the concussion group were compared to the mean performance of non-injured controls using the modified t-test of Crawford and Howell (1998). This method uses the t-distribution (with n-1 degrees of freedom), rather than the
standard normal distribution, to estimate the abnormality of an individual's scores and to test if these scores are significantly different than the scores of a control sample. In contrast to the use of z-scores, this method controls the Type 1 error rate regardless of the sample size and is robust to violations of normality (Crawford & Howell, 1998). The formula for this test is:

\[
    t = \frac{X_1 - X_2}{s\sqrt{\frac{n + 1}{n}}}
\]

Where \( X_1 \) is the individual's score, \( X_2 \) and \( s \) are the mean and standard deviation of scores in the control sample and \( n \) is the size of the control sample. These analyses were completed using the 'Singlims ES' computer program (available online: http://homepages.abdn.ac.uk/j.crawford/pages/dept/SingleCaseMethodsComputerPrograms.HTM). The threshold for statistical significance was set at \( p \leq 0.05 \).

4.4 Results

The cognitive performance across all conditions of individual participants within the concussion group, along with mean performance of non-injured controls and results from the modified t-test comparing individual scores to control group scores are presented in Table 4.4 (cDTC) and Table 4.5 (response errors).

4.4.1 Cognitive dual task cost results

At baseline (static visual interference task), it was found that no participants in the concussion group performed significantly poorer than non-injured controls (poorer performance indicated by slower response reaction time) and Participant 2 performed significantly better (faster response reaction time) than non-injured controls (\( t(9) = -3.051, p = 0.007 \)). During concurrent task performance, both Participant 1 (44 days post-concussion) and Participant 2 (58 days post-concussion) demonstrated significantly poorer performance (increased cDTC) when compared to non-injured controls across conditions. Participant 1 demonstrated significantly poorer performance during conditions involving: visual interference task + skating (\( t(9) = 2.292, p = 0.024 \)); visual interference task + skating + stickhandling (\( t(9) = 3.232, p = 0.005 \)); visual interference task + skating + stickhandling +
obstacle avoidance to the right (t(9) = 2.305, p = 0.023); and, across all conditions collapsed (t(9) = 1.824, p = 0.050). Participant 2 demonstrated significantly poorer performance during conditions involving: visual interference task + skating + stickhandling (t(9) = 2.052, p = 0.035); visual interference task + skating + stickhandling + obstacle avoidance to the right (t(9) = 1.907, p = 0.045); and, across all conditions collapsed (t(9) = 1.823, p = 0.050).

Participant 3 (123 days post-concussion) and Participant 4 (145 days post-concussion) did not demonstrate poorer performance when compared to non-injured controls during any conditions or across all conditions collapsed.

4.4.2 Response error results
At baseline (static visual interference task), it was found that no participants in the concussion group performed significantly poorer than non-injured controls (poorer performance indicated by increased response errors). During concurrent task performance, Participant 1 (44 days post-concussion), Participant 2 (58 days post-concussion) and Participant 3 (123 days post-concussion) demonstrated significantly poorer performance (increased response errors) when compared to non-injured controls. Participant 1 demonstrated significantly poorer performance during conditions involving: visual interference task + skating + stickhandling (t(9) = 2.860, p = 0.009). Participant 2 and Participant 3 demonstrated significantly poorer performance during conditions involving: visual interference task + skating (Participant 2: t(9) = 6.039, p = 0.0001; Participant 3: t(9) = 2.860, p = 0.009). Participant 4 (145 days post-concussion) did not demonstrate significantly poorer performance when compared to non-injured controls during any conditions and no concussed participants demonstrated significantly poorer performance across all conditions collapsed.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Non-injured Controls (n=10)</th>
<th>Concussed Participants (n = 4)</th>
<th>Significance (one-tailed probability)</th>
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<tbody>
<tr>
<td>Baseline (RRT, s)</td>
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<td>Participant 1: 0.89</td>
<td>t(9) = 0.381, p = 0.356</td>
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<td>Participant 2: 0.53**</td>
<td>t(9) = -3.051, p = 0.007</td>
</tr>
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<td>Participant 3: 0.80</td>
<td>t(9) = -0.477, p = 0.322</td>
</tr>
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<td></td>
<td>Participant 4: 0.70</td>
<td>t(9) = -1.430, p = 0.093</td>
</tr>
<tr>
<td>VI + S (cDTC, %)</td>
<td>-15.6 (SD: 18.3)</td>
<td>Participant 1: 28.4*</td>
<td>t(9) = 2.292, p = 0.024</td>
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<td>Participant 2: 14.6</td>
<td>t(9) = 1.573, p = 0.075</td>
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<td>Participant 3: -6.7</td>
<td>t(9) = 0.464, p = 0.327</td>
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<td>Participant 4: -25.8</td>
<td>t(9) = 0.531, p = 0.304</td>
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<td>VI + S + SH (cDTC, %)</td>
<td>-11.7 (SD: 11.8)</td>
<td>Participant 1: 28.3**</td>
<td>t(9) = 3.232, p = 0.005</td>
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<td>Participant 2: 13.7*</td>
<td>t(9) = 2.052, p = 0.035</td>
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<td>Participant 3: 6.1</td>
<td>t(9) = 1.438, p = 0.092</td>
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<td>Participant 4: -19.5</td>
<td>t(9) = -0.630, p = 0.272</td>
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<td>VI + S + OR (cDTC, %)</td>
<td>-13.1 (SD: 16.3)</td>
<td>Participant 1: -8.3</td>
<td>t(9) = 0.281, p = 0.393</td>
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<td>Participant 2: 11.9</td>
<td>t(9) = 1.462, p = 0.089</td>
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<td>Participant 3: -9.0</td>
<td>t(9) = 0.240, p = 0.408</td>
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<td>Participant 4: -35.9</td>
<td>t(9) = -1.334, p = 0.108</td>
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<tr>
<td>VI + S + SH + OR (cDTC, %)</td>
<td>-6.4 (SD: 17.5)</td>
<td>Participant 1: 35.9*</td>
<td>t(9) = 2.305, p = 0.023</td>
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<td>Participant 2: 28.6*</td>
<td>t(9) = 1.907, p = 0.045</td>
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<td>Participant 3: -4.8</td>
<td>t(9) = 0.087, p = 0.466</td>
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<td>Participant 4: -20.1</td>
<td>t(9) = -0.746, p = 0.237</td>
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<tr>
<td>VI + S + OL (cDTC, %)</td>
<td>-9.8 (SD: 18.0)</td>
<td>Participant 1: -0.1</td>
<td>t(9) = 0.514, p = 0.310</td>
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<td>Participant 2: 19.6</td>
<td>t(9) = 1.577, p = 0.077</td>
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<td>Participant 3: -14.5</td>
<td>t(9) = -0.249, p = 0.405</td>
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<td>Participant 4: -35.2</td>
<td>t(9) = -1.345, p = 0.106</td>
</tr>
<tr>
<td>VI + S + SH + OL (cDTC, %)</td>
<td>-11.4 (SD: 16.6)</td>
<td>Participant 1: 17.6</td>
<td>t(9) = 1.666, p = 0.065</td>
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<td>Participant 2: 0.3</td>
<td>t(9) = 0.672, p = 0.259</td>
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<td>Participant 3: -1.9</td>
<td>t(9) = 0.546, p = 0.299</td>
</tr>
<tr>
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<td>Participant 4: -33.1</td>
<td>t(9) = -1.246, p = 0.122</td>
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<tr>
<td>Total (all conditions) (cDTC, %)</td>
<td>-10.9 (SD: 12.7)</td>
<td>Participant 1: 13.4*</td>
<td>t(9) = 1.824, p = 0.050</td>
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<td>Participant 2: 13.5*</td>
<td>t(9) = 1.823, p = 0.050</td>
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<td>Participant 3: -4.6</td>
<td>t(9) = 0.473, p = 0.324</td>
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<td>Participant 4: -25.9</td>
<td>t(9) = -1.126, p = 0.145</td>
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* Significant difference (p ≤ 0.05)
** Significant difference (p ≤ 0.01)

Abbreviations: VI, visual interference task; S, skating; SH, stickhandling; OR, obstacle avoidance to the right; OL, obstacle avoidance to the left; SD, standard deviation; RRT, response reaction time; cDTC, cognitive dual task cost
### Table 4.5: Cognitive performance (response errors) of concussed participants compared to non-injured controls

<table>
<thead>
<tr>
<th>Condition</th>
<th>Non-injured Controls (n=10)</th>
<th>Concussed Participants (n = 4)</th>
<th>Significance (one-tailed probability)</th>
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<td>Baseline (Errors, n)</td>
<td>0.2 (SD: 0.4)</td>
<td>Participant 1: 0</td>
<td>t(9) = -0.477, p = 0.323</td>
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<td>Participant 2: 0</td>
<td>t(9) = -0.477, p = 0.323</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 3: 0</td>
<td>t(9) = -0.477, p = 0.322</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 4: 0</td>
<td>t(9) = -0.477, p = 0.323</td>
</tr>
<tr>
<td>VI + S (Errors, n)</td>
<td>0.1 (SD: 0.3)</td>
<td>Participant 1: 0</td>
<td>t(9) = -0.318, p = 0.379</td>
</tr>
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<td>Participant 2: 2*</td>
<td>t(9) = 6.039, p = 0.0001</td>
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<td>Participant 3: 1*</td>
<td>t(9) = 2.860, p = 0.009</td>
</tr>
<tr>
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<td></td>
<td>Participant 4: 0</td>
<td>t(9) = -0.318, p = 0.379</td>
</tr>
<tr>
<td>VI + S + SH (Errors, n)</td>
<td>0.2 (SD: 0.6)</td>
<td>Participant 1: 2*</td>
<td>t(9) = 2.860, p = 0.009</td>
</tr>
<tr>
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<td>Participant 2: 0</td>
<td>t(9) = -0.318, p = 0.379</td>
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<tr>
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<td>Participant 3: 0</td>
<td>t(9) = -0.318, p = 0.379</td>
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<tr>
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<td></td>
<td>Participant 4: 0</td>
<td>t(9) = -0.318, p = 0.379</td>
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<tr>
<td>VI + S + OR (Errors, n)</td>
<td>0.7 (SD: 1.3)</td>
<td>Participant 1: 2</td>
<td>t(9) = 0.953, p = 0.183</td>
</tr>
<tr>
<td></td>
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<td>Participant 2: 0</td>
<td>t(9) = -0.513, p = 0.310</td>
</tr>
<tr>
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<td>Participant 3: 1</td>
<td>t(9) = 0.220, p = 0.415</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 4: 0</td>
<td>t(9) = -0.513, p = 0.310</td>
</tr>
<tr>
<td>VI + S + SH + OR (Errors, n)</td>
<td>0.2 (SD: 0.6)</td>
<td>Participant 1: 1</td>
<td>t(9) = 1.271, p = 0.118</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 2: 0</td>
<td>t(9) = -0.318, p = 0.379</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 3: 0</td>
<td>t(9) = -0.318, p = 0.379</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 4: 0</td>
<td>t(9) = -0.318, p = 0.379</td>
</tr>
<tr>
<td>VI + S + OL (Errors, n)</td>
<td>0.6 (SD: 1.3)</td>
<td>Participant 1: 0</td>
<td>t(9) = -0.440, p = 0.335</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 2: 1</td>
<td>t(9) = 0.293, p = 0.389</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 3: 0</td>
<td>t(9) = -0.440, p = 0.335</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 4: 0</td>
<td>t(9) = -0.440, p = 0.335</td>
</tr>
<tr>
<td>VI + S + SH + OL (Errors, n)</td>
<td>0.7 (SD: 1.1)</td>
<td>Participant 1: 0</td>
<td>t(9) = -0.607, p = 0.280</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 2: 0</td>
<td>t(9) = -0.607, p = 0.280</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 3: 0</td>
<td>t(9) = -0.607, p = 0.280</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 4: 0</td>
<td>t(9) = -0.607, p = 0.280</td>
</tr>
<tr>
<td>Total (all conditions)</td>
<td>2.7 (SD: 3.4)</td>
<td>Participant 1: 5</td>
<td>t(9) = 0.645, p = 0.268</td>
</tr>
<tr>
<td>(Errors, n)</td>
<td></td>
<td>Participant 2: 3</td>
<td>t(9) = 0.084, p = 0.467</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 3: 2</td>
<td>t(9) = -0.196, p = 0.424</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant 4: 0</td>
<td>t(9) = -0.757, p = 0.234</td>
</tr>
</tbody>
</table>

* Significant difference (p ≤ 0.01)

Abbreviations: VI, visual interference task; S, skating; SH, stickhandling; OR, obstacle avoidance to the right; OL, obstacle avoidance to the left; SD, standard deviation; n, number
4.5 Discussion

This single case pilot study was conducted to act as an initial step towards a greater understanding of the influence of concussion on cognitive performance in youth ice hockey players and to inform further study and development of sport-specific measures of readiness to return to play. To our knowledge, this study shows for the first time the use of an ice hockey specific assessment protocol to compare cognitive abilities of concussed youth athletes to non-injured controls. Although generally descriptive, findings illustrate differences in cognitive abilities during concurrent ice hockey specific task performance. Specifically, when examining cDTC performance, two of the four concussed participants performed significantly poorer than non-injured controls on at least one of the six total conditions of combined visual interference and ice hockey skills, as well as across all conditions collapsed. These findings support results reported in previous study examining the influence of combined locomotor and cognitive task performance on cognitive outcomes in athletes following concussion (Catena et al., 2011; Fait et al., 2009; Fait et al., 2012), however, the current study demonstrates this influence in youth athletes for the first time.

When considering response errors during concurrent task performance, fewer differences between concussed individuals and non-injured controls were found. Here, there were only three instances across conditions where concussed participants performed significantly poorer than non-injured controls, compared to the six instances for cDTC. Further, when considering all conditions collapsed, no concussed participants demonstrated significantly more total response errors than non-injured controls, compared to two of the four concussed participants who demonstrated significantly greater total cDTC than non-injured controls. Halterman et al. (2006) found a similar contrast in cognitive performance results when examining reaction time and response accuracy on a visuospatial task, reporting significantly slower reaction times in concussed athletes compared to healthy controls, however no difference between groups specific to response accuracy. It is possible that measures of reaction time, such as that used to calculate cDTC within the current study, can be considered more sensitive than measures of response errors, where this increased sensitivity allows for the recognition of post-concussion performance deficits. This finding of increased sensitivity to impairment when using measures of cognition that are reaction time-based compared to
Response accuracy-based can be used to inform which measures are most appropriate to include within further study and during clinical situations when assessing post-concussion cognitive performance as a means to inform recovery and return to play decisions.

