Seasonal Changes in Functional Fitness and Neurocognitive Performance in Youth Ice Hockey Players

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ABSTRACT

BACKGROUND: Balance and functional movement patterns are critical components of motor skills in youth. Deficits in balance and in strength or power combined with differing rates of sensory and motor neural development may increase the risk of sports related injury. PURPOSE**:** To evaluate changes in functional fitness and concussion status over the course of a competitive season in youth ice hockey players, and to examine the relationship between these variables and injury incidence during seasonal play. METHODS**:** Thirty-six participants (8.9 ± 1.1 years) completed pre and post-season assessments including anthropometric measurements, the Functional Movement Screen (FMS), Lower Quarter Y-Balance Test (YBT-LQ) and a computerized neurocognitive assessment, the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT). Frequencies, means and standard deviation were used to describe the sample. Paired samples t-tests were used to compare pre and post-season data. Independent samples t-tests were used to compare FMS, YBT-LQ and ImPACT scores between injured and uninjured participants. RESULTS**:** Height of participants increased from pre (136.56 ± 7.64 cm) to post-season (139.95 ± 7.69 cm, $p<0.01$) and thigh circumference increased from pre (37.24 ± 4.14 cm) to post-season (38.39 ± 3.57cm, $p<0.01$). Mean composite score of the FMS was not statistically different between pre and post-season. The YBT-LQ composite score showed a significant decrease in reach distance scores between pre (86.10 ± 6.00) and post-season (83.20 ± 5.40, $p<0.001$). Neurocognitive assessments scores improved in both the injured and uninjured participants; total symptom score (pre 1.17 ± 2.82, post 0.31 ± 1.09, $p=0.96$) did not change. The majority of injuries sustained were a result of a collision that occurred with either another player and/or referee (26%) or from a collision with a fixed object (22%). There were no statistically significant relationships between FMS scores, YBT-LQ and injury incidence. CONCLUSION: Our results showed that some components of functional fitness decreased over the season, while other measures of functional fitness did not change over the season. The incidence of injury did not appear to differ by functional fitness levels or concussion status. Findings support existing evidence that suggest that a participants' neurocognitive performance may vary across sessions. Results from our study indicate that future research is needed to better understand the effects of functional fitness and concussion status as they relate to injury prevention.

KEYWORDS: Youth Athletes, Functional Movement Screen, Y-Balance Test, Neurocognitive Assessment, Ice hockey

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LIST OF ABBREVIATIONS

BESS......................................Balance Error Scoring System

BMI..Body Mass Index

CHIRPP..................................Canadian Hospitals Injury Reporting and Prevention Program

FMS.......................................Functional Movement Screen

GTHL.....................................Greater Toronto Hockey League

HL ....House League

ImPACT ....Immediate Post-Concussion Assessment and Cognitive Test

LL...Local League

MD ....Minor Development

OMHA ....Ontario Minor Hockey Association

PNF ....Proprioceptive neuromuscular facilitation

SEBT......................................Star Excursion Balance Test

SCAT ....Sport Concussion Assessment Tool

TBI ....Traumatic brain injury

YBT-LQ.................................Lower Quarter Y-Balance Test

CHAPTER 1: INTRODUCTION

1.1 THESIS INTRODUCTION

Rationale

Involvement in competitive sport at increasingly younger ages has piqued interest from parents, clinicians, coaches and teachers regarding integration of specialized training for improved performance and sports related injury reduction (Myer & Faigenbaum, 2011). Establishing baseline measurements of balance and functional movement patterns, as well as evaluating concussion status, may be important in determining whether an athlete has deficits that lead to such injury. (Cook, Burton, Hoogenboom, & Voight, 2014a, 2014b; Krumrei, Flanagan, Bruner, & Durall, 2014; Parenteau et al., 2014). Such evaluations provide valuable information to a clinician or coach and can be used to help guide the design and implementation of programs containing corrective exercises aimed at improving identified limitations, thereby reducing the risk of injury, and improving performance. In addition, evaluating baseline concussion status may assist in identifying symptoms of dizziness, neck pain, and headaches, which could ultimately place an athlete at an increased risk of sustaining an injury or subsequent concussion (Schneider, Meeuwisse, Kang, Schneider, & Emery, 2013) Furthermore, research has indicated that vestibular deficits in pediatric populations are highly prevalent in concussed patients. These deficits can have a negative impact on the ability to process sensory information involved with controlling balance and eye movement, thus, increasing risk of injury. Moreover, vestibular deficits have been shown to result in longer recovery from neurocognitive insufficiencies, extended time before returning to school, and additional time before being fully cleared to resume activities (Corwin et al., 2015).

Unfortunately, few research studies have investigated existing tools to determine which are able to accurately predict injury risk and sports related performance. There is a particular dearth of data on children playing high-risk sports such as ice hockey. Children seem to be at an increased risk of sustaining an injury because their neuromuscular systems are not fully developed and many important motor skills are still developing (Granacher, Muehlbauer, Maestrini, Zahner, & Gollhofer, 2011). Given that children are specializing in sports at younger ages than ever before, it is critical to identify appropriate tools for assessment of functional fitness parameters that can be used by clinicians, coaches and athletes to prevent injury during seasonal play and that can be used to enhance performance. Furthermore, follow-up assessments post-season will allow for an evaluation of the athlete's most current level of fitness and thus allow us to examine and characterize any changes that could act potential risk factors for injury. Thus, the overall aim of this research was to evaluate functional fitness, using a comprehensive functional movement screening tool, a dynamic balance test, as well as a computerized neurocognitive test to determine baseline concussion status, as well as investigate the occurrence of injury among youth ice hockey players. In addition, this research provides information on neuromuscular development and coordination among a group of young athletes as they mature over the course of one competitive season. This information can help to determine how often assessments should take place as well as which tools may be the most appropriate for a youth population.

1.2 RESEARCH QUESTIONS AND HYPOTHESIS

The proposed research aims to answer the following questions:

1. What is the occurrence of injury in the context of functional fitness and concussion status during the competitive season?
2. What are the changes in measures of functional fitness and concussion status over one season in male ice hockey players aged 8-11?

Hypothesis

Based on previous research, it was hypothesized that participants with lower levels of functional fitness at baseline (Chorbra et al., 2010; Garrison et al., 2015; Kiesel et al., 2007; Krumrei et al., 2014) and participants who scored lower on neurocognitive tests would sustain a greater number of injuries compared to those who scored higher (Swanik, Covassin, Stearne, & Schatz, 2007). Furthermore, it was hypothesized that some measures of functional fitness (including dynamic balance and deep squat) would improve (Zech et al., 2014; Sprague et al., 2014), while others (e.g. active straight leg raise) would get worse over the season (Sprague et al., 2014).

1.3 SIGNNIFICANCE OF THE STUDY

This study, to our knowledge, will be the first to evaluate changes in functional fitness and concussion status over the course of a competitive season in youth ice-hockey players, and to examine the relationship between these variables and injury incidence during seasonal play. Our results will have implications for schools, youth sports teams, health care practitioners and families, and our work will add to the growing body of literature aimed at understanding factors that affect injury prevention in youth sport. Results from this study will provide an opportunity for coaches, clinicians and trainers to create training conditions and programs that are designed appropriately and progressively to minimize a participants deficiencies in these areas and therefore, help prepare young athletes to the physical demands of sports practice and competition, reducing the risk of injuries as well as helping to improve sport specific performance.

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CHAPTER 2: REVIEW OF THE LITERATURE

2.1 INTRODUCTION

The rate and development of neuromuscular coordination varies greatly in youth. Deficits in balance and in strength or power combined with differing rates of sensory and motor neural development are contributors to balance ability and performance (Granacher, Muehlbauer, Maestrini, Zahner, & Gollhofer, 2011). In order to maintain balance, a continuous input from various sensory structures (visual, vestibular and somatosensory) as well as coordinated neuromuscular actions are required to maintain the body's centre of gravity over the base of support (Hrysamallis, 2011). Previous research has shown that balance training in a healthy population can have positive effects in reducing injury rates (DiStefano, Padua, DiStefano, & Marshall, 2010; Hubscher et al., 2010). It has also been shown that an imbalance or deficit in balance can increase the chances of experiencing a sports-related injury and reduce sports performance (DiStefano, Clark, & Padua, 2009; Hrysomallis, 2007).

Trends surrounding organized youth sport show that participation is starting at a younger age (Kostka et al., 2012; Washington et al., 2001). Among adolescents, 66% of injuries were associated with sport involvement (Billette & Janz, 2011). In Canada, 22% of children (ages 5-14) involved in sport are playing hockey (Government of Canada, 2013). Research suggests that the majority of injuries related to hockey are caused by contact; however, 15% of injuries are non-contact musculoskeletal injuries (Parenteau-G et al., 2014). In addition to poor balance, muscle imbalances may be attributed to poor muscle movement patterns and therefore, also lead to increased chances of sustaining an injury (Cook, Burton, Hoogenboom, & Voight, 2014). Despite these findings, a direct comparison of balance training and functional movement studies has been difficult due to the diversity of the populations studied. For example, previous research has examined the effects of balance training on various age groups, athletic status, and injury history (DiStefano et al., 2009; Granacher, Gollhofer, & Kriemler, 2010; Granacher, Muehlbauer, Maestrini, et al., 2011; Hrysamallis, 2011; Zech et al., 2010). Furthermore, there has been a lack of standardization in balance outcome measures and specific training regimens. To date, the number of studies that specifically look at balance training and functional movement in youth are limited.

The aim of this review is to (1) discuss the incidence of injury in youth hockey; (2) discuss key terminology related to balance performance and functional movement; (3) discuss the impact of balance ability, functional movement, and concussion status on sport injury risk; and (4) discuss the impact of balance ability and functional movement on performance measures. This review is necessary to establish an understanding of the current literature and provide a framework for future research that focuses on determining whether baseline measurements of balance and functional movement, including muscle imbalances, mobility, and instability as well as concussion status can help provide insight into the incidence of injury during seasonal play in youth ice hockey players.

2.2 THE INCIDENCE OF INJURY IN YOUTH ICE HOCKEY PLAYERS

Ice hockey is a popular sport for young athletes. Hockey Canada reported over 600,000 registered players under the age of 19 at the end of the 2013/2014 season (Hockey Canada, 2014). It has been recognized as a high-risk sport as a result of the speed of play, the type of equipment used, and the allowance of body checking in certain age groups and levels of play (Emery, Hagel, Decloe, & Carly, 2010). According to Emery (2010), in youth sports the rate of estimated injury varies significantly in the literature, indicating differences in the classifications of injury, skill level of players, age, as well as methodological discrepancies and inconsistent reporting (Emery et al., 2010).

Emery et al. (2010), conducted a systematic review and meta-analysis to identify risk factors for injury and severe injury in youth ice hockey. The authors caution that although reportedly high injury rates occur, ranging from 11.7 injuries per 1000 player hours to 34.4 per 1000 player hours, it is important to compare the various studies closely, paying attention to the various definitions of injury and the different populations studied (Emery et al., 2010). Results of the review demonstrated that in all observed studies there was an increase in risk of injury during participation in games compared with practices. In addition, cohorts that allowed body checking clearly demonstrated an increased risk for injury and concussion in comparison to non-body checking groups. According to the studies in this review, the odds of incurring a severe injury in the body checking group were 2.01 times greater than in the non-body checking group (Emery et al., 2010). Other factors such as level of play, player position and age provided inconsistent findings.

Currently in Ontario, body contact is prohibited until Minor Bantam (ages 13-14) from a representational league (OMHA, 2015), with the exception of the Greater Toronto Hockey League (GTHL), which recently reported the progressive removal of body contact from the Minor Bantam “A” level. Prior to the start of the 2011-2012 season, the Ontario Minor Hockey Association (OMHA) determined that body checking would be removed from all age divisions of House League and House League Select hockey. Recently, the OMHA announced as part of a two year pilot project, the decision to remove body contact for all recreational hockey programs including House League (HL), Select, Local League (LL) and Minor Development (MD), effective for the 2015-2016 season (Ontario Minor Hockey Association, 2015). However, it is important to note that accidental and unintentional contact does occur and remains a cause of injury (Forward et al., 2014).

Forward et al. (2014) used a comparative epidemiological study looking at ice hockey injuries between male and female youth in Canada. In this cross-sectional, retrospective study, all hockey-related injuries suffered by children seven to 17.5 years of age were identified using the Canadian Hospitals Injury Reporting and Prevention Program (CHIRPP) database (Forward et al., 2014). The CHIRPP database is created from 10 pediatric and four general hospitals in Canada. Thirty-four percent of boys between the ages of seven and 12 suffered an injury. The top three injuries for both male and female players were soft tissue injuries followed by sprains/strains and fractures. Of additional importance was the number of concussions sustained for male players. In the seven to eight year old players, 6.5% sustained a concussion and 13% suffered minor head injuries. These numbers increased to 7.0 % and 14.5% respectively in the next age group of nine and ten year old boys.

The need for injury prevention strategies is evident based on the high number of injuries in youth ice hockey. Although these studies have identified a variety of risk factors for injury, incorporating pre-screening tools that enable researchers to evaluate multiple risk factors may be of great importance. A rigorous scientific approach is important to understanding the complexity of injury risks in order to develop prevention programs, improve player retention and improve safety policies related to injury in youth ice hockey players (Emery, 2010).

2.3 BALANCE AND FUNCTIONAL MOVEMENT TERMINOLOGY

Balance is the ability to maintain the body's centre of gravity over its base of support. Balance can be required when a person is attempting to maintain a static posture (static balance), perform voluntary movement or execute a reactionary movement after receiving a stimulus from the environment (dynamic balance) (Heyward, 2014). Static balance requires the individual to establish a stable base of support and maintain this position while minimizing segment and body movements (Gribble, 2012). Dynamic balance is much more intricate and often necessitates movement around the base of support. To maintain balance it is necessary to have coordinated muscle movements, neuromuscular efficiency and an active range of motion (flexibility). In addition, input from various sensory structures (visual, vestibular and somatosensory) is required. It is an intricate balance of relayed messages from these sensory structures with the visual system helping to provide information regarding the body's location relative to its environment; the somatosensory system recognizing location and movements of body parts; the vestibular system providing information about head position along with how fast and in what direction the head is accelerating (Heyward, 2014). Similar to the requirements necessary to maintain balance, performing functional movements also utilizes the principles of proprioceptive neuromuscular facilitation (PNF), muscle synergy, and motor learning (Cook, Burton, & Hoogenboom, 2006). These types of fundamental human movements require a combination of strength, flexibility, range of motion, coordination, balance, mobility and stability, and are commonly performed by using multi-joint and multi-planar actions.

Previous pediatric literature has suggested that the development of a number of physical and physiological variables are often influenced by the level of biological maturation (Faigenbaum, Lloyd, & Myer, 2013). Varying rates of myelination of motor neurons, enhanced inter- and intramuscular coordination, differences in hormonal profiles and increases in lean body mass, all have the potential to influence physical performance (Lloyd et al., 2014; Lloyd et al., 2015). Previous literature proposed that both muscular strength and stature can account for up to 70% of the variation of motor skills in activities like throwing, jumping and sprinting in 7 to 12 year old boys (Teeple, Lohman, Misner, Boileau, & Massey, 1975). Increases in limb lengths and body dimensions, as well as the maturation of muscle mass have the potential to affect movement proficiency during the adolescent stage of development; therefore, this population has the difficult task of learning to move with these constantly changing levels of coordination (Quatman-Yates, Quatman, Meszaros, Paterno & Hewett, 2012). Additional research has suggested that maturation and movement proficiency may also have an impact on overall performance measures (Lloyd et al., 2014; Lloyd et al., 2015; Myer, Lloyd, Brent, & Faigenbaum, 2013).

2.4 BALANCE ABILITY AND SPORT INJURY RISK

It has been shown that youth have higher intrinsic risk factors for sustaining an injury compared to adults. Neuromuscular constraints such as deficits in postural control and muscular strength are contributing factors, and; therefore, improved balance performance may have the potential to be beneficial for reducing the risk of injuries (Granacher, Muehlbauer, Gollhofer, Kressig, & Zahner, 2011; Hytonen, Pyykko, Aalto, & Starck, 1993). Hubscher and colleagues (2010) completed a systematic review on neuromuscular training for sports injury prevention. Using seven methodologically well-conducted trials, their analysis showed evidence that proprioceptive/neuromuscular training can be effective in reducing the incidence of certain types of sports injuries among adolescent and young adult athletes (Hubscher et al., 2010). Despite the plethora of research in this area, few studies have been conducted to determine if poor baseline balance scores can predict the risk of injury during regular seasonal play.