4.5.1 Influence of condition on cognitive performance

This study found that the performance of some conditions during the study protocol resulted in significant deficits in cognitive performance amongst concussed participants, while others did not. Performance during the most complex combination of concurrent tasks (4 tasks: visual interference task + skating + stickhandling + obstacle avoidance right), resulted in the greatest amount of relative cDTC across participants (Participant 1: 35.9%; Participant 2: 28.6%), where this performance was considered significantly poorer than non-injured controls (Participant 1: t(9) = 2.305, p = 0.023; Participant 2: t(9) = 1.907, p = 0.045). These findings are consistent with previous study of concussed adults during the performance of combined cognitive and locomotor tasks, where increased task complexity resulted in greater dual task costs (Fait et al., 2012).

During the completion of the most complex combination of concurrent tasks, it is interesting to note that a significant influence when comparing concussed participants to non-injured controls was only found during obstacle avoidance to the right side and not to the left. Why the side of circumvention resulted in different effects on cDTC is unclear at this point. When using an identical protocol to examine the influence of completing tasks of increased complexity on cognitive performance in youth ice hockey players, Fait et al. (2011) also found that participants demonstrated significantly greater cDTC during the most complex experimental condition and only when avoiding the obstacle to the right side. One possible explanation put forth by Fait et al. (2011) was related to the side of the body that participants stickhandle most comfortably on, where increased comfort related to stickhandling side may result in less cognitive resources required to avoid an obstacle on that side leading to the potential for lower levels of cDTC. In their study, seven of eight healthy youth ice hockey players stickhandled most comfortably on the left side. Related to the current study, it appears that the side of the body concussed participants stickhandled most comfortably was not a factor as Participant 1 stickhandled on the right side and Participant 2 stickhandled on
the left side, and both demonstrated significant cDTC when avoiding the obstacle to the right side.

Although the largest cDTC were found during the completion of conditions of the greatest complexity, significant performance deficits related to cDTC and response errors when comparing concussed participants to non-injured controls were also found during the completion of conditions of lesser complexity (Participant 1 demonstrated significantly greater cDTC during visual interference task + skating and significantly greater cDTC and response errors during visual interference task + skating + stickhandling; Participant 2 demonstrated significantly greater response errors during visual interference task + skating and significantly greater cDTC during visual interference task + skating + stickhandling; and, Participant 3 demonstrated significantly greater response errors during visual interference task + skating). These findings suggest that completing concurrent cognitive and motor tasks can discriminate performance between concussed participants and non-injured controls, despite a lower level of task complexity. From a clinical perspective, these findings begin to support further development of improved assessment protocols to be used in youth following concussion and the value in assessing concurrent task performance at different levels of complexity.

4.5.2 Influence of time since injury on cognitive performance

Descriptively, time since injury (days post-concussion) appeared to influence the cognitive abilities of concussed athletes during concurrent task performance. Specific to cDTC, the greatest dual task costs for each condition and all conditions collapsed were demonstrated by the participants who sustained their concussions most recently (Participant 1, 44 days post-concussion; and, Participant 2, 58 days post-concussion). Further, these participants were the most likely to perform worse than non-injured controls, demonstrating significantly higher cDTC scores on three of six conditions for Participant 1 (visual interference task + skating; visual interference task + skating + stickhandling; and, visual interference task + skating + stickhandling + obstacle avoidance to the right) and two of six conditions for Participant 2 (visual interference task + skating + stickhandling; and, visual interference task + skating + stickhandling + obstacle avoidance to the right), as well as for all conditions collapsed. What
is most intriguing about these findings is that although these participants were a considerable time post injury (44 and 58 days), were no longer reporting post-concussion symptoms, and did not perform significantly poorer than non-injured controls on isolated cognitive assessment (baseline/static visual interference task), they demonstrated significant deficits in reaction time during sport-specific task performance. Although traditional and internationally recognized post-concussion rehabilitation protocols and recommendations (McCrory et al., 2009) would view these participants as ready to return to sport participation (no post-concussion symptoms, no deficits on isolated cognitive assessment), it is clear that based on the assessment of cognitive abilities during real-world and sport-specific task performance, this may not be the case.

Using the most extreme case as an example, during concurrent visual interference task performance, skating, stickhandling and obstacle circumvention to the right (most complex of conditions), concussed participants 1 (44 days post-concussion) and 2 (58 days post-concussion) respectively reacted to visual stimuli 36% and 29% slower than when reacting to the same visual stimuli in the absence of concurrent task performance. Functionally, related to ice hockey participation, this slowed ability to respond to visual stimuli (e.g., an opponent) may result in the inability to avoid an injurious situation (e.g., body contact from an opponent) and the potential for a secondary concussive event. The uncovering of residual deficits following concussion, despite being considered fully recovered, is supported by previous laboratory-based study where concurrent cognitive and motor tasks were assessed in concussed college-aged athletes (Fait et al., 2009; Fait et al., 2012). Together, these findings support the notion of using a more ecologically valid assessment of performance in order to determine readiness to return to sport participation following concussion.

4.5.3 Study limitations
The small sample size of this study can be considered a limitation, only allowing for limited descriptive report of cognitive performance between four concussed individuals and a small non-injured control group. Further study involving larger numbers of concussed and non-injured athletes is needed in order to support the current findings and to further explore the use of concurrent and sport-specific task performance when assessing outcomes following
concussion in this population. Additionally, in order to generalize findings outside of youth males, inclusion of ice hockey players of different ages and genders is needed. Although overall differences in cognitive performance (cDTC) were found between non-injured controls and concussed participants up to 58 days post-injury, the length of time post-injury for the concussed participants involved in this study can be considered a limitation. It is possible that additional cognitive performance deficits would have been found in athletes who had experienced more recent concussions and further insight into the influence of time since injury on task performance could have been obtained. Due to the limited access to ice time at community ice hockey rinks, study participants were grouped in order to complete multiple assessment sessions across a given testing day, making it difficult to assess individual athletes closer to the time of their injury. Future study would benefit from additional resources specific to ice time availability and a more focused approach to recruiting participants who have experienced more recent concussions.

The potential influence of participant skill level could be viewed as a limitation to this study. Although participants were included within the study according to the competition level for which their ice hockey team participated at (either A or AA) in order to examine participants of similar ice hockey playing ability, great variability in skill level amongst participants may still have existed. Capacity theories are often considered the dominant cause of dual task costs during concurrent task performance (Abernathy, 1988), where decreased performance is due to competition between tasks for a finite pool of cognitive resources (Maki & McIlroy, 2007). It has been argued that the more automatic task completion is, the less cognitive resources are needed to perform this task and the less influence this task performance will have on potential dual task costs (Haggard et al., 2000). It is possible that in more skilled youth ice hockey players, performing ice hockey related tasks may be more automatic and thus, less likely to influence dual tasks costs specific to cognitive performance. Future study could use additional measures of baseline ice hockey skill performance (e.g., skating ability, stickhandling skills etc.) as a means to categorize participants according to skill level and further explore the influence of ice hockey skills on concurrent task performance.

Finally, future study should focus directly on exploring dual tasks costs from both a cognitive
and a motor perspective. Although ice hockey requires a high level of cognitive activity, including the need to quickly respond to visual stimuli, it also involves significant motor demands. Considering that performance decrements during concurrent task completion may be a result of competition between tasks for a finite pool of cognitive resources (Maki and McIlroy, 2007), it is possible that allocation of these resources towards cognitive performance may result in decrements in motor performance (or vice versa). When examining concurrent cognitive (reaction time to visual stimuli) and locomotor (skating) performance in healthy youth ice hockey players, Fait et al. (2011) reported that participants compromised skating speed to maintain cognitive performance during a visual interference task. The collection and comparison of cognitive and motor dual task costs in future studies can provide a more accurate description of performance deficits in the presence of concurrent tasks.

4.6 Conclusion

Participation in the sport of ice hockey can be considered highly cerebral, where the ability to respond to concurrent stimuli is necessary. If deficient in the ability to respond to and avoid potentially injurious situations (e.g. body contact from an opponent) as the result of a concussion, youth ice hockey players may be at risk for repeated, and more serious, brain injury. This pilot descriptive study demonstrated that despite being up to 58 days post-concussion, reporting no post-concussion symptoms and performing at a comparable level to non-injured controls on an isolated assessment of cognitive performance, when performing concurrent ice hockey specific skills, concussed youth ice hockey players demonstrated deficits in cognitive abilities. Although preliminary, the findings presented within this study support the need for further research exploring the use of ecologically valid and sport specific assessment protocols to provide a more accurate index of readiness to return to play following concussion. The eventual implementation of such an assessment within clinical athlete populations may help to reduce the risk of repeated concussive injuries and promote improved outcomes following sport-related concussion.
4.7 References


Chapter 5

5  Sport-related concussion and occupational therapy: Expanding the scope of practice

This chapter presents a commentary on the potential inclusion of occupational therapy services during the management of concussion in youth athletes. Specific to this thesis’ guiding conceptual model, this chapter aims to address the need for improved management of concussion in youth ice hockey players by considering the person, environment and occupation during the delivery of an occupational therapy-based approach to rehabilitation.

An abbreviated version of this chapter was published within Physical and Occupational Therapy in Pediatrics:


5.1 Introduction

Sport participation is a common occupation for many children and youth and can lead to improved physical and psychosocial health (Strong et al., 2005). Despite these benefits, it exposes children and youth to the increased risk of injury. Concussion, also referred to as mild traumatic brain injury, is one of the most common sports injuries reported in the pediatric population, where a child is six times more likely to suffer a concussion during organized sport participation than during other physical leisure activities (Browne & Lam, 2006). Children and youth can experience a range of neurobehavioural deficits following concussion including somatic, cognitive and emotional/behavioural post-concussive symptoms (Kirkwood, Yeates, & Wilson, 2006) that can have a significant impact on daily function.

The profession of occupational therapy has yet to be widely recognized or utilized within the world of sport when rehabilitating athletes following a concussion. However, the importance of an interdisciplinary approach to sport-related concussion management has been promoted internationally (McCrory et al., 2005; McCrory et al., 2009). The combinations of symptoms
associated with sport-related concussion can have a significant impact on occupational performance, both on and off the playing field. Occupational therapists can assume a variety of roles (listed below) specific to the safe return of athletes to their meaningful daily occupations. This commentary aims to act as a starting point for exploration of sport-related concussion from an occupational perspective and to expand the scope of occupational therapy practice into the world of sport.

5.2 Role of occupational therapy

5.2.1 Development of client-centred rehabilitation goals

Practicing in a client-centred manner is a key competency for occupation therapists (CAOT, 2007). Client-centred practice emphasizes equality, sharing and partnership between the therapist and the client (Fearing & Clark, 2000). It incorporates an understanding that the client is the expert on their life and related daily activities (Fearing & Clark, 2000), where key principles include determining who the client is, respecting the client’s value system, assisting the client to set meaningful occupational goals and to utilize the therapists’ skills and expertise to allow the client to achieve these goals (CAOT, 2002). Using a client-centred approach, rehabilitation goals specific to the performance of functional activities that are meaningful and important (e.g. return to sport, return to school, activities of daily living etc.) can be identified collaboratively between the therapist, the youth athlete and their family. It has been reported that increased attention to client priorities during goal setting and treatment can lead to improved client motivation, satisfaction and rehabilitation outcomes (Law, Baptiste, Carswell, McColl, Polatajko, & Pollock, 2005; Law, Baptiste, & Mills, 1995; Sumsion & Smyth, 2000).

One measure that can be used to identify occupational performance issues of youth athletes following sports-related concussion in a client-centred manner is the Canadian Occupational Performance Measure (COPM) (Law et al., 2005). This measure allows the therapist and the client to collaboratively identify occupational performance issues in the areas of self-care, productivity and leisure that can be addressed within the rehabilitation process. Additionally, the COPM allows the youth athlete to rate their performance and satisfaction with
performance specific to identified occupational performance issues prior to rehabilitation and again throughout the rehabilitation process as a measure of outcome (Law et al., 1990). Incorporating a client-centred approach to rehabilitation is a role that occupational therapists can assume within a multidisciplinary sport-related concussion management and rehabilitation team, allowing for the identification and treatment of the functional issues that are important to the youth athlete and their family.

5.2.2 Energy conservation

According to the most recent consensus statement on concussion in sport (McCrory et al., 2009) the cornerstone of concussion management is physical and cognitive rest until post-concussive symptom resolution has occurred. Although the recommendation of rest and its relation to avoiding sport and/or school participation may be clear to most (e.g. do not take part in sport-related activities etc.), its relation to how rest can be incorporated into all aspects of daily function may not be as apparent. As a member of a multidisciplinary sport-related concussion rehabilitation team, occupational therapists can assume the role of educating the youth athlete and their family on the importance of rest during their recovery and how rest can be incorporated into their daily activities. Furthermore, occupational therapists can provide the athlete and family with client-centred energy conservation strategies in order to reduce both physical and cognitive exertion. Providing clients from a wide range of clinical populations with energy conservation strategies is a common practice in occupational therapy, where general education on avoiding excessive exertion and individualized client-centred plans specific to particular daily activities can be delivered. One approach to energy conservation is the adherence to the four P’s (CAOT, 2012). Applying the concepts of prioritizing, planning, pacing and positioning (physically and environmentally) to the completion of daily tasks can assist in limiting unnecessary physical and cognitive demands of the youth athlete and can contribute to both achieving the goal of appropriate rest until post-concussive symptoms have resolved and promoting effective reintegration into daily activities.