McGuine et al., (2000), explored the relationship between pre-season measurements of balance and its ability to predict ankle injuries in male and female high school basketball players ($n = 210$). In this cohort study, balance was measured using quantified postural sway scores while participants performed unilateral balance tests with eyes open and eyes closed. Balance was measured using a force platform interfaced to a computer. Results indicated that participants who suffered an ankle sprain had higher postural sway scores ($p = 0.001$). Furthermore, they showed that participants who exhibited higher postural sway scores had nearly seven times as many ankle sprains as subjects who demonstrated low postural sway scores ($p = 0.0002$) (McGuine, Greene, Best, & Leverson, 2000).

McHugh and colleagues (2006) found contradictory results when assessing balance pre-season and predicting the associated risks of noncontact ankle sprains in high school athletes ($n = 169$). Athletes participated in a variety of sports including football, men's and women's basketball and soccer, and women's gymnastics. Balance was measured in a single stance on an instrumented tilt board. The board had a switch placed on the contralateral foot to detect when that foot was used to correct balance (McHugh, Tyler, Tetro, Mullaney, & Nicholas, 2006). Activation of these switches were recorded and represented when participants were out of balance. Results indicated no statistically significant correlation between poor balance ability and increased risk of noncontact inversion ankle sprains ($p = .72$). However, the authors did note that a higher body mass index (BMI) in male athletes was associated with increased risk ($p < 0.05$) and the combination of a previous injury and being overweight further increased risk ($p < 0.01$) (McHugh et al., 2006).

McKeon and Hertel (2010) conducted a systematic review on postural control and lateral ankle instability using only studies that assessed postural control measures in participants on a stable force plate. It was determined that poor postural control was most likely associated with an increased risk of a lateral ankle sprain (McKeon & Hertel, 2008). In contrast, however, it was noted that although chronic ankle instability is often claimed to be associated with deficits in postural control, these limitations were not demonstrated consistently in the literature. Therefore, it was suggested that those with chronic ankle instability may benefit from more complex and challenging functional tasks that have the potential to better identify these deficits. The authors proposed the use of the Star Excursion Balance Test (SEBT), a test of dynamic balance, as a potential tool to identify those with postural control deficits and to help identify those who are potentially at an increased risk for injury (McKeon & Hertel, 2008).

Since youth athletes are a population with specific balance requirements that integrate multi-joint movements and place an emphasis on whole body movements rather than performing movements in isolation, it is important that the majority of assessments used for athletes be dynamic in nature. Although a single-leg stance test may be purposeful when used to determine balance improvement of a participant post-injury and determine readiness to return to play, it may not be as useful for an athlete as it only measures a few of the systems essential for maintaining balance. Plisky et al. (2006) explored the relationship between dynamic balance ability and its associated risk of lower extremity injury in a population of boys' and girls' high school basketball players (girls n = 105; boys n = 130). In this prospective cohort study, the anterior, posteriomedial and posteriolateral reach distances were measured using the Star Excursion Balance Test and limb lengths were measured bilaterally. Coaches and athletic trainers recorded time loss due to injuries using the Athletic Health Care System Daily Injury Report. Injury was defined as " any injury to the limb including the hip, but not the lumbar spine or sacroiliac joint, that resulted from a team-sponsored basketball practice or game that caused restricted participation or inability to practice in the current or next scheduled practice or game" (Plisky, Rauh, Kaminski, & Underwood, 2006, p. 913). Results indicated that for all players, anterior right/left reach distance differences greater than or equal to 4 cm was significantly associated with lower extremity injury. Furthermore, a decrease in normalized right anterior reach distance, and decreased normalized posteromedial, posterolateral, and composite reach distances bilaterally were also significantly correlated with lower extremity injury (Butler et al., 2013). These results were consistent with previous studies that reported that poor balance contributed to an increased risk of ankle injury in a population of basketball players (McGuine et al., 2000). Pilsky et al. (2006) theorized that in addition to assessing dynamic balance, tests that have the ability to measure multiple domains of function (balance, strength, range of motion) simultaneously, may improve the accuracy of identifying athletes at risk for injury through pre-participation assessment (Plisky et al., 2006).

Despite a number of studies conducted to determine the relationship between balance and risk of injury, little research has been conducted in prepubertal youth, and little is known about which tools may be the most appropriate to effectively evaluate balance. In addition, the high injury rates among youth ice hockey players and the growing number of participants in this sport warrants the identification of modifiable factors that may contribute to injury risk in this population.

2.5 FUNCTIONAL MOVEMENT AND SPORT INJURY RISK

Pre-participation assessments have often entailed fitness parameters that include evaluations of muscular strength and endurance, flexibility, power, speed, aerobic fitness, agility, and BMI thought to be indicative of injury risk (Dossa, Cashman, Howitt, West, & Murray, 2014; Grant et al., 2015; Kennedy et al., 2012). Recently there has been an overwhelming interest to include the Functional Movement Screen (FMS) as a tool to rank and grade movement patterns and identify existing muscle imbalances and asymmetries. Information gathered from the FMS has been shown to demonstrate a correlation between lower scores (≤14 on a 21 point scale) and an increased risk of injury (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Garrison, Westrick, Johnson, & Benenson, 2015; Kiesel, Plisky, & Voight, 2007).

Chorba and colleagues (2010) found using a retrospective design that in a population of NCAA II female college athletes (n = 38; *M* age = 19.24 ± 1.20) participating in soccer, basketball or volleyball demonstrated that players who scored 14 or less were found to be significantly more likely to sustain an injury over the course of the competitive season (p = .0496). Injury was defined as “any musculoskeletal injury that occurred as a result of participation in an organized intercollegiate practice or competition that required medical advice from a certified athletic trainer” (Chorba et al., 2010, p.49). When comparing athletes who scored >14 to those who scored ≤14, the latter were found to experience a four-fold increase in risk of injury on the FMS with 69% of these sustaining an injury throughout the season. In addition, 82% of athletes who scored ≤13 suffered an injury during the competitive season (Chorba et al., 2010).

Kiessel, Plisky and Voight (2007) explored the relationship between composite FMS scores and American football players (n = 46) and the likelihood of suffering an injury. The authors used the term “serious injury”, defined as “membership on the injured reserve and time-loss over 3 weeks" over the course of one competitive season (p.149). Results indicated that the mean FMS scores for participants who suffered and did not suffer a serious injury during the season were 14.3 ± 2.3 and 17.4 ± 3.1, respectively. To determine the FMS cut-off score that maximized the specificity and sensitivity of the test a receiver-operator characteristic (ROC) curve was used. This indicated a composite cut-off score of 14 on the FMS (Kiesel et al., 2007).

Adding to the increasing body of evidence that indicates a predictive relationship between FMS scores and the development of injuries, Garrison et al. (2015) investigated the associated between composite FMS scores and injury development in college athletes (n = 160; ages 17 -22). Injury was defined as "any musculoskeletal pain complaint, on or off the field of competition, in which the injury was associated with athletic participation; the injury required consultation with a certified athletic trainer, physical therapist, or physician; and, the injury resulted in modified training for at least 24 hours or the injury required protective splinting or taping for continued sports participation" (Garrison et al., 2015, p.23). The mean FMS composite score for the injured group was 13.6 and 15.5 for the uninjured group. An independent t-test indicated a statistically significant difference between the two groups (Garrison et al., 2015). Similar to Kiesel et al. (2007) the ROC curve analysis indicated that a composite FMS score of 14 or less should be used to maximize sensitivity and specificity. Logistic regression models generated odds ratios of 5.61 (2.73, 11.51) for the FMS score 14 or less indicating that an athlete with a composite score of 14 or less has more than five times greater chance of injury compared with an athlete who has a composite score of 15 or higher. Additionally, if an athlete had a history of prior injury, the odds ratio was increased to 15.11 (6.60, 34.61) placing this athlete at a 15 times greater chance of injury when compared to an athlete with a composite score of 15 or higher with no history of past injury (Garrison et al., 2015).