5.2.3 Return to play

When considering return to play or return to sport participation following a concussion,
current international consensus guidelines (McCrory et al., 2009) recommend following a graduated return to play protocol. This protocol is designed to reintroduce the athlete to sport activity using a step-wise progression of physical exercise and sport-specific skills (see Table 5.1) upon post-concussive symptom resolution. It is recommended that each stage within the gradual return to play protocol take 24 hours to complete and that athletes are to drop to the previous asymptomatic stage of the protocol if any post-concussive symptoms occur during any one stage of the step-wise protocol (McCrory et al., 2009). Furthermore, due to a different physiological response and the potential for longer recovery, a more conservative approach to return to play that can include extended periods of asymptomatic rest is recommended for children (McCrory et al., 2009). With unique consideration of the occupational and environmental demands of the particular sport an athlete is returning to (e.g. physical and cognitive demands of the particular sport and context in which it is played), occupational therapists can be involved in the design and supervised delivery of individualize, client-centred gradual return to play protocols. In particular, considering the cognitive demands of a particular sport can be a unique contribution of occupational therapy during the return to play process, where in addition to the currently recommended step-wise physical exertion, occupational therapists can explicitly incorporate gradual cognitive exertion into the rehabilitation protocol. It has been reported that following concussion, performance deficits arise when motor and cognitive tasks are performed concurrently that may have otherwise gone unnoticed if assessed in isolation of one another (Fait, McFadyen, Swaine, & Cantin, 2009; Parker, Osternig, van Donkelaar, & Chou, 2007). Developing and implementing a step-wise gradual return to play protocol that is functional, sport-specific and considers the influence of cognitive exertion on performance and post-concussive symptom exacerbation can help provide a more accurate index of a youth athlete’s ability to safely return to full sport participation.

5.2.4 Return to school
The post-concussive symptoms experienced by youth athletes following a sport-related concussion can have a detrimental effect on school-based occupations and performance (Grady, 2010; Halstead, 2010; McCrory et al., 2004). Somatic symptoms, such as headache, nausea and dizziness, along with cognitive symptoms related to deficits in memory and
Table 5.1: Gradual return to play protocol

<table>
<thead>
<tr>
<th>Rehabilitation Stage</th>
<th>Activity/Functional Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No activity</td>
<td>Complete cognitive and physical rest.</td>
</tr>
<tr>
<td>2. Light aerobic exercise</td>
<td>Walking, swimming or stationary cycling at $&lt;70%$ of maximal predicted heart rate. No resistance training</td>
</tr>
<tr>
<td>3. Sport-specific exercise</td>
<td>Sport-specific drills (skating in hockey, running in soccer). No head impact activities</td>
</tr>
<tr>
<td>5. Full-contact practice</td>
<td>Participate in normal practice/training activities, following medical clearance</td>
</tr>
<tr>
<td>6. Return to play</td>
<td>Normal game play</td>
</tr>
</tbody>
</table>

*Modified version of recommendations presented at Third International Conference on Concussion in Sport (McCrory et al., 2009)

Attention can greatly impede new learning (Grady, 2010), where increased cognitive activity inherent to school-based occupations prior to recovery can result in exacerbation of post-concussive symptoms and prolong recovery (Grady, 2010; Lee & Perriello, 2009; McCrory et al., 2005). Despite the recommendation for cognitive rest and the related limitations on school-based activities, prolonging return to school for too long may impede a child’s recovery further by way of falling behind in school and related feelings of stress and anxiety, or disruption in social or familial occupations and routines (Kirkwood et al., 2008). Furthermore, returning to school after an absence may lead to expectations to make-up missed school work at an accelerated rate, where at this stage in recovery, the child often cannot handle the increased cognitive demands and workload (Grady, 2010).
Much like returning to sport participation, a gradual return to full school-based occupations with the provision of modifications to school demands and environments is recommended following concussion (Grady, 2010; Halstead, 2010; Kirkwood et al., 2008; Lee & Perriello, 2009; Piebes, Gourley, & Valovich McLeod, 2009). Kirkwood et al. (2006) recommend three stages of support required for effective transition back to school following a concussion which include: 1) initial transitional support (school personnel informed of injury and potential consequences, reintegration into school occurs gradually, student not expected to make-up all missed work); 2) general school-based support (regular monitoring of student performance by school personnel, ensure rest time and breaks as needed, reduce total workload and cognitively demanding tasks such as testing); and, 3) specific classroom-based support (delay testing, flexible assignment time limits and due dates, preferential seating and environmental modifications to limit distractions). Using aspects of the Person-Environment-Occupation (PEO) Model (Law et al., 1996) to guide occupational therapy involvement, where optimal occupational performance of school-based activities occurs when the abilities of the person are best matched with the demands of the occupations themselves and the environment in which these occupations are performed (Strong et al., 1999), occupational therapists can assist the student athlete to best meet school demands and their individual performance goals.

Occupational therapists can be involved in this stage of the rehabilitation process in order to develop client-centred return to school care plans that address the specific functional deficits and needs of the student athlete. In addition, communication of the return to school care plan and general concussion education to school personnel is paramount to ensure an effective return to school process (Grady, 2010; Kirkwood et al., 2006; Piebes et al., 2009). Within the multidisciplinary sport-related concussion rehabilitation team, occupational therapists can act as the liaison between the student athlete (and their family) and school personnel, making sure that guidance counsellors, school nurses and teachers are aware of the child’s concussion-related deficits, that appropriate modifications are made within the school environment and that changes to the return to school care plan are implemented appropriately as recovery progresses.
5.2.5 Cognitive function

As stated previously, cognitive symptoms are common following concussion (Kirkwood, Yeates, & Wilson, 2006), where deficits in information processing, attention and memory can often persist (Mittenberg & Strauman, 2000). International sport concussion consensus guidelines (McCrory et al., 2009) highlight the benefit of neuropsychological assessment following sport-related concussion as a means to measure cognitive recovery. Occupational therapy can contribute to this neuropsychological evaluation by documenting any functional cognitive deficits assessed using function-based standardized assessments or thorough observation of meaningful and important daily occupations. In the event that persisting cognitive deficits exist and influence one’s performance of daily tasks, occupational therapy can contribute to the rehabilitation process by developing appropriate interventions. To date, when considering cognitive rehabilitation for individuals with concussion, there is substantial empirical evidence in support of using compensatory strategy training for memory and attention deficits (Cicerone et al., 2000; Cicerone et al., 2005), where the use of such strategies has been recommended specifically for the concussion population (Gordon, Dooley, & Wood, 2006; Ponsford, 2005). Compensatory strategies for attention deficits used by the occupational therapist when treating sport-related concussion may include task modification (completing one task at a time, breaking tasks down into stages), removing distractions from the environment, pacing and planning task completion for optimal times of the day (high energy, low post-concussive symptoms) (Michel & Mateer, 2006; Radomski et al., 2009; Sohlberg & Mateer, 2001). Compensatory strategies for memory deficits provided by the occupational therapist to the youth athlete could be the use of a memory notebook/planner or additional external memory aids (Cappa et al., 2005; Cicerone et al., 2005; Sohlberg & Mateer, 1989). It is often thought that cognitive capacity is a finite commodity where competing demands for this capacity can cause performance deficits (Pashler, 1999) and that sustaining a concussion may contribute to decreasing one’s available cognitive capacity (Ebersbach, Dimitrijevic, & Poewe, 1995). The inclusion of occupational therapy within the sport-related concussion rehabilitation process can allow for the provision of compensatory cognitive strategies that may allow youth athletes to better function within their daily lives and help conserve cognitive resources until they have recovered from their
injury.

5.2.6 Retirement from sport/exploring alternative occupations

To date, there are no evidence-based recommendations to determine when an athlete, let alone a youth athlete, should no longer participate in sport due to repeated concussion or related deficits (McCrory, 2001). In the event that a youth athlete and their family receives the clinical recommendation or decides independently to no longer play a given sport or sports due to a history of concussion, an occupational therapist can play a large role in helping the youth athlete to explore alternative occupations. To many youth athletes, sport participation can be considered an occupation of great importance and meaning. The role of an occupational therapist in this situation would be to enable the athlete to identify and participate in different occupations that can also be considered important and meaningful to the athlete, as well as being well-matched to the athlete’s current needs and abilities. As mentioned previously, using aspects of the PEO model (Law et al., 1996) to guide clinical practice where the demands of the occupation and the environmental context in which it is performed are matched to the current abilities of the person, can help youth explore alternative occupations that provide similar satisfaction and meaning, without exposing them to an increased risk of re-injury and further deficits during the performance of daily activities.

5.3 Conclusion

Sport-related concussion is a common injury for youth, where post-concussive symptoms can influence one’s ability to perform daily occupations of importance and meaning. This commentary attempted to highlight the issue of sport-related concussion within the youth sport population and to present, for the first time, potential roles for occupational therapists during the rehabilitation process of the youth athlete post-concussion. A holistic, client-centred approach that enables children and youth to return to occupations both on and off the playing field is important following sport-related concussion. The potential roles for occupational therapy presented serve as a springboard for reflection and hopefully, action amongst occupational therapists, to expand their scope of practice into the world of sport.
5.4 References


*Occupational Therapy, 66*(3), 122-133.


Chapter 6

6 Summary and general discussion

6.1 Introduction

Ice hockey participation is a popular and meaningful activity amongst Canadian youth. Despite the numerous benefits of sport participation, involvement in ice hockey can expose youth to an increased risk of injury, including concussions. Concussion can result in combinations of somatic, cognitive and emotional/behavioural symptoms (Kirkwood, Yeates, & Wilson, 2006) that can greatly influence one's ability to safely participate in sport, as well as to engage in meaningful activities outside of the sport context (e.g., school, family and social activities). Further, it is thought that the developing brain of children and youth may be more vulnerable to concussion and related functional deficits (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2001; McCrory, Collie, Anderson, & Davis, 2004). Despite growing public interest in sport-related concussion, along with the popularity of ice hockey amongst Canadian youth, the risk of concussion within this population and the implications for safe and meaningful participation in activities both inside and outside of sport, to date, little research has been conducted specific to concussion in youth ice hockey players. International consensus has promoted the need for further study specific to youth concussion and management paradigms (McCrory et al., 2009). This dissertation was written in order to begin to address this need. Using the PEO Model (Law et al., 2006) as a conceptual framework (see Figure 6.1), this work provides an initial step towards a greater understanding of concussion in youth and a selection of methods that consider the relationship between person, environment and occupation factors can be used to assist in the identification, assessment and management of this injury in youth ice hockey players.

This sixth and final chapter begins by summarizing the key findings of this research. Next, the contribution to the fields of sport-related concussion and rehabilitation, specific to areas of identification, assessment and management of concussion in youth ice hockey players, while considering the importance of person, environment and occupation factors, are discussed. This chapter concludes with suggestions for future study with a focus on the need
to further inform the management of concussion by way of evidence-based options for rehabilitative interventions.

Figure 6.1: Person-Environment-Occupation (PEO) Model. Overlap between person, environment and occupation factors indicates improved occupational performance (modified from Law et al., 1996).

6.2 Summary of findings

Chapter 2 of this thesis explored the head impacts sustained by female youth during ice hockey competition and addressed the following objectives: 1) to describe the number and biomechanical characteristics of head impacts sustained by female youth ice hockey players; and, 2) to explore the influence of player and game characteristics on head impacts sustained by female youth ice hockey players. This study presented, for the first time, a description of the severity and frequency of head impacts sustained by female youth ice hockey players. Recording the head impacts sustained by 27 female youth ice hockey players (age: 12.5 ± 0.5 years) across 66 ice hockey games highlighted that, although at a lower severity and frequency than their male counterparts, head impacts are occurring in female youth ice hockey despite intentional body contact being prohibited.

Using multiple regression, this study was able to explore the factors, and interactions between factors, most associated with head impacts of greater severity and frequency.
Considering the highest order effects specific to head impact severity, a four-way interaction revealed that in older players who had a greater BMI and spent more time in active hockey participation (time on ice), playing the forward position significantly predicted greater linear acceleration of head impacts (Estimate = 1.00; SE = 1.01; $t = 2.80; P = 0.008$), and two three-way interactions revealed that in older players who had a greater BMI, playing the forward position (Estimate = 26.01; SE = 2.82; $t = 3.03; P = 0.008$) and more time spent in active hockey participation (time on ice) (Estimate = 0.02; SE = .005; $t = 4.66; P = 0.0002$) significantly predicted greater rotational acceleration of head impacts. Specific to head impact severity, a significant two-way interaction revealed that during tournament games, increased ice time significantly predicted increased HITsp (Estimate = 0.003; SE = 0.002; $t = 2.28; P = 0.03$) and a significant main effect for age was found (Estimate = 0.95; SE = 0.29; $t = 3.24; P = 0.002$), where an increase in age significantly predicted an increase in HITsp. Finally, with regards to the frequency of head impacts, a significant main effect for BMI (Estimate = 0.90; SE = 1.04; $t = -2.73; P = 0.008$) was found, where having a higher BMI significantly predicted a higher number of head impacts sustained per game. Although no concussions were sustained by the female youth ice hockey players during this study, the findings provide important insight into the player and game characteristics associated with experiencing head impacts during female youth ice hockey competition and contributes to the ability to better identify the risks associated with sustained head impacts that may lead to a concussive event.

The objective of Chapter 3 of this thesis was to explore both the effect of baseline strength performance on future concussion occurrence, as well as the influence of concussion occurrence on post-injury strength performance, within youth ice hockey players. A three-year prospective longitudinal research design was used to assess pre-injury/baseline upper and lower body strength performance of 178 male and female ice hockey players (age: $11.5 \pm 1.1$ years) at the start of each ice hockey season, as well as follow-up assessment on the same strength measures within 18 of these participants following a concussion. This design provided the unique opportunity to follow a group of youth ice hockey players over time to explore how experiencing a concussion can influence strength performance. By way of accounting for heterogeneity in outcome (a phenomenon inherent to concussion) and
accommodating for variable and missing data, using linear mixed-effects modeling to analyze the data collected allowed for optimal exploration of the effects of concussion on strength within this population. Average effects of concussion occurrence on upper and lower body strength were generated across all participants. This study found that when considering post-concussion symptom severity, having a concussion and being in the symptomatic stage post-injury (e.g., experiencing post-concussion symptoms) had a significant effect on upper body (non-dominant hand grip, Estimate = -0.03; SE = 0.02; \( t = -2.01; P = 0.05 \)) and lower body (squat jump height, Estimate = -0.05; SE = 0.02; \( t = -2.51; P = 0.02 \); and, countermovement jump height, Estimate = -0.03; SE = 0.02; \( t = -2.20; P = 0.04 \)) strength following concussion. More surprisingly, even in the absence of post-concussion symptoms (in the asymptomatic stage post-injury), which is thought to be an indicator of recovery following concussion (McCrory et al., 2009), having a concussion had a significant effect on lower body strength (leg maximal voluntary contraction, Estimate = -1.05; SE = 0.47; \( t = -2.27; P = 0.04 \)). These findings suggest the need to consider strength performance when assessing post-concussion abilities and when making decisions regarding the safe return to full sport participation following a concussion.