Bardenett et al. (2015) investigated the ability of the FMS to predict injury in a population of high school athletes. Participants (n =167) included 90 females and 77 males and were recruited from one public high school during the fall season of 2012. Represented sports included boys and girls cross-country, boys football, boys and girls soccer, girls swimming, girls tennis, and girls volleyball. There were no statistically significant associations between the total FMS composite scores and the ability to predict injury (p=0.954); however, further analysis of data indicated injured athletes scored lower on the shoulder mobility movement test (p=.001). Interestingly, the authors discovered that higher scores for the in-line lunge were shown in athletes who were injured, as compared to lower scores in uninjured athletes (p=.022). The authors could not explain this "counterintuitive finding" (Bardenett et al., 2015, p. 307).

Dossa et al. (2014) used a prospective cohort study design to investigate the ability of the FMS to predict the incidence of injury among a group of major junior hockey players (n = 20, ages 16-20). Injury was defined as "a physical condition that occurred during a game or practice which resulted in the player missing at least one game" (Dossa et al., 2010, p.424). In addition, a subcategory of injury was developed for those injuries sustained due to contact that may have involved contact with the ice or boards, collisions with another player and/or contact with a puck or stick. The mean FMS scores for players that sustained an injury was 15.0 and for those who were not injured was 14.4. All injuries sustained were a result of contact. A total of 17 injuries were reported and of those, seven occurred in players with an FMS score of ≤14 and ten in players who had a FMS score of ≥14. Results did not support the hypothesis that low FMS scores (≤14) can predict injury risk in hockey players (Dossa et al., 2014). Participants were selected from only one team, reflecting a small sample size and possibly limiting the statistical strength of the data. In addition, the definition of injury used may have eliminated potential musculoskeletal injuries from the analysis.

Although there have been a number of studies evaluating the use of FMS as a tool to help identify an athlete's risk of injury, there is a lack of research from youth ice hockey players. The FMS is an inexpensive and non-invasive tool that can assess functional movement patterns and determine existing functional movement limitations and asymmetries.

2.6 THE PATHOPHYSIOLOGY OF CONCUSSION

According to Grady (2010), a concussion is a type of traumatic brain injury (TBI) that has often been used in the medical literature interchangeably with mild TBI. Over the years our understanding of the pathophysiology of concussion has evolved, leading to an improved definition of concussion. The 4th International Conference on Concussion in Sport, has defined concussion as a mechanism of injury that results in direct or indirect forces to the head resulting in symptoms including somatic, cognitive, emotional disturbances, and/or altered sleep patterns (McCrory, 2012; Schatz & Moser, 2011). A concussed individual can clinically present with a wide variety of symptoms, some of which may include nausea, headaches, fatigue, sadness, mood symptoms, impaired sleep-wake cycles, and difficulty concentrating and remembering (Pardini et al., 2004). The exact biochemical events that lead to a concussion are likely a combination of stretching, shearing, compression or deformation injuries to the neural tissue which gives rise to a set of cellular and cerebral blood flow changes (Aligene & Lin, 2013).

2.7 CONCUSSION STATUS AND SPORT INJURY RISK

Current literature suggests that during pre-adolescent developmental periods, the human brain may be more susceptible to concussions (Schatz & Moser, 2011). Neuropsychological assessments have the potential to contribute meaningful information pertaining to concussion status. A recent study by Field, Collins, Lovell, & Maroon (2003) on athletes in high school demonstrated prolonged cognitive recovery post-concussion in areas such as working memory, processing speed, and reaction time. Such computerized neurocognitive assessments have become an increasingly popular tool for assessing the cognitive function of athletes (Meehan, d'Hemecourt, Collins, Taylor, & Comstock, 2012). These assessments often evaluate multiple aspects of neurocognitive function including verbal memory, visual design memory, concentration, attention, brain processing speed, and reaction time.

An advantage of conducting such tests at the beginning of a season is that they can then be used for comparison after a concussion has been sustained to determine changes in brain functioning (MacDonald et al., 2015). Currently, one of the most popular computerized neurocognitive tests used among schools in the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) (ImPACT Application, Inc, Pittsburgh, PA).

As the reliability of a baseline neurocognitive assessment is important for proper comparisons between pre and post-concussion symptoms, Elbin et al., (2011) conducted a case series study to investigate the 1-year test-retest reliability of the ImPACT online version in a population of high school athletes (Elbin, Schatz, & Covassin, 2011; MacDonald et al., 2015). A total of 369 non-concussed athletes completed two mandatory baseline cognitive assessments approximately 1 year apart. Results indicated that motor processing speed (0.85 ICC) was the most stable composite score. This was followed by reaction time (0.76), and visual memory (.70), and verbal memory (.62). The authors concluded that the online ImPACT baseline is a consistent measure of neurocognitive performance (Elbin et al., 2011). Recently, Lichtenstein (2014) conducted a cross-sectional study to determine the prevalence of invalid baseline scores in pre-high school athletes. A total of 502 athletes between the ages of 10 and 18 years completed baseline neurocognitive tests. Results indicated that younger athletes had a greater number of invalid baseline tests than older youth athletes. In addition, it was concluded that the number of invalid tests increases when testing is completed in a large group (Lichtenstein, Moser, & Schatz, 2014). Although the ImPACT test is reliable and valid, to help minimize any invalid assessments, all computerized baseline neurocognitive testing should take place in a private setting. Until recently, there was no established computerized baseline test for children under the age of 10; ImPACT has now developed such a tool.

Although neurocognitive assessments are frequently used in the evaluation of concussions, it should also be used to help identify baseline symptoms of dizziness, neck pain, and headaches, which could also conceivably place an athlete at an increased risk of sustaining an injury or concussion, is equally important. Schneider and colleagues (2013) collected secondary data from two prospective cohort studies from ice hockey rinks located in Alberta and Quebec, Canada. A total of 3832 male ice hockey players aged 11 to 14 years participated in the project. The main outcome measure was concussions that occurred during the season. Results demonstrated that those athletes that reported having a headache and neck pain at baseline were at increased risk of sustaining a concussion during the season (IRR = 1.67; 95% confidence interval [CI], 1.15-2.41 and IRR = 1.47; 95% CI, 1.01-2.13). In addition, those players in the Pee Wee non-body checking cohort demonstrated that a pre-season report of dizziness was also a risk factor for concussion (IRR = 3.11; p5% CI, 1.33-7.26) (Schneider et al., 2013). To our knowledge there have been no further studies conducted that relate pre-season measurements of concussion status in order to predict risk of injury. Further research is warranted in order to reduce both short-term and long-term implications of youth ice hockey injuries.

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CHAPTER 3: MANUSCRIPT

TITLE: SEASONAL CHANGES IN FUNCTIONAL FITNESS AND NEUROCOGNTIVE ASSESSMENTS IN YOUTH ICE HOCKEY PLAYERS

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3.1 ABSTRACT

BACKGROUND: Balance and functional movement patterns are critical components of motor skills in youth. Deficits in balance and in strength or power combined with differing rates of sensory and motor neural development may increase the risk of sports related injury. PURPOSE**:** To evaluate changes in functional fitness and concussion status over the course of a competitive season in youth ice hockey players, and to examine the relationship between these variables and injury incidence during seasonal play. METHODS**:** Thirty-six participants (8.9 ± 1.1 years) completed pre and post-season assessments including anthropometric measurements, the Functional Movement Screen (FMS), Lower Quarter Y-Balance Test (YBT-LQ) and a computerized neurocognitive assessment, the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT). Frequencies, means and standard deviation were used to describe the sample. Paired samples t-tests were used to compare pre and post-season data. Independent samples t-tests were used to compare FMS, YBT-LQ and ImPACT scores between injured and uninjured participants. RESULTS**:** Height of participants increased from pre (136.56 ± 7.64 cm) to post-season (139.95 ± 7.69 cm, $p<0.01$) and thigh circumference increased from pre (37.24 ± 4.14 cm) to post-season (38.39 ± 3.57cm, $p<0.01$). Mean composite score (CS) of the FMS was not statistically different between pre and post-season. The YBT CS showed a significant decrease in reach distance scores between pre (86.10 ± 6.00) and post-season (83.20 ± 5.40, $p<0.001$). Neurocognitive assessments scores improved in both the injured and uninjured participants; total symptom score (pre 1.17 ± 2.82, post 0.31 ± 1.09, $p=0.96$) did not change. The majority of injuries sustained were a result of a collision that occurred with either another player and/or referee (26%) or from a collision with a fixed object (22%). There were no statistically significant relationships between FMS scores, YBT-LQ and injury incidence. CONCLUSION: Our results showed that some components of functional fitness decreased over the season, while other measures of functional fitness did not change over the season. The incidence of injury did not appear to differ by functional fitness levels or concussion status. Findings support existing evidence that suggest that a participants' neurocognitive performance may vary across sessions. Results from our study indicate that future research is needed to better understand the effects of functional fitness and concussion status as they relate to injury prevention.