Chapter 4 of this thesis met the objective of exploring the effect of concussion on cognitive performance in male youth ice hockey players when completing concurrent ice hockey specific skills. In this pilot study, the cognitive abilities during concurrent ice hockey skill performance of 4 male youth ice hockey players who had experienced a concussion within the previous ice hockey season (age: 11.7 ± 0.3 years) were compared to 10 non injured-controls (age: 11.8 ± 0.8 years). This study found that despite comparable performance during an isolated assessment of cognition (static visual interference task), male youth ice hockey players who were <58 days post-concussion demonstrated significantly poorer cognitive performance (increased dual task cost specific to verbal reaction time to visual stimuli) across all conditions when completing a visual interference task concurrently with ice hockey specific skills compared to non-injured control participants (\( p = 0.05 \)). Although preliminary, these findings suggest that when completing combined real world and sport specific tasks, residual post-concussion cognitive deficits may be detected. This study acts as an initial step towards the development of a more accurate index of readiness to return to play. By way of informing the need for more sensitive assessment of abilities following
concussion, this study can promote safer participation in sport for athletes who have experienced a concussion.

Finally, Chapter 5 of this thesis presented a commentary on the role of occupational therapy during the management of sport-related concussion in youth athletes. Although not a traditional component of post-concussion care, this chapter highlights six potential roles for occupational therapy specific to sport-related concussion (development of client-centred rehabilitation goals, energy conservation, return to play, return to school, addressing cognitive function and exploring alternative occupations) are presented along with supporting literature. This chapter was designed to promote improved management of sport-related concussion in youth and to ignite interest amongst occupational therapists to apply their skills and abilities to this population and stream of clinical practice. Further discourse and research-based exploration of approaches to managing concussion across health professions is needed in order to best meet the needs of the sport community.

6.3 Contributions

To date, little information exists specific to concussion in youth athletes and the need for more focused study of concussion and management paradigms within this population has been recommended internationally (McCrory et al., 2009). As a result, it is important that concussion in youth athletes be studied where a variety of factors can be explored as a means to help inform our general understanding of the injury and promote improved outcomes amongst youth athletes. The contributions of this research are discussed in relation to the identification, assessment and management of concussion in youth ice hockey players, along with the consideration of person, environment and occupation factors related to conceptual framework (PEO Model, Law et al., 1996) used to guide inquiry. This conceptual framework allowed for the identification and exploration of previously unexplored gaps in research specific to sport-related concussion in youth ice hockey players, and to do so while considering the influence of a variety of factors (person, environment and occupation) on how to best identify, assess and manage this injury.
6.3.1 Identification

In order to better understand concussion in youth ice hockey players, we must first gain a greater sense of when and why this injury is occurring. Although high speed play, environmental hazards (e.g., ice, boards etc.) and frequent body contact have been suggested as contributors to concussion in youth ice hockey (Williamson & Goodman, 2006), focused study on the factors that can lead to these injuries is important in order to identify prevalence and risk, and to allow members of the youth ice hockey community to make informed decisions regarding participation. As forces applied to the head are the prominent cause of concussion (McCrory et al., 2009), exploring the prevalence and nature of head impacts sustained by youth ice hockey players can help inform a greater understanding of what factors may lead to concussion within the youth population. Previous study has explored the head impacts sustained by male youth ice hockey players (Cubos et al., 2009; Mihalik et al., 2008; Mihalik et al., 2010; Mihalik at al., 2012; Reed et al., 2011), however despite reports that rates of concussion amongst female ice hockey players are higher than males (Agel and Harvey, 2010), prior to this dissertation, the head impacts sustained by female youth ice hockey players had yet to be explored.

Chapter 2 of this thesis addressed the objectives of: 1) describing the number and biomechanical characteristics of head impacts sustained by female youth ice hockey players; and, 2) exploring the influence of player and game characteristics on head impacts sustained by female youth ice hockey players. According to the PEO Model (Law et al., 2006), used as a conceptual framework to guide inquiry throughout this thesis, Chapter 2 explores the identification of the head impacts sustained amongst female youth ice hockey players through the consideration of person factors (e.g., player position, body size), environment factors (e.g., the context of female youth ice hockey, how much time players are on the ice in a given game) and occupation factors (e.g., engaging in ice hockey participation). The interactions between player and game characteristics and head impact biomechanics presented within this chapter provide insight into what factors (and combinations of factors) contribute to head impacts of greatest severity and frequency that may lead to a concussive event during female youth ice hockey competition. Further, this study supports the importance of exploring this phenomenon from a multifactor and broad prospective that
considers not just the individual, but what activities the individual is performing and in what environment they are performed.

It is known that concussions are a result of a direct blow to the head or anywhere else on the body that results in biomechanical forces being transmitted to the head and brain (McCrory et al., 2009). Although no concussions were sustained within this study, the findings provide a first step towards a greater understanding of the nature of biomechanical forces being applied to the head during female youth ice hockey competition. Although no threshold for concussion specific to impact force or frequency was found, this study provides insight into the occurrence of head impacts in youth female ice hockey, as well as the player and game characteristics associated with these impacts. It is possible that with further study, these characteristics may be shown to result not only in head impacts of increased severity and frequency, but also in an increased risk for concussion within this population.

6.3.2 Assessment
Following injury, assessment of one's abilities can help inform the presence and severity of impairment, the stage of recovery and the need for specific rehabilitation services. Specific to sport-related concussion, assessment is often used to inform recovery from the injury and to determine readiness to return to activities of importance and meaning, including sport participation. Traditionally, the assessment of post-concussion symptoms is used to inform readiness to reintegrate into physical activity, where the absence of symptoms during gradual and step-wise exercise performance is used to inform return to play decisions (McCrory et al., 2009). Further, international consensus on sport-related concussion suggest that objective evaluation of balance and cognitive function can be useful when assessing the motor and cognitive domains of neurologic functioning respectively (McCrory et al., 2009). To date, limited research has explored post-concussion measures of performance outside of the traditional assessment of post-concussion symptoms, neurocognitive performance and balance performance, and even less so in the youth population. In order to most effectively manage concussion in youth, it is paramount that we have a more thorough understanding of what aspects of performance are affected as a result of a concussion and what techniques can be used to assess this performance. Again, this research was guided by the PEO Model (Law
et al., 1996) that posits that one’s ability to perform an occupation (e.g., a task or activity of meaning and importance) is influenced by the overlap (or fit) between person factors (e.g., one’s physical or cognitive abilities), environment factors (e.g., the demands inherent to the environment an occupation is being performed in) and occupation factors (e.g., the demands inherent to the task or activity being performed). In order to appropriately assess performance following concussion in youth athletes, it is important to acknowledge that participating in the sport of ice hockey requires the combination of a variety of factors specific to the person, environment and occupation and to consider the contribution of each when assessing the ability to return to full sport participation. Following the PEO Model (Law et al., 1996), the strength of a youth ice hockey player explored in Chapter 3 can be considered a person factor, where if deficient as a result of a concussion, can obstruct the fit between person, environment and occupation factors (e.g., no longer having the strength required to skate quickly enough to avoid contact from an opponent within the competitive ice hockey environment) and result in impaired occupational performance (e.g., hockey playing ability). Further, the approach to assessment described in Chapter 4 of this thesis is unique as it incorporates factors from the person, environment and occupation by assessing an individual’s cognitive abilities when performing ice hockey specific occupations within an ice hockey specific environment. The consideration of the relationship between these factors can contribute to the development of a more sensitive and accurate index of if youth ice hockey players can handle the occupational and environmental demands inherent to the ice hockey environment, and can better inform return to play decisions following concussion.

Chapter 3 and Chapter 4 of this thesis where designed to explore novel methods to assess performance in youth athletes following concussion, while considering the contribution of person factors, environment factors and occupation factors that may have been overlooked in previous study and clinical practice specific to concussed youth. The chapters respectively achieved the objectives of: 1) exploring both the effect of baseline strength performance on future concussion occurrence, as well as the influence of concussion occurrence on post-injury strength performance; and, 2) exploring the effect of concussion on cognitive performance in male youth ice hockey players when completing concurrent ice hockey specific skills, where data presented can be used to generate evidence specific to the novel
assessment of performance in youth ice hockey players following concussion. These chapters explored the use of non-traditional measures of performance (Chapter 3, upper and lower body strength; and, Chapter 4, cognition during sport specific skill completion) to assess functional deficits that, until now, have never before been used within a youth sport context.

Of the two novel approaches to assessment of post-concussion performance explored within this dissertation, the assessment of strength described in Chapter 3 is the most practical for immediate clinical use and incorporation into currently used post-concussion assessment protocols. Baseline (pre-concussion) and post-concussion assessment of upper and lower body strength performance is quick, cost-effective and can act as an additional tool to help inform whether an athlete is ready to gradually progress from rest to physical activity to eventual game play following a concussion (e.g., if post-concussion strength performance is deficient when compared to pre-concussion scores, rehabilitation protocols designed to return strength to pre-injury levels can be used in order to best meet the functional needs of the athlete prior to return to sport competition). When related to the internationally recommended guidelines to be used when returning to sport participation (McCrory et al., 2009; see Table 5.1), the assessment of strength performance could be completed prior to progressing from rest to physical activity and more directly prior to the resumption of strength training activities.

When considering the novel approach to the assessment sport-specific functional performance following concussion in youth ice hockey players, the experimental protocol as presented within Chapter 4 of this dissertation poses significant barriers to current clinical use. In order to be used within the clinical and youth sport communities, the level of post-processing to determine performance results would have to be minimized. Here, algorithms and technology could be used to generate immediate and practical results to clinicians and athletes specific to reaction time (and related cDTC) and response error performance, along with the clinical significance of these results. Further, modification to the protocol to allow for the exploration of dual tasks costs from both a cognitive and a motor perspective, as discussed in Chapter 4, would provide a more comprehensive assessment of the influence of concurrent and real-world task completion on functional performance. With further study to
validate its use and development to improve its clinical utility, the presented approach to the real world assessment of sport-specific performance in youth ice hockey players could be used as a final assessment during the post-concussion rehabilitation process. When related to the internationally recommended guidelines to be used when returning to sport participation (McCrory et al., 2009; see Table 5.1), this approach to assessment could be used just prior to returning to full-contact practice and/or game play, where the ability to handle the multiple demands presented within an ecologically valid and sport-specific environment can more accurately indicate readiness to return to sport participation.

The findings presented expand our understanding of what domains of function are influenced by concussion and what are the most appropriate methods to be used to accurately assess performance following concussion as a means to inform readiness to return to play. Although preliminary, this work can act as a foundation for future research exploring the assessment of abilities post-concussion in youth athletes and can help to inform the development of more comprehensive and youth specific rehabilitation protocols with the end goal of improving outcomes within this population.

6.3.3 Management

In the context of this thesis, the management of sport-related concussion includes the provision of strategies and approaches that can be used to treat the injury and promote successful reintegration into daily activities, including sport. Chapter 5 of this thesis, entitled 'Sport-related concussion and occupational therapy: Expanding the scope of practice', was designed to contribute directly to the management of sport-related concussion in youth athletes. Addressing the objective of describing the use of occupational therapy as an approach to providing clinical care following sport-related concussion, this chapter provided practical suggestions that when incorporated within a rehabilitation protocol, may help to improve outcomes following a concussion. To date, it is appropriate to say that the profession of occupational therapy has yet to be recognized or utilized within the world of sport when providing clinical care to athletes following a concussion. As healthcare professionals with a primary concern for assisting clients to perform the activities that they need or want to perform, along with being trained in assessing and developing client-centred
interventions related to physical, cognitive and affective deficits, occupational therapy is well suited to contribute to a multidisciplinary approach to sport-related concussion management. This chapter contributes directly to the need for improved information related to approaches and strategies that can be used to help manage concussion by providing the first description of the practical use of occupational therapy during the rehabilitation of sport-related concussion. The approach to concussion management presented within this chapter is consistent with this dissertation’s conceptual framework guided by the PEO Model (Law et al, 2006), where the consideration of the relationship between person, environment and occupation factors to enable improved occupational performance inside and outside of the sport context for youth athletes following concussion is paramount. It is hoped that this commentary can act as a method to inspire occupational therapists, as well as other health care professionals, to become involved in the delivery of post-concussion care resulting in improved outcomes for athletes young and old.

6.4 Suggestions for future study

In addition to the chapter specific recommendations for future research to further inform the findings presented within this thesis, additional study specific to evidence-based approaches to management/intervention following sport-related concussion is needed. A study to meet this need that builds off of the real world and sport specific assessment of cognitive performance during concurrent ice hockey skill completion presented in Chapter 4 is proposed.

To date, several studies have demonstrated the influence of concurrent cognitive and locomotor tasks on performance in college-aged athletes (Catena, van Donkelaar, & Chou, 2007; Fait, McFadyen, Swaine, & Cantin, 2009; Parker, Osternig, Lee, Donkelaar, & Chou, 2005; Parker, Osternig, van Donkelaar, & Chou, 2007; Parker, Osternig, van Donkelaar, & Chou, 2008), and Chapter 4 of this thesis, entitled 'Concussion and concurrent cognitive and sport-specific task performance in youth ice hockey players: A pilot study', demonstrates the influence of concurrent ice hockey skill completion on cognitive performance within youth ice hockey players. Despite an emerging focus on the assessment of concurrent performance following concussion in athletes, there remains a paucity of literature examining whether
concurrent sport specific task performance can be improved through training. To date, the literature on training methods for improving concurrent task performance is limited, but offers some support for concurrent task training as an effective strategy to limit performance deficits and improve functional outcomes when addressing neurologic conditions (Brauer & Morris, 2010; Evans, Greenfield, Wilson, & Bateman, 2009; Pellecchia, 2005). What remains unclear is whether or not concurrent sport specific task performance can be trained in youth hockey players who have experienced a concussion. Examining the ability to train concurrent task performance in youth hockey players will provide an initial step towards the development of ecologically valid rehabilitative treatment protocols that promote safe return-to-play for youth athletes following concussion and improve outcomes post-injury.