KEYWORDS: Youth Athletes, Functional Movement Screen, Y-Balance Test, Neurocognitive Assessment, Ice hockey

3.2 INTRODUCTION

Participation in organized youth sport is starting at a younger age than ever before (Kostka et al., 2012; Washington et al., 2001). In Canada, ice hockey (herein referred to as hockey) is one of the most popular activities, with 22% of children (ages 5-14) participating annually (Government of Canada, 2013). Hockey is positively associated with motor skill development and higher self-esteem; however, it is also associated with a high risk of injury (Black et al., 2016). Although the majority of injuries related to hockey are caused by contact, approximately 15% are non-contact musculoskeletal injuries (Parenteau-G et al., 2014). An injury of particular concern in hockey is concussions. Current research suggests that during pre-adolescent developmental periods, the human brain may be more susceptible to concussions (Schatz & Moser, 2011). In the past decade, emergency department visits for paediatric concussions has increased by over 50% (Zemek, 2015). Over a 15-year period (January 1995 to December 2009) the Canadian Hospitals Injury Reporting and Prevention Program (CHIRPP) database reported that in seven to eight year old hockey players, 6.5% sustained a concussion and 13% suffered other minor head injuries. These numbers increased to 7.0 % and 14.5%, respectively in the next age group of nine and ten year old boys (Forward et al., 2014).

There are several intrinsic characteristics, such as poor neuromuscular control and muscle imbalances, that can increase an athlete's susceptibility to injury (Black et al., 2016; Cook, Burton, Hoogenboom, & Voight, 2014a). It is critical to identify appropriate tools to assess balance and functional movement patterns in order to determine whether an athlete has deficits that could increase their risk of injury (Cook, Burton, Hoogenboom, & Voight, 2014a, 2014b; Krumrei, Flanagan, Bruner, & Durall, 2014; Parenteau et al., 2014). Previous research in athletic populations has demonstrated a predictive relationship between injury and tools that assess functional movement patterns (Chorba, Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Garrison, Westrick, Johnson, & Benson, 2015; Kiesel, Plisky, & Voight, 2007; Krumrei et al., 2014) as well as tools that assess neuromuscular control (Gonell, Romero, & Soler, 2015). The ability to perform dynamic actions that require the body to maintain postural control is important for successful athletic performance and reduced risk of injury. Among youth, the rate of growth can vary significanty over the course of a season, thus influencing performance and injury risk. Previous research in athletic populations indicates that testing movement patterns and neuromuscular control over a season may be useful; but the findings are not consistent (Zech, Klahn, Hoeft, Eulenburg, & Steib, 2014; Sprague, Mokha, & Gatens, 2014).

In addition to assessing musculoskeletal fitness, concussion status should be assessed pre and post-season to allow coaches to determine changes in neurocognitive function, as well as the risk for future injury or re-injury (Schneider, Meeuwisse, Kang, Schneider, & Emery, 2013). Researchers have shown that the risk of sustaining a concussion is 70% higher among those who report neck pain at baseline compared to those who did not report neck pain at baseline. Similarly, those who report headaches at baseline are 50% more likely to sustain a concussion during the season compared to those who do not report headaches (Schneider et al., 2013). There is a clear need to monitor signs and symptoms associated with a concussion over the season.

At this time, there is a lack of standardized evidence-based pre and post-season testing batteries for children playing hockey. Thus, the primary purpose of this study was to evaluate functional fitness and concussion status over the course of a competitive season in male youth (aged 8-11 years) hockey players. A secondary purpose was to investigate the occurrence of injury in the context of functional fitness and concussion status. Based on previous research, it was hypothesized that participants with lower levels of functional fitness at baseline (Chorbra et al., 2010; Garrison et al., 2015; Kiesel et al., 2007; Krumrei et al., 2014) and participants who scored lower on neurocognitive tests would sustain a greater number of injuries compared to those who scored higher (Swanik, Covassin, Stearne, & Schatz, 2007). Furthermore, it was hypothesized that some measures of functional fitness (including dynamic balance and deep squat) would improve (Zech et al., 2014; Sprague et al., 2014), while others (e.g. active straight leg raise) would get worse over the season (Sprague et al., 2014).

3.3 METHODS

Study Design & Sample

Children 8-11 years of age playing ice hockey with the Ontario Minor Hockey Association completed pre-season and post-season assessments.. Recruitment began by presenting the details of the prospective research project to all executive board members from the local minor hockey association. Following approval from the board members, coaches, team managers and team trainers were approached to discuss the project and guage potential interest. Lastly, an information session for all potential players and parents was held. Parents and parents were encouraged to ask questions regarding specific details pertaining to the project. Eligible participants were then able to enrol. Participants were male who were free from injury and were members of a representative team from either the Novice (age 8 years), Atom (ages 9-10) or Minor Peewee (age 11) divisions. Exclusion criteria included a recent report (< 3 months) that indicated a musculoskeletal or head injury that could have affected their performance during testing. Thirty-eight participants completed baseline testing; two participants voluntarily withdrew from the study thereafter. The project was approved by the University of Ontario Institute of Technology Research Ethics Board. Participants provided assent, and parental consent was obtained prior to assessments.

Procedures

All participants completed testing individually at pre and post-season testing sessions. Upon arrival, participants were measured for height and weight, and then completed the computerized neurocognitive assessment with trained research assistants (graduate or undergraduate students in Kinesiology). Finally, a researcher (MA) trained in the administration of the functional movement screen (FMS) protocol and the lower quarter y-balance test (YBT-LQ) administered each of these tests along with the remaining anthropometric measurements. Each of these measures is described below.

Measures

Anthropometrics

Height, weight, and circumferences of the bicep, thigh and waist were assessed using a standard medical scale and a tape measure to the nearest 0.5 cm, 0.1 kg and 0.1 cm, respectively. Body mass index (BMI) was calculated as weight (kg)/height^2 (m).

Lower Quarter Y-Balance Test (YBT-LQ)

The YBT-LQ uses three maximal reaching tasks in the anterior, posterior-medial and posterior-lateral directions using the right and left foot to assess active range of motion and dynamic balance. In children under 13 years of age, the YBT-LQ has demonstrated excellent interrater reliability within sessions (ICC > 0.995) and between sessions ($0.907 \leq \text{ICC} \leq 0.974$) (Faigenbaum et al., 2014).

Participants performed all trials in each direction with each foot; the best of three valid attempts were measured. They were permitted to rest for a maximum of 20 seconds between each reach. Participants were permitted two practice trials for each of the three reach distances for each leg prior to formal testing. To ensure participant consistency within skill performance, no verbal feedback was provided during either the practice trials or the testing trials. Reach distances were read on the side closest to the participant being tested to the nearest 0.5 cm. Trials were considered invalid if the participant: 1) was unable to return to their start position without the loss of balance, 2) touched down with the reach foot to gain balance, and 3) lifted the stance foot from the centre platform. The YBT-LQ composite score was calculated using the sum of the 3 reach distances (anterior, posteromedial and posterolateral) and dividing by three. This was done separately for both the right and left leg. To allow for a more accurate comparison between participants, reach distance was first normalized to limb length: (reach distance / limb length) x 100). Further detail on the YBT-LQ protocol can be found elsewhere (Smith, Chimera, & Warren, 2015).