This proposed study could use the same protocol as that presented within Chapter 4 of this thesis, where the cognitive performance (cognitive/reaction time dual task cost and response errors) of youth ice hockey players is measured during the completion of concurrent ice hockey specific skills of various levels of complexity (e.g., combinations of visual interference task, skating, stickhandling an ice hockey puck and avoiding an obstacle). The primary objective of this proposed study would be to determine whether or not the concurrent sport specific task performance of youth ice hockey players can be improved through training. Furthermore, this study would examine the difference in cognitive performance between healthy youth ice hockey players and youth ice hockey players who had sustained a concussion, as well as which training strategy (single task, training on an isolated ice hockey skill vs. dual task, training on combined ice hockey skills) results in the greatest improvements in performance.

The study could follow a multi-group pretest-posttest design where following pretest/baseline assessment, participants will be randomly assigned to one of six groups. Participants who have not sustained a concussion would be randomly assigned to: 1) Group #1: Dual-task training; 2) Group #2: Single-task training; 3) Group # 3 (Control Group): No training. Participants who have sustained a concussion would be randomly assigned to: 4) Group #4: Dual-task training; 5) Group #5: Single-task training; 6) Group # 6 (Control Group): No training. Outcome measures specific to cognitive function (e.g., cognitive dual task cost and
response errors) would be collected prior to and following the completion of respective training protocols. The training protocols would utilize the same tasks completed during the sport-specific pretest and posttest assessment sessions, however on a repeated schedule. Details on the study's design and testing timeline are presented in Figure 6.1 and Table 6.1 respectively.

Change scores could be calculated to represent the differences found in cognitive performance prior to and following the training protocol. A two-way analysis of variance (ANOVA) could be used to compare the difference scores generated by the study’s groups where the independent variables are represented by type of training and concussion history. Post hoc analysis (Bonferroni t-test) could be used to determine which of the compared means are significantly different. Further statistical modeling could be used in order to observe where the greatest change occurs in performance across all tasks. This information may help provide additional insight into the amount of training required to observe changes in task performance in order to inform the development of rehabilitative protocols post-concussion within the youth ice hockey player population that incorporate real world task performance relevant to the individual.

Using similar methods to those employed during the assessment of cognitive performance during concurrent ice hockey skill completion in concussed athletes presented in Chapter 4 of this thesis, this proposed study could address the need for interventions specific to improving functional performance in ice hockey players following concussion. If found to be an effective intervention, it is possible that if by way of assessment, a youth ice hockey player is found to have impaired cognitive abilities during concurrent sport-specific performance, this performance can be trained and improved prior to returning to full sport participation. Returning to play with improved cognitive abilities may contribute to improved post-concussion outcomes and a decreased risk for re-injury.

### 6.5 Concluding remarks

Together, the chapters presented within this thesis aimed to satisfy the need for further
information specific to the identification, assessment and management of concussion in youth athletes. Overall, the direction of this research is to minimize concussion-related impairment within youth athletes, more specifically youth ice hockey players, and act as a preliminary evidence base for future study and the development of youth specific post-concussion rehabilitation treatment protocols. From the perspective of the researcher, it is hoped that this research will help to promote further interest and exploration of research questions specific to concussion in youth. From the perspective of the clinician, it is hoped that this research will provide a preliminary evidence base that can inform improved clinical care and decision making specific to concussion and sport participation in youth athletes. Finally, from the perspective of the youth ice hockey community, it is hoped that this research can provide those directly affected by youth ice hockey-related concussion with additional insight into the risks associated with play, along with the methods and strategies that can be used to promote improved outcomes for the youth athlete. Overall, although the sport of ice hockey and the youth athlete population were the focus of this research, the concepts explored, methods used and findings generated can act as a foundation for further study and clinical use across sports and athlete populations.
Figure 6.2: Study design
Table 6.1: Study testing schedule

<table>
<thead>
<tr>
<th>Days Post</th>
<th>Baseline/Pretest Assessment</th>
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<tbody>
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<td>7</td>
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<tr>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

**Dual-Task Training:**
**Group #1 (healthy) and Group #4 (concussion)**

- Baseline/Pretest: X
- Training Session #1: X
- Training Session #2: X
- Training Session #3: X
- Follow-up/Posttest: X

**Single-Task Training:**
**Group #2 (healthy) and Group #5 (concussion)**

- Baseline/Pretest: X
- Training Session #1: X
- Training Session #2: X
- Training Session #3: X
- Follow-up/Posttest: X

**No Training (Control):**
**Group #3 (healthy) and Group #6 (concussion)**

- Baseline/Pretest: X
- Follow-up/Posttest: X
6.6 References


Appendix A

Ethics approval to collect head impacts data (see Chapter 2)

MEMORANDUM

To: Dr. N. Lobson
Cognitive Neurology
Room A421

From: Philip Hébert MD

Date: July 2, 2008

Subject: An fMRI Study of the Neural and Clinical Implications of Pediatric Sports-Related Concussion

Project Identification Number: 146-2008
Approval Date: July 2, 2008

The Research Ethics Board of Sunnybrook Health Sciences Centre has conducted a full Board review of the research protocol referenced above on the above captioned date and approved the involvement of human subjects as specified in the protocol.

The approval of this study includes the following documents:

- Information Sheet/Consent form HTS dated June 26, 2008 for Parent and Child
- Information sheet/Consent form (Parent) and Assent (Child) dated June 26, 2008

The quorum for approval did not involve any member associated with this project.

Should your study continue for more than one year you must request a renewal on or before one year from the approval date. Please advise the Board of the progress of your research annually and/or any adverse reactions or deviations which may occur in the future.

The above Project Identification Number has been assigned to your project. Please use this number on all future correspondence.

Philip G. Hébert, MD PhD FCFPC
Chair, Research Ethics Board
Appendix B

Consent to collect head impacts data (see Chapter 2)

INFORMED CONSENT TO PARTICIPATE IN A RESEARCH STUDY

TITLE OF THE STUDY:
An fMRI Study of the Neural and Clinical Implications of Pediatric Sports-Related Concussion

PRINCIPAL INVESTIGATORS
Sunnybrook Health Sciences Center, Toronto:
Dr. Nancy Lobaugh 416-480-6100 x1620

University of Toronto, Toronto:
Dr. Michelle Keightley 416-946-4004

CO-INVESTIGATORS
Montreal Neurological Instution and Hospital, Montreal:
Dr. Alain Ptito

Toronto Rehabilitation Institute, Toronto:
Dr. Karen Johnston

COLLABORATORS
Sunnybrook Health Sciences Center, Toronto:
Dr. Richard Aviv
Dr. Sean Symons

SPONSORS: This research is funded by grants awarded to Dr Michelle Keightley (Principal Investigator) and the listed co-investigators by the Canadian Institutes for Health Research and the Ontario Neurotrauma Foundation.

You are being asked to consider participating in a research study, on behalf of your child. A research study is a way of gathering information on a treatment, procedure or medical device or to answer a question about something that is not well understood.

This form explains the purpose of this research study, provides information about the study, the tests and procedures involved, possible risks and benefits, and the rights of participants. Please read this form carefully and ask any questions you may have. You may take as much time as you wish to decide whether or not to participate. Feel
free to discuss it with your friends and family, or your family doctor. Please ask the study staff or one of the investigator(s) to clarify anything you do not understand or would like to know more about. Make sure all your questions are answered to your satisfaction before deciding whether to participate in this research study.

**INTRODUCTION**

You are being asked to consider participating in this study on behalf of your child because he/she is healthy, and is currently participating in youth hockey.

**WHY IS THIS STUDY BEING DONE?**

The purpose of this study is to understand the effects of sports-related concussion on brain function in youth. The impact of concussion on brain structure and activity is largely unknown for youth. The risk of concussion is high among youth athletes in sports such as hockey. We are using brain-imaging methods to measure brain structure and brain activity changes in youth hockey players who sustain concussions, compared to youth hockey players who have not had a concussion. We hope to use this knowledge to help form return-to-play guidelines for youth athletes that will help prevent further injury from returning to play too soon.

**WHAT WILL HAPPEN DURING THE STUDY?**

This study will take place in our laboratories at the University of Toronto and at Sunnybrook and on the ice during the hockey season. All participants will be tested one time each year for three years, at the beginning of each hockey season. Because the testing takes some time, it will not occur all at once, so that your child is not overwhelmed. In certain situations, we will ask your child to participate in additional testing during the hockey season.

**Neuropsychological testing.** In a lab at the University of Toronto (500 University Ave.), your child will complete a battery of neuropsychological tests that examine all aspects of thinking (e.g. memory, attention, perception, etc.). It will take about 1½ hours to complete the tests.

**Brain imaging.** In a lab at Sunnybrook Health Sciences Center (2075 Bayview Ave.), we will take MRI (magnetic resonance imaging) scans of your child’s brain. The MRI machine is a powerful magnet that looks like a big doughnut, and your child will lie down on a bed with their head and shoulders in the “doughnut hole”. We will put some pillows around your child’s head to keep it from moving and then ask your child to stay very still while we scan their brain to get the pictures. Some of the brain scans will take pictures of the brain’s structure and some others will take pictures of the brain’s activity. During the brain activity scans, your child will be asked to perform a computer task. Your child will need to be in the machine for about 1½ hours.

**Additional testing during hockey season.** Three groups of children will be asked to participate in two additional brain imaging and neuropsychological testing sessions during the hockey season. Each scan session will take 1½ hours, and each neuropsychological testing session will take about 1½ hours.
• **Group 1: Children with concussions.** Should your child have a concussion, they would come to Sunnybrook for a set of MRI scans within 3 days of having the concussion, and another set after their concussion symptoms are resolved, and before they return to playing hockey.

• **Group 2: Children with other injuries.** Should your child sustain an orthopedic injury that prevents them from playing hockey (e.g. they get a sprain, hurt a muscle, etc.); they may be asked to come to Sunnybrook for another set of MRI scans within three days of the injury, and again after the symptoms resolve and before they return to playing hockey. We will compare their brain activity with the children who have received a concussion.

• **Group 3: Children with no injuries.** We will also ask some children who do not receive any injuries to come in for extra scans near the end of the hockey season. These children will be randomly selected from participants who have not had an injury. These children will be tested twice, at times that match one of the injured participants. For example, if a participant who had a concussion was scanned 2 days after concussion, and then 10 days later, your child would be scanned two times, 10 days apart. We will compare their brain activity with the children who have received concussions and other injuries.

**Overall number of sessions and hours of commitment during one season**

<table>
<thead>
<tr>
<th>Group</th>
<th>fMRI sessions (# of sessions, total hours)</th>
<th>Neuropsychological testing sessions (#, total hours)</th>
<th>Total hours of testing over year</th>
</tr>
</thead>
<tbody>
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<td>Baseline only (no additional testing)</td>
<td>1, 1.5hrs</td>
<td>1, 1.5 hrs</td>
<td>3</td>
</tr>
<tr>
<td>Group 1: Concussed</td>
<td>3, 4.5hrs</td>
<td>3, 4.5hrs</td>
<td>9</td>
</tr>
<tr>
<td>Group 2: Other Injury</td>
<td>3, 4.5hrs</td>
<td>3, 4.5hrs</td>
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<td>Group 3: No Injury</td>
<td>3, 4.5hrs</td>
<td>3, 4.5hrs</td>
<td>9</td>
</tr>
</tbody>
</table>

“**On-Ice” Testing.** During the hockey season, your child will be asked to wear a helmet with sensors in it. The sensors are hidden inside so the outside of the helmet looks like a regular helmet. The helmets are Canadian Sports Association (CSA) approved. Before each game, the helmet needs to be turned on by a small switch. The helmet’s sensors will measure any hits to your child’s head. Specifically, the sensors measure the direction and force of impact. The information for the sensors will be sent to a computer on the sidelines that collects information about every player’s head impacts. Members of our research team will be at the games to run the computer and collect the information from the helmets.

**Additional Measurements.** During the hockey season, a team official or volunteer will take height, weight and head circumference measurements of your child each month.
This allows us to track changes in development as well as use head measurements for the fMRI scans. These monthly measurements will take place before or after a game or practice in the change room at the hockey arena.

**HOW MANY PEOPLE WILL PARTICIPATE IN THIS STUDY?**
Girls and boys from four youth hockey teams have been invited to participate in this study. We anticipate 13 children from each team will participate. The length of this study for participants is 3 years, and we expect that most participants will be asked to participate one time each year.

**WHAT ARE THE RESPONSIBILITIES OF STUDY PARTICIPANTS?**
If you decide, on your child’s behalf, to participate in this study, your child will be asked to do the following:

- Participate in annual neuropsychological testing (1½ hrs) and brain imaging studies (1½ hrs) before the start of the hockey season each year (3 years).
- Wear the special hockey helmet during the hockey games.
- Participate in additional testing (approximately 3 hrs neuropsychological testing and 3 hours brain imaging) during the hockey season if a concussion or orthopaedic injury is sustained, or if selected as part of the group with no injuries.
- In the case of a concussion or an orthopaedic injury, agree to not allow your child to return to play until the symptoms have resolved and the second testing session has been completed.

**WHAT ARE THE RISKS OR HARMS OF PARTICIPATING IN THIS STUDY?**
There are no known harms associated with participation in this study. MR imaging does not involve any form of radiation or injections. However, some people may feel uncomfortable lying still in the confined space of the MRI scanner, and your child may feel dizzy for a few minutes at the end of the MRI study. At any time, your child may ask to be taken out of the scanner without any penalty or consequences. If you decide to participate in this study, and you are concerned that your child has experienced a side effect from the MRI scanning, you should contact Dr. Nancy Lobaugh at Sunnybrook, 416-480-6100 x1620.
WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?
Your child will not benefit directly from participating in this study. The information gained from this research may be used in the future to help formulate return-to-play guidelines after concussion and other forms of assessment to better identify concussion.

CAN PARTICIPATION IN THIS STUDY END EARLY?
Participation in research is voluntary. You and your child can choose to end your participation at any time. The investigator(s) may decide to remove your child from the study without your consent if (s)he is unwilling or unable to follow the study procedures.

WHAT ARE THE COSTS OF PARTICIPATING IN THIS STUDY?
Participation in this study will not involve any additional costs to you or your private health care insurer.

ARE STUDY PARTICIPANTS PAID TO PARTICIPATE IN THIS STUDY?
You will not be paid to participate in this study. If you decide to participate in this study, you will be reimbursed for your parking or public transportation costs. Your child will be reimbursed $30.00 for their participation in the MRI part of the study. If the MRI study is not completed for any reason, your child will still receive the full reimbursement.

DO THE INVESTIGATORS HAVE ANY CONFLICTS OF INTEREST?
The investigators do not have any conflicts of interest.
WHAT ARE THE RIGHTS OF PARTICIPANTS IN A RESEARCH STUDY?

All participants in a research study have the following rights:

You have the right to have this form and all information concerning this study explained to you and if you wish, translated into your preferred language.

1. Participating in this study is your choice (voluntary). You have the right to refuse to participate, or to stop participating in this study at any time without having to provide a reason. If you choose to withdraw, it will not have any effect on your future medical treatment or health care. Should you choose to withdraw from the study you are encouraged to contact immediately either Dr. Nancy Lobaugh, Cognitive Neurology, Sunnybrook Health Sciences Centre, 416-480-6100 x1620 or Dr. Michelle Keightley, Department of Occupational Science & Occupational Therapy & Rehabilitation Sciences, University of Toronto, 416-946-4004.

2. You have the right to receive all significant information that could help you make a decision about participating in this study. You also have the right to ask questions about this study and your rights as a research participant, and to have them answered to your satisfaction, before you make any decision. You also have the right to ask questions and to receive answers throughout this study. If you have any questions about this study, you may contact the persons in charge of this study (Principal Investigator): Dr. Nancy Lobaugh, Cognitive Neurology, Sunnybrook Health Sciences Centre, 416-480-6100 x1620. If you have questions about your rights as a research participant or any ethical issues related to this study that you wish to discuss with someone not directly involved with the study, you may call Dr. Philip C. Hébert, Chair of the Sunnybrook Research Ethics Board at (416) 480-4276.

3. By signing this consent form, you do not give up any of your legal rights.

4. You have the right to receive a copy of this signed and dated informed consent package before participating in this study.

5. You have the right to be told about any new information that might reasonably affect your willingness to continue to participate in this study as soon as the information becomes available to the study staff. This may include new information about the risks and benefits of being a participant in this study.

6. If you become sick or injured as a direct result of your participation in this study, your medical care will be provided.

7. Any of your personal information (information about you and your health that identifies you as an individual) collected or obtained, whether you choose to participate or not, will be kept confidential and protected to the fullest extent of the law. All personal information collected will be kept in a secure location. The study staff and the Sunnybrook Research Ethics Board will have access to your personal information for purposes associated with the study, but will only be allowed to access your records under the supervision of the Principal Investigator and will be obligated to protect your privacy and not disclose your personal information. None of your personal information will be given to anyone without your permission unless required by law. When the results of this study are published, your identity will not be disclosed. The data for this study will be retained for 7 years following publication of the results.

8. If, as a result of your participation in this study, any new clinically important medical information about your health is obtained, you will be given the opportunity to decide whether you wish to be made aware of that information.

9. You have the right to access, review and request changes to your personal information (i.e. address, date of birth).

10. You have the right to be informed of the results of this study once the entire study is complete.
DOCUMENTATION OF INFORMED CONSENT

Full Study Title: An fMRI Study of the Neural and Clinical Implications of Pediatric Sports-Related Concussion

Name of Participant: ________________________________________

Participant/Substitute decision-maker
By signing this form, I confirm that:

- This research study has been fully explained to me and all of my questions answered to my satisfaction
- I understand the requirements of participating in this research study
- I have been informed of the risks and benefits, if any, of participating in this research study
- I have been informed of any alternatives to participating in this research study
- I have been informed of the rights of research participants
- I have read each page of this form
- I authorize access to my personal health information (medical record) and research study data as explained in this form
- I have agreed to participate in this study or agree to allow the person I am responsible for to participate in this study
- This informed consent document will be kept by Dr. Michelle Keightley

____________________________        ________________
Name of participant/Substitute decision-maker (print)  Signature  Date

Person obtaining consent
By signing this form, I confirm that:

- I have explained this study and its purpose to the participant named above
- I have answered all questions asked by the participant
- I will give a copy of this signed and dated document to the participant

____________________________        ______________________
Name of Person obtaining consent (print)  Signature  Date

Statement of Investigator
I acknowledge my responsibility for the care and well being of the above participant, to respect the rights and wishes of the participant as described in this informed consent document, and to conduct this study according to all applicable laws, regulations and guidelines relating to the ethical and legal conduct of research.

____________________________        ________________
Name of Investigator (print)  Signature  Date
ASSISTANCE DECLARATION  (check here if not applicable)
The participant/substitute decision-maker was assisted during the consent process as follows:
The consent form was read to the participant/substitute decision-maker, and the person signing
below attests that the study was accurately explained to, and apparently understood by, the
participant/substitute decision-maker.
The person signing below acted as a translator for the participant/substitute decision-maker during
the consent process. He/she attests that they have accurately translated the information for the
participant/substitute decision-maker, and believe that that participant/substitute decision-maker
has understood the information translated.

____________________________        _______________________       ___
Name of Person Assisting (Print)                 Signature                  Date
Appendix C

Assent to collect head impacts data (see Chapter 2)

INFORMED ASSENT TO PARTICIPATE IN A RESEARCH STUDY

TITLE OF THE STUDY:
An fMRI Study of the Neural and Clinical Implications of Pediatric Sports-Related Concussion

PRINCIPAL INVESTIGATORS
Sunnybrook Health Sciences Center, Toronto:
Dr. Nancy Lobaugh 416-480-6100 x1620

University of Toronto, Toronto:
Dr. Michelle Keightley 416-946-4004

CO-INVESTIGATORS
Montreal Neurological Institution and Hospital, Montreal:
Dr. Alain Ptito

Toronto Rehabilitation Institute, Toronto:
Dr. Karen Johnston

COLLABORATORS
Sunnybrook Health Sciences Center, Toronto:
Dr. Richard Aviv
Dr. Sean Symons

SPONSORS: This research is funded by grants awarded to Dr Michelle Keightley (Principal Investigator) and the listed co-investigators by the Canadian Institutes for Health Research and the Ontario Neurotrauma Foundation.

You are being asked to consider participating in a research study, on behalf of your child. A research study is a way of gathering information on a treatment, procedure or medical device or to answer a question about something that is not well understood.

This form explains the purpose of this research study, provides information about the study, the tests and procedures involved, possible risks and benefits, and the rights of participants.

Please read this form carefully and ask any questions you may have. You may take as much time as you wish to decide whether or not to participate. Feel free to discuss it with your friends and family, or your family doctor. Please ask the study staff or one of the
investigator(s) to clarify anything you do not understand or would like to know more about. Make sure all your questions are answered to your satisfaction before deciding whether to participate in this research study.

**INTRODUCTION**

You are being asked to consider participating in this study because you are healthy, and are playing hockey.

**WHY IS THIS STUDY BEING DONE?**

We want to look at how your brain works while you play a game on the computer that makes you think. We want to learn what your brain looks like and how your brain works. We want to compare brains of children who have not hit their head with children who have hit their head in hockey. We need to know what normal brains look and act like so that we can compare them to the brains of children who have hit their head.

**WHAT WILL HAPPEN DURING THE STUDY?**

This study will take place in our laboratories at the University of Toronto and at Sunnybrook and on the ice during the hockey season. At the beginning of the hockey season for three years, we will do some testing. The tests will measure all types of thinking and we will also take pictures of your brain. There will also be on-ice testing with special helmets that will measure any hits to your head. We will split up the testing so you do not have to do it all on one day. If you hit your head or have another injury we may ask you to do the tests again.

**Neuropsychological testing.** In our lab at the University of Toronto (500 University Ave.) we will do some tests that make you think in different ways. These tests let us see how well you are thinking. We use the tests to look at differences between children who hit their head and children who have not hit their head. These tests will take about 1½ hours.

**Brain imaging.** In our lab at Sunnybrook Health Sciences Center (2075 Bayview Ave.) we will take some pictures of your brain. We will use magnetic resonance imaging, or MRI to take these pictures. After that we will test how well you play our computer game. After you take a short break, we will measure your brain activity while playing the computer game. If you hit your head during hockey, then we will ask you to come back and play the computer game again while we take more pictures of your brain. The brain pictures will take about 1½ hours, an your Mom and/or Dad can stay with you the whole time.

We will use a MRI machine to take your brain pictures. The MRI machine is a powerful magnet that looks like a big doughnut, and you will lie down on a bed with your head and shoulders in the “doughnut hole”. We will put some pillows around your head to keep it from moving and then ask you to stay very still while we take the pictures. For the brain activity part of the study, you will also be inside the MRI machine and playing a computer game. You will push a button, when you see certain pictures and words. You will be lying still in the MRI machine for about 1½ hours in total.

**Helmet Sensors.** During your hockey games, you will use a special helmet. The helmet has sensors in it that tells a computer how hard you hit the ice or boards if you fall down. The sensors are hidden inside the helmet. The helmet will look like a regular helmet from the outside and will be just as safe as a regular helmet. The sensors will send information to a laptop computer. A member of the research team will be at your games to help turn on the helmets and save the information on the computer.
**Additional testing during hockey season.** Three groups will be asked to take more brain pictures and do more thinking tests during the hockey season. Each brain picture session will take 1½ hours, and the thinking tests will take about 1½ hours.

- **Group 1: Children with concussions.** Should you hit your head and get a concussion, you would come to Sunnybrook to take brain pictures within 3 days of having the concussion. You would come back for another set of pictures after your concussion symptoms are gone, and before you return to playing hockey. We will also ask you to do the thinking tests again before you go back to playing hockey.

- **Group 2: Children with other injuries.** Should you get a sprain or hurt a muscle from playing hockey, you may be asked to come to Sunnybrook for another set of brain pictures within three days of the injury, and again after the symptoms are gone and before you return to playing hockey. We will also ask you to do the thinking tests again before you go back to playing hockey. We will compare your brain activity and test scores with the children who have hit their head.

- **Group 3: Children with no injuries.** We may also ask you to come in for extra brain pictures at the end of the season even if you do not receive any injuries. You would be randomly selected from all of the children who have not had an injury. You would do the brain pictures and thinking tests twice, at times that match one of the injured children. For example, if a child hit their head and was scanned 2 days after, and then 10 days later, you would be scanned two times, 10 days apart. We will compare your brain activity and test scores with the children who have hit their head and had other injuries.

**Additional measurements.** Every month, a trainer or adult volunteer from the team will take some measurements. They will measure your weight, height and how big around your head is. These measures will be done at the hockey arena in the change room before or after a game or practice.

**HOW MANY PEOPLE WILL PARTICIPATE IN THIS STUDY?**
Girls and boys from four youth hockey teams have been invited to participate in this study. We anticipate 13 children from each team will participate. The length of this study for participants is 3 years, and we expect that most participants will be asked to participate one time each year.

**WHAT ARE THE RESPONSIBILITIES OF STUDY PARTICIPANTS?**
If you and your parent(s) decide to participate in this study, you will be asked to:

- Complete thinking tests (1½ hrs) and take brain pictures (1½ hrs) before the start of the hockey season each year (3 years).
- Wear the special hockey helmet during the hockey games.
- Do thinking tests and take brain pictures again (about 3 hours of thinking tests and 3 hours of brain pictures) if you hit your head, get another injury, or are healthy and randomly selected during the hockey season.
- If you hit your head or get another injury, agree not to return to playing hockey until the symptoms have gone and the second set of tests and brain pictures are done.
WHAT ARE THE RISKS OR HARMS OF PARTICIPATING IN THIS STUDY?
There are no known harms for participating in this study. The tests will not hurt you. Nothing we will ask you to do involves any form of radiation or injections. However, some people may feel uncomfortable lying still in the big magnet. At any time, you may ask to be taken out of the scanner. You might think it is fun to see what your brain looks like on the computer. If you are interested, we can give you a picture of your brain when we are finished. If you decide to participate in this study, and have any questions you and your parent(s) should contact Dr. Nancy Lobaugh at Sunnybrook, 416-480-6100 x1620.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?
You will not benefit directly from participating in this study. The information gained from this research may be used in the future to help players after concussion by making return-to-play guidelines after concussion and other forms of assessment to better identify concussion.

CAN PARTICIPATION IN THIS STUDY END EARLY?
Participation in research is voluntary. You and your parent(s) can choose to end your participation at any time. The investigator(s) may ask you to leave the study without asking if you cannot or do not want to follow the study procedures.

WHAT ARE THE COSTS OF PARTICIPATING IN THIS STUDY?
Participation in this study will not cost you or your parent(s) any money.

ARE STUDY PARTICIPANTS PAID TO PARTICIPATE IN THIS STUDY?
You will not be paid to participate in this study. If you decide to participate in this study, your parent(s) will be reimbursed for your parking or public transportation costs. You will be reimbursed $30.00 for taking pictures of your brain with the MRI scanner. If the MRI study is not completed for any reason, your will still receive the $30.00.

DO THE INVESTIGATORS HAVE ANY CONFLICTS OF INTEREST?
The investigators do not have any conflicts of interest.
WHAT ARE THE RIGHTS OF PARTICIPANTS IN A RESEARCH STUDY?

All participants in a research study have the following rights:

You have the right to have this form and all information concerning this study explained to you and if you wish, translated into your preferred language.

1. Participating in this study is your choice (voluntary). You have the right to refuse to participate, or to stop participating in this study at any time without having to provide a reason. If you choose to withdraw, it will not have any effect on your future medical treatment or health care. Should you choose to withdraw from the study you are encouraged to contact immediately either Dr. Nancy Lobaugh, Cognitive Neurology, Sunnybrook Health Sciences Centre, 416-480-6100 x1620 or Dr. Michelle Keightley, Department of Occupational Science & Occupational Therapy & Rehabilitation Sciences, University of Toronto, 416-946-4004.

12. You have the right to receive all significant information that could help you make a decision about participating in this study. You also have the right to ask questions about this study and your rights as a research participant, and to have them answered to your satisfaction, before you make any decision. You also have the right to ask questions and to receive answers throughout this study. If you have any questions about this study, you may contact the persons in charge of this study (Principal Investigator): Dr. Nancy Lobaugh, Cognitive Neurology, Sunnybrook Health Sciences Centre, 416-480-6100 x1620. If you have questions about your rights as a research participant or any ethical issues related to this study that you wish to discuss with someone not directly involved with the study, you may call Dr. Philip C. Hébert, Chair of the Sunnybrook Research Ethics Board at (416) 480-4276.