Instructions were modified due to the age of the participants. Modifications included age-appropriate verbal instructions; images of each movement for the participant to view, and observations of demonstrations for each movement in each of the three reach directions. Only one other study to our knowledge has made similar modifications (Faigenbaum et al., 2014). These modifications were necessary to ensure participants were completing the tasks appropriately.

Functional Movement Screen (FMS)

The FMS was used to rank and grade movement patterns and to assist in the identification of functional limitations and asymmetries. As outlined by Cook et al. (2014a), seven movement patterns used were: 1) the deep squat, which assesses functional mobility of the hips, knees and ankles, 2) the hurdle step, which assesses stride mechanics, 3) the in-line lunge, which assesses mobility and stability of the hip and trunk, quadriceps flexibility and ankle and knee stability, 4) shoulder mobility and scapular stability, which assesses bilateral shoulder range of motion and requires thoracic spine extension and normal scapular mobility, 5) active straight leg raise, which assesses posterior chain flexibility, 6) trunk stability push up, which assesses spinal stabilization during a closed-chain upper body movement and (7) the rotary stability test, which evaluates multi-plane trunk stability. Previous research conducted by Parenteau et al. (2014) found that interrater and intrarater reliability of the FMS among a group of young elite hockey players aged 13-16 was excellent (ICC of 0.96 for both the video rating sessions and the field rating sessions).

Each movement performed during the screening test was graded and ranked by the primary investigator using prescribed guidelines as set out in previous literature (Cook, Burton, Hoogenboom, & Voight, 2014a, 2014b). Each movement was evaluated using a 0-3 ordinal scale: 0 = pain during the movement; 1 = participant was unable to execute the correct movement; 2 = participant used compensatory movements to execute the movement, and; 3 = participant performed movement with accuracy and precision without pain or compensation.

Prescribed guidelines used in previous research were used as a guide to assist in the instructions provided to each participant; however, similar to the YBT-LQ, instructions were modified to accommodate the age of the participants in order to make the tasks easier to understand. To our knowledge, no other studies using FMS in this age group have reported modifying the instructions. Again, these modifications were necessary to ensure participants were completing the tasks appropriately.

Neurocognitive Assessment

The online version of the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) (ImPACT Application, Inc, Pittsburgh, PA) was used to evaluate multiple aspects of neurocognitive function including verbal and visual memory, visual motor speed, impulse control, and reaction time. Among high school athletes (Elbin, Schatz, & Covassin, 2011; MacDonald et al., 2015) reliability was shown to be good for motor processing speed (0.85 ICC), followed by reaction time (0.76), visual memory (0.70), and verbal memory (0.62). The authors concluded that the online ImPACT baseline is a consistent measure of neurocognitive performance (Elbin et al., 2011). No validity or reliability studies are available on paediatric populations using this version of the ImPACT.

Assessments were conducted individually under the supervision of a member of the research team. To accommodate for varying levels of reading ability and comprehension, all on-screen instructions were read out-loud for each participant in order to ensure consistency and understanding for each of the separate assessments.

Injury Reports

Baseline data on injury and medical history were collected using the Hockey Development Centre for Ontario Player Information Medical Form (Hockey Development Centre for Ontario, 2015). During the hockey season, on-ice injuries that occurred during a game and/or practice, as well as any injury sustained during dry-land training or warm-up, were tracked by team staff and/or by the parent using the Sports Injury Tracker Form (Sports Medicine Australia, 2015). The injury report form asked for information pertaining to the session type, mechanism, location and type of injury, time, date, and playing time lost. Separate categories were specified for mechanism of injury and included, body contact (body checking, cross-checking, tripping, slashing), and environmental contact (puck, net, boards). Locations of injuries were initially recorded into individual categories but then later were placed into main groupings (upper limbs, lower limbs, trunk/abdomen, head/neck) for analysis purposes. Injury type was classified according to various categories such as over-exertion injures which included muscle strains or sprains.

Injury was defined as "any physical complaint sustained by a player that results from a hockey game or hockey training, irrespective of the need for medical attention or time-loss from hockey activities" (Fuller et al., 2006). The primary investigator reviewed each of the injury report forms to ensure they were completed accurately and that they met the injury criteria.

Statistical Analysis

Frequencies, means and standard deviations were calculated to describe the sample. Paired samples t-tests were used to compare pre and post-season data. Independent samples t-tests were used to compare FMS, YBT-LQ and ImPACT scores between injured and uninjured participants. Statistical analyses were conducted using SPSS v24 (IBM Corp., Armonk, NY, USA), a effect sizes were calculated using G*Power 3.1 (Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G., 2009). Statistical significance was set at $p<0.05$.

3.4 RESULTS

The average age of the sample was 8.9 ± 1.1 years with a BMI of 17.1± 1.9 kg/m^2 (n=38). There were significant changes in anthropometric measures from pre-season to post-season. Height of participants increased from pre-season (136.6 ± 7.6 cm) to post-season (140.0 ± 7.7 cm, $p<0.001$, d=0.4) and thigh circumference increased from pre-season (37.2 ± 4.1 cm) to post-season (38.4 ± 3.6 cm, $p<0.001$, d=0.3). Additional sample characteristics are presented in Table 1.

Only two participants reported pain during the FMS shoulder mobility test, which resulted in a score of zero. There were improvements in the active straight leg raise from pre-season (2.0 ± 0.5) to post-season (2.3 ± 0.6, p=0.02, d=0.9). The mean composite score of the FMS was not different between pre-season (15.1±1.8) and post-season (15.6 ± 2.3, p=0.16, d=0.2). None of the other FMS scores changed over the season (Table 2).

A decrease in total YBT-LQ mean composite reach scores was observed in the right leg from pre-season (86.0 ± 6.0) to post-season (83.3 ± 5.7, $p<0.001$, $d=0.5$) and in the left leg from pre-season (86.2 ± 6.4) to post–season (83.1 ± 5.6, $p<0.001$, $d=0.5$). The YBT-LQ composite score also decreased between pre-season (86.1 ± 6.0) and post-season (83.2 ± 5.4, $p<0.001$, $d=0.5$) (Table 3).

Mean scores and standard deviations for each ImPACT assessment are presented in Table 4. Significant differences were found in all assessments with the exception of total symptom score (pre-season 1.2 ± 2.8, post-season 0.3 ± 1.1, $p=0.96$, $d=0.4$).

Details pertaining to injury cause, type and location are presented in Figures 1, 2 and 3. Of the 36 participants, 17 (47.2%) sustained at least one hockey injury during the season. Of these 17 injured players, three reported sustaining two injuries, and one player reported three injuries. The majority of injury types sustained were reported as a result of a collision that occurred with either another player and/or referee (26%) or from a collision with a fixed object (22%). Thirty-nine percent of injuries presented were categorized as contusions, bruises, or inflammation. Another 39% of injuries were from participants who reported symptomatic pain. The majority of injures were to the head or neck area (39%), followed by upper (22%) and lower limb injures (22%).

Differences in FMS composite scores and YBT-LQ scores between injured and uninjured participants are illustrated in Figure 4. There was no difference between the total FMS score ($p=0.65$) or the YBT-LQ composite score ($p=0.45$) when comparing the injured vs. uninjured participants. The mean FMS score for injured participants did not change from pre-season (14.5 ± 2.0) to post-season (15.0 ± 2.4, $p=0.39$, $d=0.2$). Differences were found between the mean YBT-LQ composite scores for the injured participants from pre-season (86.5 cm ± 7.6) to post-season (83.6 cm ± 4.2, $p=0.02$, $d=0.4$) and uninjured from pre-season (85.8 cm ± 4.3) to post-season (82.85 ± 6.7, $d=0.5$).

Figure 5 illustrates mean ImPACT scores for various assessments for injured and uninjured participants. Verbal memory scores improved in the uninjured group from pre-season (80.6 ± 10.3) to post-season (86.5 ± 8.6, $p=0.02$, $d=0.6$). Visual motor speed scores improved significantly in both the injured ($p=0.01$, $d=0.8$) and uninjured participants ($p<0.01$).