13. By giving us your assent, you do not give up any of your legal rights.

14. You have the right to receive a copy of this signed and dated informed assent package before participating in this study.

15. You have the right to be told about any new information that might reasonably affect your willingness to continue to participate in this study as soon as the information becomes available to the study staff. This may include new information about the risks and benefits of being a participant in this study.

16. If you become sick or injured as a direct result of your participation in this study, your medical care will be provided.

17. Any of your personal information (information about you and your health that identifies you as an individual) collected or obtained, whether you choose to participate or not, will be kept confidential and protected to the fullest extent of the law. All personal information collected will be kept in a secure location. The study staff and the Sunnybrook Research Ethics Board will have access to your personal information for purposes associated with the study, but will only be allowed to access your records under the supervision of the Principal Investigator and will be obligated to protect your privacy and not disclose your personal information. None of your personal information will be given to anyone without your permission unless required by law. When the results of this study are published, your identity will not be disclosed. The data for this study will be retained for 7 years following publication of the results.

18. If, as a result of your participation in this study, any new clinically important medical information about your health is obtained, you will be given the opportunity to decide whether you wish to be made aware of that information.

19. You have the right to access, review and request changes to your personal information (i.e. address, date of birth).

20. You have the right to be informed of the results of this study once the entire study is complete.
**DOCUMENTATION OF ASSENT**

Full Study Title: *An fMRI Study of the Neural and Clinical Implications of Pediatric Sports-Related Concussion*

Name of Participant: ________________________________________________________________

**Person obtaining assent**

By signing this form, I confirm that:

- I have explained this study and its purpose to the participant named above
- I have answered all questions asked by the participant
- I was present when the participant gave verbal assent
- I will give a copy of this signed and dated document to the participant

<table>
<thead>
<tr>
<th>Name of Person obtaining Assent (print)</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
</table>

**Statement of Investigator**

I acknowledge my responsibility for the care and well being of the above participant, to respect the rights and wishes of the participant as described in this informed assent document, and to conduct this study according to all applicable laws, regulations and guidelines relating to the ethical and legal conduct of research.

<table>
<thead>
<tr>
<th>Name of Investigator (print)</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
</table>

**ASSISTANCE DECLARATION**  (check here if not applicable)

The participant/substitute decision-maker was assisted during the assent process as follows:

The assent form was read to the participant/substitute decision-maker, and the person signing below attests that the study was accurately explained to, and apparently understood by, the participant/substitute decision-maker.

The person signing below acted as a translator for the participant/substitute decision-maker during the assent process. He/she attests that they have accurately translated the information for the participant/substitute decision-maker, and believe that that participant/substitute decision-maker has understood the information translated.

<table>
<thead>
<tr>
<th>Name of Person Assisting (Print)</th>
<th>Signature</th>
<th>Date</th>
</tr>
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Appendix D

Form to collect strength performance and post-concussion symptom data
(see Chapter 3)

Fitness testing data Sheet

Date:______________________
Player Name:__________________
Player Team:___________________
Player jersey#:___________________
Player ID:_________________________

Testing Type:
Baseline____ Follow up____

Height:_____________
Weight:_____________
Head circ:_____________

<table>
<thead>
<tr>
<th>Hand Grip</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
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<tbody>
<tr>
<td>Right</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td></td>
<td></td>
<td></td>
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<table>
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<tr>
<th>Peg Board (Circle Dominate Hand)</th>
<th>Total Time</th>
<th>Total Drop</th>
<th>Total Correct pegs</th>
<th>Total Score</th>
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<tbody>
<tr>
<td>Right</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jump test</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Squat Jump</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Counter Movement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jump</td>
<td></td>
<td></td>
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<tr>
<th>Force Plate</th>
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</thead>
<tbody>
<tr>
<td>A1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2</td>
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<td></td>
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</tr>
<tr>
<td>A3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B3</td>
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<td></td>
</tr>
<tr>
<td>Leg MVC Max 1</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg MVC Max 3</td>
<td></td>
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Team: ___________  Player: ___________  Jersey #: ____
Date of PCS: ___________

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<th>Score</th>
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<tbody>
<tr>
<td>Headache</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Nausea</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Vomiting</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Balance Problems</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Dizziness</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Fatigue</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Trouble falling asleep</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Sleeping more than usual</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Sleeping less than usual</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Drowsiness</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Sensitivity to light</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Sensitivity to noise</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Irritability</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Sadness</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Nervousness</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Feeling more emotional</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Numbness or tingling</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Feeling slowed down</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Feeling mentally foggy</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Difficulty remembering</td>
<td>0 1 2 3 4 5 6</td>
</tr>
<tr>
<td>Visual Problems</td>
<td>0 1 2 3 4 5 6</td>
</tr>
</tbody>
</table>

Total PCS Score: ________

(*Note: 0 = no symptom, 1 = minor, 6 = severe)
Appendix E

Ethics approval to collect strength performance data
(see Chapter 3)

Office of the Vice-President, Research
Office of Research Ethics

PROTOCOL REFERENCE #20747

October 5, 2007

Dr. Michele Keightley
Occupational Therapy
Rehabilitation Sciences Bldg.
500 University Ave.
University of Toronto
Toronto M5G 1V7

Dear Dr. Keightley,

Re: Your research protocol entitled "An Investigation of the Clinical Implications of Sports-Related Concussion in Children and Youth"

ETHICS APPROVAL

Original Approval Date: October 5, 2007
Expiry Date: October 4, 2008

We are writing to advise you that the Health Sciences Research Ethics Board has granted approval to the above-named research study, for a period of one year. Ongoing projects must be renewed prior to the expiry date.

The following consent documents have been approved for use in this study: Sample Participant Assent Form, (received September 17, 2007), Sample Parent Consent Form for Son/Daughter’s Participation, Sample Parent consent Form for Son/Daughter’s Participation Completing the Working Memory Task (received September 27, 2007). Participants should receive a copy of their consent form.

During the course of the research, any significant deviations from the approved protocol (that is, any deviation which would lead to an increase in risk or a decrease in benefit to participants) and/or any unanticipated developments within the research should be brought to the attention of the Office of Research Ethics.

Best wishes for the successful completion of your project.

Yours sincerely,

Jenny Peto
Research Ethics Coordinator
Parent Consent Form for Son/Daughter’s Participation in: An Investigation of Sports-Related Concussion in Children and Youth

December 6th, 2007

Dear parent/guardian,

My name is Michelle Keightley. I am part of a research team at the University of Toronto that is studying Sports-Related Concussion in Children and Youth. Before agreeing to let your son/daughter take part in this study, it is important that you understand how your son/daughter will be involved.

What is the study about?

We want to learn more about recovery from sports-related concussion in children and youth. Specifically, we want to know how your son/daughter feels after a concussion. Things like headaches, feeling sick to their stomach or feeling more tired than normal. We want to know if these feelings affect performance on brain and body fitness tests. This information can help create return-to-play guidelines specific to youth hockey players.

2. We also want to look at how your son/daughter’s stage of development might affect their recovery. Currently, there is little or no research that focuses on this.

• How will my son/daughter and I be involved in this study?

We want to invite your son/daughter to take part in the study. As a participant, your son/daughter will:

1. Complete body and brain fitness tests. These tests will be done at the start of each hockey season. These tests will take about 2 hours in total.

2. Every month we will measure your son/daughter’s height, weight and head circumference. This will take about 5 minutes.

3. Your son/daughter will do a skating test at the beginning, middle and end of the hockey season. This test will take about 10 minutes to finish.
4. Your son/daughter will be asked to answer a questionnaire about their self-efficacy (confidence) related to playing hockey at the beginning and end of the hockey season. This will take about 10 minutes to finish.

5. After a concussion or other injury not involving the neck or spine (knee, ankle, arm etc.), your son/daughter will do some of these tests again. Specifically 1 day, 2 days, 3 days, 5 days and 7 days post-injury. These tests will take about 45 minutes to finish.

6. Once your son/daughter is fully recovered, they will do all of the brain and body fitness tests, and self-efficacy questionnaire again. These tests will take about 2 1/4 hours to finish.

7. The school performance of your son/daughter before and after their injury. This will be recorded using school report cards.

Additionally, we will have an equal number of control subjects who have not been injured complete the same tests. A non-injured player’s scores will be compared to an injured player’s scores. These players will be matched based on testing time (e.g., early vs. late in the season) and developmental age. This will help us look at how time in the hockey season and an athlete’s level of development affects the brain.

Will anyone know what they say?
All the information we collect about your son/daughter will be kept private. Rather than use their name on study papers, an assigned identification number which is made up of your son’s/daughter’s hockey jersey number and their initials (first name, middle name and last name) will be used. If the information collected is related to a specific test, the identification number will be made up of your son’s/daughter’s hockey jersey number, their initials, as well as the date on which the test was completed. No one but the study staff and your family doctor will know that it was your son/daughter who was in the study.

We will not make public anything that might identify your son/daughter, unless required by law. For example, we have a legal duty to report suspected child abuse and potential harm to self or others. If the results of the study are published, your son/daughter’s name will not be used. All data collected from the 8 participating teams will be combined to form one large data set. As a result, individual teams and players will not be identified.

Do I have to do this?
If you decide not to let your son/daughter take part in this study, that is okay. If you decide to let them take part, but then at any time during the study you no longer want them to participate, that is okay. This will not affect their involvement with their hockey team.

What are the risks and benefits?
We do not think there are any risks or direct benefits to your child for participating in the study. If they do have a concussion, they will be cared for by registered health professionals (i.e. neurosurgeon and clinical neuropsychologists). These professionals can make informed decisions on when returning to play hockey is appropriate. As a result, your child may miss games and practices following a concussion. Additionally, there is the possibility that your child may feel self-conscious about their injury. However, by receiving proper care it is anticipated that this will prevent the risk of future concussions. Additional injuries may impact their future hockey and learning potential.
What if I have questions?
Please ask me to explain anything you don’t understand before signing the consent form. My phone number is 416-946-4004. If you leave a message, I will return your call within 48 hours.

If you have any questions about your rights as a research participant, feel free to contact Jill Parsons, the Research Ethics Officer for the Health Sciences by phone at (416) 946-5806 or by e-mail at jc.parsons@utoronto.ca.

Thank you for thinking about helping us with this project.

Yours truly,

Michelle Keightley, Ph.D., C.Psych.
Assistant Professor
Department of Occupational Science and Occupational Therapy
Rehabilitation Sciences Building (Centre for Function and Well-Being)
Faculty of Medicine, University of Toronto
500 University Ave., 9th Floor
Toronto, ON, M5G 1V7
CONSENT FORM #1

An Investigation of the Clinical Implications of Sports-Related Concussion
In Children and Youth

The researcher explained this study to me. I read the letter and understand what this study is about.

I understand that I may have my son/daughter drop out of the study at any time.

I agree to let my son/daughter participate in the following aspects of this study:

1. Complete body and brain fitness tests. These tests will be done at the start of each hockey season. These tests will take about 2 hours in total.

2. Have height, weight and head circumference measured monthly. This will take about 5 minutes.

3. Complete a skating test at the beginning, middle and end of the hockey season. This test will take about 10 minutes to finish.

4. Complete a questionnaire about self-efficacy (confidence) related to playing hockey, at the beginning and end of the hockey season. This will take about 10 minutes to finish.

5. After a concussion or other injury not involving the neck or spine (knee, ankle, arm etc.), complete body and brain fitness tests. Specifically 1 day, 2 days, 3 days, 5 days and 7 days post-injury. These tests will take about 45 minutes to finish.

6. Once fully recovered, complete all of the brain and body fitness tests, and self-efficacy questionnaire again. These tests will take about 2 1/4 hours to finish.

Signing your name on the next page means that you agree to let your son/daughter take part in these aspects of the study.
I agree to let my son/daughter participate in the above mentioned aspects of this study. I know I can change my mind at any time.

________________________  ________________________  _________
Parent Name (please print)  Signature  Date

________________________  ________________________  _________
Youth’s name (if under 14)  Signature  Date

Player’s Age  _________  Team & League Name  ________________________________
Player’s Month of Birth  _______________  Player’s Year of Birth  ____________
Number of years registered on a select or “rep” hockey team  ___________

I confirm that I have explained the study to the participant to the extent compatible with the participants understanding, and that the participant has agreed to be in the study.

________________________  ________________________  _________
Researcher’s Name  Signature  Date
CONSENT FORM #2

An Investigation of the Clinical Implications of Sports-Related Concussion
In Children and Youth

Please complete this form below and return it using the self-addressed stamped envelope provided.

I agree to let my son/daughter participate in the following aspect of this study:

1. Provide the researcher with access to report cards documenting the pre- and post-concussion school performance of my son/daughter. In order to provide such access to report cards, I agree to provide the researcher with a copy of my son’s/daughter’s report card.

_________________________        ________________________            _________
Parent Name (please print)        Signature                  Date

_________________________        ________________________            _________
Youth’s name (if under 14)       Signature                  Date

Player’s Age    Team & League Name
Player’s Month of Birth           Player’s Year of Birth
Number of years registered on a select or “rep” hockey team

I confirm that I have explained the study to the participant to the extent compatible with the participants understanding, and that the participant has agreed to be in the study.

_________________________        ________________________            _________
Researcher’s Name                Signature                  Date
Appendix G

Assent to collect strength performance data
(see Chapter 3)

Assent Form: An Investigation of the Clinical Implications of Sports-Related Concussion in Children and Youth

Study title:

An Investigation of the Clinical Implications of Sports-Related Concussion in Children and Youth

Who am I?

My name is Michelle Keightley and I work as a Neuropsychologist and a teacher at the University of Toronto.

Why you are here?

The researchers want to tell you about a study on youth who have had a concussion while playing hockey. They want to see if you would like to be in this study. This form tells you about the study. If there is anything you do not understand, please ask your parent, your guardian or the study staff.

Why are they doing this study?

The researchers want to learn more about recovery from sports-related concussion in children and youth. Specifically, the researchers will want to know how you feel after a concussion. Things like headaches, feeling sick to your stomach or feeling more tired than normal. They want to know if these feelings affect how you perform on different brain tests. This will allow return-to-play guidelines specific for children and youth to be made.
What will happen to you?