3.5 DISCUSSION

Changes to cardiorespiratory fitness, muscular strength, and physical performance over the course of a competitive season have been previously described (Koutedakis, 1995); however, there are limited studies that look at changes in the quality of movement within a youth population. This is the first study, to our knowledge, to examine changes in functional fitness and concussion status over a competitive season in youth hockey players. Our primary finding is that functional movement does not change over the season, but dynamic balance decreases significantly. Our secondary finding is that there were improvements in most neurocognitive scores from pre to post-season, regardless of whether an athlete sustained an injury. These findings have implications for coaches and trainers working with youth hockey players, as they provide insight into expected changes, that is, athletes with significant differences from these data may be at increased risk of injury. This information can help guide the development of targeted injury prevention programs, that focus on identified limitations detected during pre-season screening.

With regards to functional movement, there was no change in the composite FMS score; however, the active straight leg raise score improved significantly from pre-season to post-season (moderate effect size). The lack of change in the composite FMS score is consistent with previous research (Sprague, 2014). In a sample of adult athletes (20.1 ± 1.1 years), no differences were observed in composite FMS scores from pre-season to post-season; however, contrary to our findings, there was a decrease in the active straight leg raise scores over the season (pre-season 2.9 ± 0.3, post-season: 2.7 ± 0.5). These differences could be related to the sports in which the athletes were engaging. Sprague (2014) indicated that the negative change found in their study may have been due to a cumulative effect of repetitive eccentric loading on the hamstrings, as is often observed in sports like soccer. This repetitive loading leads to increased tightness in the hamstrings and consequently, poorer performance on the active straight leg raise. The differences between the age of the athletes in these studies may also explain differences in results. Specifically, muscle stiffness or tightness has been shown to increase with age (Wu, Delahunt, Ditroilo, Lowery, & De Vito, 2016). Thus, it is possible that adult athletes experience an increase in tightness of the hamstrings, while sport participation over one season would not influence hamstring tightness in youth athletes.

When comparing injured and uninjured athletes, no differences were observed in FMS scores. The existing scientific literature suggests that participants with scores lower than 14 are at an increased risk of injury (Chorba et al., 2010; Kiesel, et al., 2007). Both injured (pre: 14.5, post: 15) and uninjured (pre: 15.6, post: 16.2) participants in our study were above this threshold. As the majority of studies comparing injury and FMS scores have been conducted in college and adult age athletes (Chorba et al., 2010; Garrison et al., 2015; Kiesel, et al., 2007), it is possible that the FMS was not sensitive enough to detect injury in a youth athlete population. Accordingly, future research is needed to establish a threshold in younger athletes.

With regards to dynamic balance, results from this study indicate that reach distance scores decreased over the season. The mean decrease in the YBT-LQ composite score was 2.8 cm (95% CI: 0.5-5.3), with a low to moderate effect (0.5). These findings are important as they indicate a *reduced* ability to perform a dynamic balance task. In contrast to the current study, previous research in youth field hockey players (age 14.9 ± 3 years) has shown improvements in dynamic balance using a similar assessment. Although these improvements occurred following a 10-week program that incorporated specific neuromuscular activities that incorporated balance training as part of the players' warm-up routines, the control group also demonstrated improvements in measures of dynamic balance (Zech et al., 2014). More recently, in a group of 7-12 year old soccer players, YBT-LQ scores showed no improvement in overall reach distance scores following a 10-week warm-up intervention (Rossler et al., 2016). These inconsistencies in research may be explained by previous paediatric literature that has suggested that the development of a number of physical variables are often influenced by the level of biological maturation (Faigenbaum, Lloyd, & Myer, 2013). Increases in limb length and body dimensions, as well as the maturation of muscle mass have the potential to affect movement proficiency during the adolescent stage of development (Quatman-Yates, Quatman, Meszaros, Paterno & Hewett, 2012). In other words, balance may not improve or may become worse because of this highly vulnerable growth period in which youth often exhibit temporary disruptions in motor control performance (Malina, Bouchard, & Bar-Or, 2004).

When comparing injured and uninjured athletes, no differences were observed in the composite YBT-LQ reach distance scores. Our findings, in combination with previous research, suggest that reach distance alone may not be sensitive enough to detect athletes at an increased risk of injury (Wright, Dischiavi, Smoliga, Taylor, & Hegedus, 2016). It is possible that analyzing movement patterns qualitatively in addition to quantitative analysis may allow for a more comprehensive examination of the quality of movement and therefore offer further insight into risk of injury. Thus, future research should attempt to investigate the effectiveness of this screening tool along with other age appropriate tools to be used in a younger population.

With regards to the neurocognitive testing, significant improvements were observed in the memory (verbal, visual, word, and design) and speed (reaction time and visual motor speed) domains of the test in all participants from pre-season to post-season. These assessments evaluated attentional and visual processing, scanning, learning, memory function and response speed. These improvements may reflect underlying changes in cognitive maturity and brain development during the academic school year, which in our study, coincided with the competitive season. Previous research in this area is mixed. In a population of high school student athletes that performed pre-season and post-season testing approximately one-year apart, scores were consistent in motor processing speed (0.85 ICC). This was followed by reaction time (0.76), visual memory (0.70), and verbal memory (0.62), leading authors to conclude that the online ImPACT test was a stable measure of neurocognitive performance (Elbin et al., 2011). However, in a recent study by Moser et. al (2016), reliability was found to be high for verbal memory, visual motor speed, and symptom scores, but less reliable for visual memory and reaction time in a sample of youth athletes 10-12 years old. A possible explanation for the improvements observed in our study is that younger athletes have periods of cognitive development that are more rapid than those of older adolescents (McCrory, Collie, Anderson, & Davis, 2004). It has been suggested that improvements in neurocognitive tests are a reflection of the cognitive development and maturational growth during these formidable years (Moser, 2016). Thus further research on the utility of implementing evidence-based tools to effectively evaluate concussion status of youth is needed in order to assist with proper diagnosis upon sustaining a head injury, as well as assist in the return-to-play decision criteria.

Strengths of this study are that all but two participants recruited at baseline completed the injury report forms as well as pre-season and post-season testing, that data were objectively measured using tools with established accuracy, and that all data were collected by trained assessors. However, there are some limitations worth highlighting. First, the sample size was small. As per an estimate using effect sizes calculated from the present study (d=0.25), a sample of approximately 500 would be needed for an alpha of 0.05, a beta of 80% to compare between injured and uninjured athletes. Our sample size also limited our ability to compare between different levels of fitness, years of experience, previous injuries and other possible effect-modifier variables. Second, the neurocognitive test used has not been validated for young athletes; however, it should be noted that this test has been used in samples as young as 10 years of age (Moser, 2016) and with hockey players (Vernau et al., 2015). Therefore, future research is needed to further validate use of the ImPACT in young athletes.

Future research is also needed to determine whether more frequent assessments performed throughout the season would have demonstrated alternative results and allowed for more accurate and precise monitoring of neurocognitive function. Our findings from the computerized neurocognitive assessment showed marked improvements in composite scores from pre-season to post-season. These results have implications for schools, youth sports teams, health care practitioners and families as much of the current research shows inconsistencies in the results leading us to question the validity of these testing methods. Additional research is needed to determine if this particular neurocognitive assessment is the most practical for young athletes

In conclusion, our results that some aspects of functional fitness declined over the season, while other measures of functional fitness did not change over the season. In addition, the occurrence of injury did not appear to differ by functional fitness levels or concussion status. There is much literature aimed at identifying risk factors for injury in youth hockey (Emery et al., 2010; Emery & Meeuwisse, 2006; Lemez et al., 2014; McKay et al., 2013; Wattie et al., 2007). The results from this study indicate that future research is needed to better understand the effects of functional fitness and concussion status as they relate to injury prevention.

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Table 1. Changes in sample characteristics and anthropometric measures from pre-season to post-season (n = 36).

	Pre-season $\bar{x}$ ± SD	Post-season $\bar{x}$ ± SD	Effect Size (Cohen's d)
Age	8.9± 1.1	[redacted]	
Height (cm)	136.6 ± 7.6	140.0 ± 7.7	0.4***
Weight (kg)	32.1 ± 6.5	33.9 ± 6.3	0.3***
Body mass index (kg/m^2)	17.1 ± 1.9	17.2± 1.7	0.1
Waist circumference (cm)	60.9 ± 5.7	61.4 ± 4.8	0.1
Bicep circumference (cm)	20.2 ± 2.2	20.3 ± 2.0	0.1
Thigh circumference (cm)	37.2 ± 4.1	38.4 ± 3.6	0.3***
Seated height (cm)	72.1 ± 4.2	74.0 ± 3.4	0.5***
Right leg length (cm)	83.3 ± 6.1	85.7 ± 6.2	0.4***

SD = standard deviation; $\bar{x}$ = mean; * $p<0.05$; ** $p<0.01$; ***$p<0.001$

Table 2. Changes in Functional Movement Screen scores from pre-season to post-season (n=36).