If you want to be in the study these things will happen:

1. You will complete tests to see how fit your body is and how fit your brain is at the start of each hockey season for the next three years. These tests will take about 2 hours to finish.
2. Every month we will measure your height, weight and head circumference to see how much you have grown. This will take about 5 minutes to finish.
3. You will answer a questionnaire about your self-efficacy (confidence) related to playing hockey at the beginning and end of the hockey season. This will take about 10 minutes to finish.
4. You will do a skating test the beginning, in the middle and at the end of your hockey season. This test will take about 10 minutes to finish.
5. If you have a concussion or have any other type of injury (knee, ankle, arm or other parts of your body) during the hockey season, you will do some of these tests again 1 day, 2 days, 3 days, 5 days and 7 days after your concussion or injury. These tests will take about 45 minutes to finish.
6. Once you feel completely better after your concussion, you will do all of the brain and body fitness tests, and self-efficacy questionnaire that you did at the start of the season again. These tests will take about 2 hours and 15 minutes to finish.

Risks and Benefits?

We do not think there are any risks or direct benefits to you participating in the study. If you do have a concussion, you will receive care from registered health professionals (i.e. neurosurgeon and clinical neuropsychologists). Participating in the study will take up some of your free time in order to complete the body and brain fitness tests. Also, if you do get injured and/or have a concussion, you may have to miss hockey games and practices until you are better.

By participating in this study, you can help children and youth athletes like you. Their recovery and return-to-play decisions are currently based on information collected mostly from adults. This study will produce information on youth hockey players that currently doesn’t exist. This can help them return to playing the sport of hockey after a concussion.

What if you have any questions?

You can ask any questions that you have about the study at anytime. If you have a question later that you didn’t think of now, you can call me, Michelle Keightley at 416-946-4004 or ask me or the other researchers next time.
Who will know what I did in the study?

Any information you give to the study staff will be kept private (or secret). Your name will not be on any study paper and no one but the study staff and your family doctor will know that it was you who was in the study.

Do you have to be in the study?

No. If you don’t want to be in the study, you don’t have to. Remember, being in this study is up to you and no one will be upset if you don’t want to participate or if you change your mind later and want to stop.

Please talk to his over with your parents before you decide whether or not to be in the study. We will also ask your parents to give permission for you to take part in this study. Even if your parents say “yes”, you can still decide not to do this.

Signing your name at the bottom means that you agree to be in this study.

Assent

I want to take part in this study. I know I can change my mind at any time.

________________________
Verbal assent given Yes
Print name of child

________________________  __________  __________
Signature of Child  Age  Date

I confirm that I have explained the study to the participant to the extent compatible with the participants understanding, and that the participant has agreed to be in the study.

________________________  __________________
Printed name of person obtaining assent  Signature of person obtaining assent  Date
Appendix H

Ethics approval to collect concurrent cognitive and ice hockey skill performance data
(see Chapter 4)

PROTOCOL REFERENCE # 25443

September 13, 2010

Dr. Michele Keightley
Department of Occupational Science and
Occupational Therapy
160-500 University Ave.
Toronto, On M5G 1V7

Mr. Nicholas Reed
Department of Occupational Science and
Occupational Therapy
160-500 University Ave.
Toronto, On M5G 1V7

Dear Dr. Keightley and Mr. Reed:

Re: Your research protocol entitled, “Training Dual-Task Performance in Youth Hockey
Players: Towards the Treatment of Sport-Related Mild Traumatic Brain Injury” by Dr. M.
Keightley (supervisor), Mr. N. Reed (PhD candidate)

We are writing to advise you that a member of the Health Sciences Research Ethics Board has
granted approval to an amendment (received Aug. 30, 2010) to the above referenced research
study under the REB’s delegated review process. This amendment will allow researchers to add
one physical assessment (balance) and 3 neuropsychological assessments to be completed on
site (at hockey rink) during the pilot assessment session to further determine the influence of
isolated task completion and concurrent task completion on motor and neurocognitive
performance.

All your most recently submitted documents have been approved for use in this study.

Any changes to the approved protocol or consent materials must be reviewed and
approved through the amendment process prior to its implementation. Any adverse or
unanticipated events should be reported to the Office of Research Ethics as soon as
possible.

Best wishes for the successful completion of your project.

Yours sincerely,

Marianna Richardson
Research Ethics Coordinator
Appendix I

Consent to collect concurrent cognitive and ice hockey skill performance data
(see Chapter 4)

Parent Consent Form for Child’s Participation in Pilot Phase:
Training Dual-Task Performance in Youth Hockey Players: Towards the Treatment of Sport-Related Mild Traumatic Brain Injury

Dear parent/guardian,

My name is Nick Reed. I am part of a research team at the University of Toronto that is studying Sports-Related Concussion in Children and Youth. Before agreeing to let your child take part in this study, it is important that you understand how your child will be involved.

What is the study about?
We want to learn more about recovery from sports-related concussion in children and youth. Specifically, we want to know how your child can perform several hockey-related skills both alone and combined with each other before and after an on-ice training program. After a concussion, it is believed that one may not be able to handle multiple tasks occurring at the same time during playing hockey (e.g. skating, stickhandling, reacting to teammates or opponents). This information can help create return-to-play guidelines specific to youth hockey players and may help develop new ways to treat youth hockey players after a concussion.

In order to complete this study, it is important that we are sure the measures used to determine if youth hockey players can perform several hockey-related skills both alone and combined with each other are appropriate to use with youth hockey players. As well, this pilot study allows us to see what differences exist when performing hockey-related skills of different complexities between youth hockey players who have and have not had a concussion in the past year. Your son will act as a pilot subject that will help inform a larger future study.

Currently, there is little or no research that focuses on this.

How will my child and I be involved in this study?
We want to invite your child to take part in the study. As a participant, your child will:

1. Your child’s height and weight will be measured. This will take about 5 minutes.
2. Together with your child, you will complete a concussion history questionnaire and medical history questionnaire. This will take about 20 minutes to complete.

3. Your child will be asked to complete an off-ice balance assessment. This will take about 5 minutes to complete.

4. Your child will be asked to complete 3 off-ice neuropsychological/thinking assessments:
   - Working Memory Task (on computer). This will take about 10 minutes to complete
   - Stroop Colour and Word Test (paper and pencil). This will take about 3 minutes to complete.
   - Children’s Colour Trails A and B (paper and pencil). This will take about 2 minutes to complete.

5. Your child will be asked to complete combinations of the following on-ice tasks:
   a) Skating from one marker to another marker on a hockey rink
   b) Skating from one marker to another marker on a hockey rink while navigating around one physical obstacle
   c) Skating from one marker to another marker on a hockey rink while stick handling a puck
   d) Skating from one marker to another marker on a hockey rink while completing a ‘brain game’ projected onto a screen in front of them

Completing these tasks will take approximately 45 minutes. Your child will be videotaped while completing these tasks. The videotape will be used to better assess player performance. It will be stored securely in a locked cabinet and will not be shared with anyone outside of the research team.

**Will anyone know what they say?**
All the information we collect about your child will be kept private. Rather than use their name on study papers, an assigned identification number that contains no personal identifiers will be used. No one but the study staff will know that it was your child who was in the study.

We will not make public anything that might identify your child, unless required by law. For example, we have a legal duty to report suspected child abuse and potential harm to self or others. If the results of the study are published, your child’s name will not be used. All data collected from all participants will be combined to form one large data set. As a result, individual players will not be identified.

**Do I have to do this?**
If you decide not to let your child take part in this study, that is okay. If you decide to let them take part, but then at any time during the study you no longer want them to participate, that is okay. This will not affect their involvement with their hockey team.

**What are the risks and benefits?**
With any type of physical fitness testing there will be some physical risks. However these risks are minimal and in fact are less than what they experience on a daily basis through their sport of hockey. Players will be asked to wear full hockey equipment at all times. In the event that there
are any adverse effects, personnel trained in handling and managing athletic injuries will be present for the testing, and the athlete will be referred to their family doctor. Some participants may feel anxious about their performance or the testing in general. The research study team will explain the tests in detail and take special care to emphasize that their results will be completely confidential and not shared with anyone outside of the research team. The results of their testing will only be presented in aggregate with all other participants’ data and no one person’s data will be identifiable.

Your child will have access to free ice-time and hockey skill practice during this study.

**What if I have questions?**
Please ask me to explain anything you don’t understand before signing the consent form. My phone number is 416-978-8591. If you leave a message, I will return your call within 48 hours.

If you have any questions about your rights as a research participant, feel free to contact Jill Parsons, the Research Ethics Officer for the Health Sciences by phone at (416) 946-5806 or by e-mail at jc.parsons@utoronto.ca.

Thank you for thinking about helping us with this project.

Yours truly,

Nick Reed, M.Sc.OT, OT Reg. (Ont.), Ph.D Candidate
Graduate Department of Rehabilitation Science
Faculty of Medicine
University of Toronto
BrainFit Lab
brainfitlab.com
416.978.8591
CONSENT FORM

Training Dual-Task Performance in Youth Hockey Players: Towards the Treatment of Sport-Related Mild Traumatic Brain Injury

The researcher explained this study to me. I read the letter and understand what this study is about.

I understand that I may have my child drop out of the study at any time.

I agree to let my child participate in the following aspects of this study:

1. Have height and weight measured. This will take about 5 minutes.
2. Complete a concussion history and medical services/diagnosis history questionnaire
3. Complete an off-ice balance assessment and three thinking tasks/”brain games”. This will take about 20 minutes to complete.
4. Complete combinations of on-ice skating and hockey skill tasks. These tasks will take about 45 minutes to complete

Signing your name on the next page means that you agree to let your child take part in these aspects of the study.
I agree to let my child participate in the above mentioned aspects of this study. I know I can change my mind at any time.

__________________________  ________________________  _________
Parent Name (please print)   Signature                         Date

__________________________  ________________________  _________
Youth’s name                 Signature                         Date

Player’s Age  
Player’s Date of Birth
Number of years registered on a select or “rep” hockey team

I confirm that I have explained the study to the participant to the extent compatible with the participants understanding, and that the participant has agreed to be in the study.

__________________________  ________________________  _________
Researcher’s Name            Signature                         Date
Appendix J

Assent to collect concurrent cognitive and ice hockey skill performance data
(see Chapter 4)

Participant Assent Form:

Pilot Phase:
Training Dual-Task Performance in Youth Hockey Players: Towards the Treatment of Sport-Related Mild Traumatic Brain Injury

Study title:

Pilot Phase- Training Dual-Task Performance in Youth Hockey Players: Towards the Treatment of Sport-Related Mild Traumatic Brain Injury

Who am I?

My name is Nick Reed and I work as a Occupational Therapist and a teacher at the University of Toronto.

Why you are here?

The researchers want to tell you about a study on youth who have had a concussion while playing hockey. They want to see if you would like to be in this study. This form tells you about the study. If there is anything you do not understand, please ask your parent, your guardian or the study staff.

Why are they doing this study?

The researchers want to learn more about recovery from sports-related concussion in children and youth. Specifically, the researchers want to know if youth hockey players can learn to do many things at once when playing hockey (skating, stickhandling, reacting to teammates and players on the other team). In players that have a concussion, sometimes it is hard to do all of these things at once when playing hockey. This will allow return-to-play guidelines specific for children and youth to be made and to start to find new ways to help hockey players get back to playing hockey after a concussion.

The part of the study you will be involved in is called the Pilot Phase. This means that you will complete some of the parts of a larger future study in order to see if these parts of the study work properly and can be used with youth hockey players like you. You are helping us test out the different parts of our research study.
What will happen to you?

If you want to be in the study these things will happen:

1. Your height and weight will be measured. This will take about 5 minutes.
2. With your parent/guardian, you will be asked to complete a concussion history and medical history questionnaire. This will take about 20 minutes.
3. You will be asked to complete an off-ice balance assessment. This will take about 5 minutes to complete.
4. You will be asked to complete three off-ice neuropsychological/ thinking assessments:
   - Working Memory Task (on computer). This will take 10 minutes to complete
   - Stroop Colour and Word Test (paper and pencil). This will take 3 minutes to complete.
   - Children’s Colour Trails A and B (paper and pencil). This will take 2 minutes to complete.
5. You will be asked to complete combinations of the following on-ice tasks:
   - Skating from one marker to another marker on a hockey rink
   - Skating from one marker to another marker on a hockey rink while skating around an obstacle
   - Skating from one marker to another marker on a hockey rink while stick handling a puck
   - Skating from one marker to another marker on a hockey rink while completing a ‘brain game’ projected onto a screen in front of you

Completing these tasks will take approximately 45 minutes. Your will be videotaped while completing these tasks. The videotape will be used to better assess player performance. It will be stored securely in a locked cabinet and will not be shared with anyone outside of the research team.

Risks and Benefits?

With any type of physical fitness testing there are some risks that you might get hurt. However these risks are smaller that what they might be when you are playing hockey on a normal day. You will be asked to wear full hockey equipment at all times. If you do get hurt, people trained in helping people after sports injuries will be there to help. You may feel anxious or nervous about how you do on the tests. The research study team will explain the tests to you to make sure you do the best you can and will make sure that nobody else knows how you did.

You will have access to free ice-time and hockey skill practice over the course of the study.

By participating in this study, you can help children and youth athletes like you. Their recovery and return-to-play decisions are currently based on information collected mostly from adults. This study will produce information on youth hockey players that currently doesn’t exist. This can help them return to playing the sport of hockey after a concussion.
What if you have any questions?

You can ask any questions that you have about the study at anytime. If you have a question later that you didn’t think of now, you can call me, Nick Reed at 416-978-8591 or ask me or the other researchers next time.

Who will know what I did in the study?

Any information you give to the study staff will be kept private (or secret). Your name will not be on any study paper and no one but the study staff and your family doctor will know that it was you who was in the study.

Do you have to be in the study?

No. If you don’t want to be in the study, you don’t have to. Remember, being in this study is up to you and no one will be upset if you don’t want to participate or if you change your mind later and want to stop.

Please talk to his over with your parents before you decide whether or not to be in the study. We will also ask your parents to give permission for you to take part in this study. Even if your parents say “yes”, you can still decide not to do this.

Signing your name at the bottom means that you agree to be in this study.

---

Assent

I want to take part in this study. I know I can change my mind at any time.

_________________________  Verbal assent given  Yes

Print name of child

_________________________  ______________  ______________

Signature of Child  Age  Date

I confirm that I have explained the study to the participant to the extent compatible with the participants understanding, and that the participant has agreed to be in the study.

_________________________  ______________  ______________

Printed name of person obtaining assent  Signature of person obtaining assent  Date