	Pre-season $\bar{x} \pm SD$	Post-season $\bar{x} \pm SD$	Effect Size (Cohen's d)
Deep squat	2.2 ± 0.6	2.1 ± 0.5	0.2
Hurdle step	1.8 ± 0.4	1.7 ± 0.5	0.2
In-line lunge	2.2 ± 0.8	2.3 ± 0.7	0.1
Shoulder mobility	2.8 ± 0.6	3.0 ± 0.2	0.4
Active straight leg raise	2.0 ± 0.5	2.3 ± 0.6	0.5*
Trunk stability push-up	2.2 ± 0.5	2.3 ± 0.7	0.2
Rotary stability	1.9 ± 0.3	1.9 ± 0.3	0
FMS Composite Score	15.1 ± 1.8	15.6 ± 2.3	0.2

SD = standard deviation; $\bar{x}$ = mean; * $p<0.05$; ** $p<0.01$; *** $p<0.001$

Table 3. Changes in reach distance scores from the Y-Balance Test from pre-season to post-season (n=36).

	Pre-season $\bar{x} \pm SD$	Post-season $\bar{x} \pm SD$	Effect Size (Cohen's d)
YBT-LQ Composite Right Leg ANT, PM, PL[a]	86.0 ± 6.0	83.3 ± 5.7	0.5**
YBT-LQ Composite Left Leg ANT, PM, PL[a]	86.2 ± 6.4	83.1 ± 5.6	0.5***
YBT-LQ Composite Score Right and Left Leg[b]	86.1 ± 6.0	83.2 ± 5.4	0.5***

[a] Sum of the 3 reach distances (anterior, posteromedial, posterolateral)/3 in centimeters; [b] Average of right and left limb in centimeters; ANT = anterior; PM = posteromedial; PL = posterolateral; YBT-LQ = Y-Balance Test Lower Quarter; ** $p<0.01$; *** $p<0.001$

Table 4: Changes in neurocognitive measures from the ImPACT from pre-season to post-season (n=36).

	Pre-season $\bar{x} \pm SD$	Post-season $\bar{x} \pm SD$	Effect Size (Cohen's d)
Symptoms (total score)	1.2 ± 2.8	0.3 ± 1.1	0.4
Verbal memory	81.7 ± 9.8	85.9 ± 7.3	0.5*
Visual memory	69.8 ± 10.0	75.4 ± 12.7	0.5*
Visual motor speed	20.6 ± 3.7	23.1 ± 3.7	0.7**
Reaction time	0.9 ± 0.1	0.8 ± 0.1	1**
3 letters correct	78.9 ± 16.2	86.5 ± 12.6	0.5*
Word memory	92.0 ± 9.1	95.2 ± 6.1	0.4**
Design memory	76.8 ± 11.6	82.7 ± 11.1	0.5**

SD = standard deviation; $\bar{x}$ = mean; * $p<0.05$; ** $p<0.01$

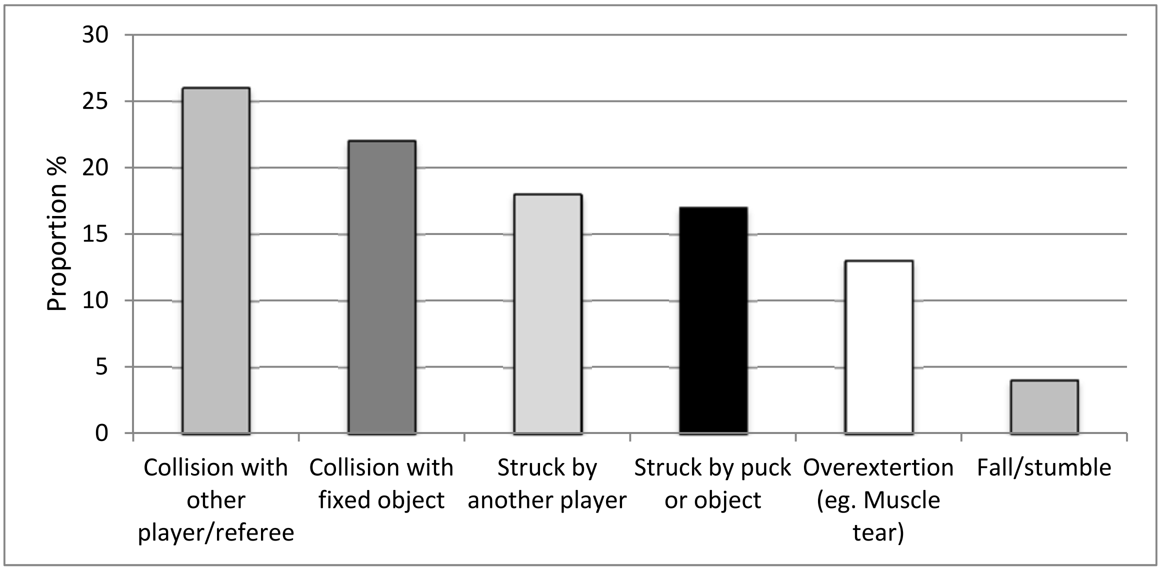

Figure 1: Injury rates by mechanism.

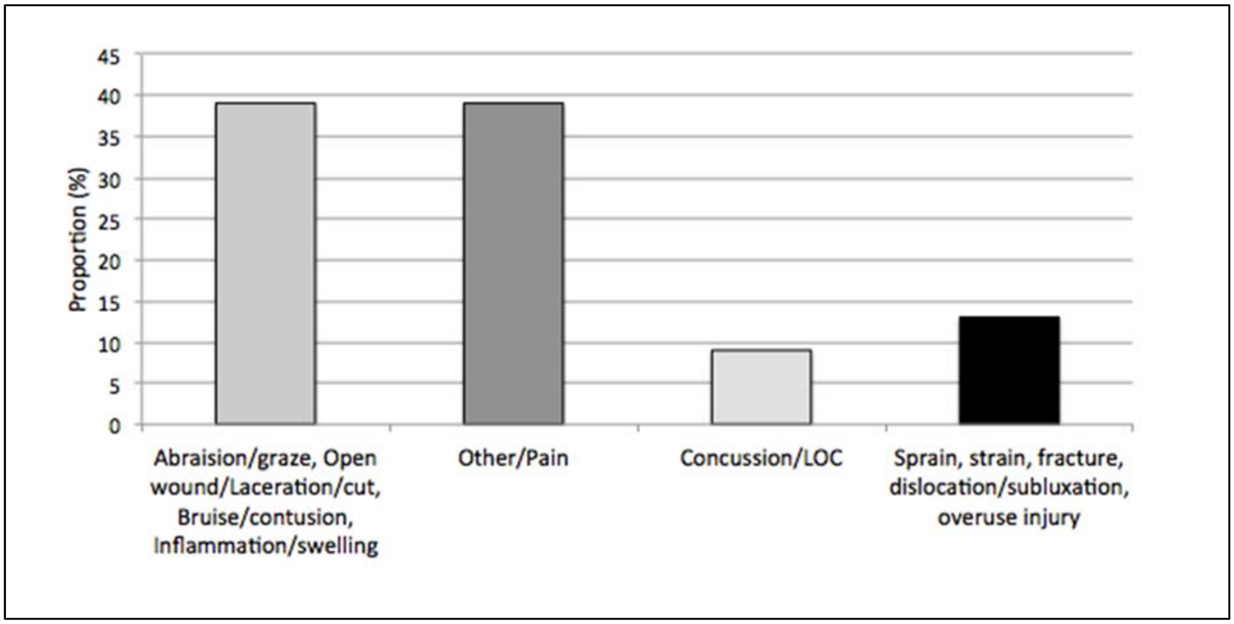

Figure 2: Injury rates by type.

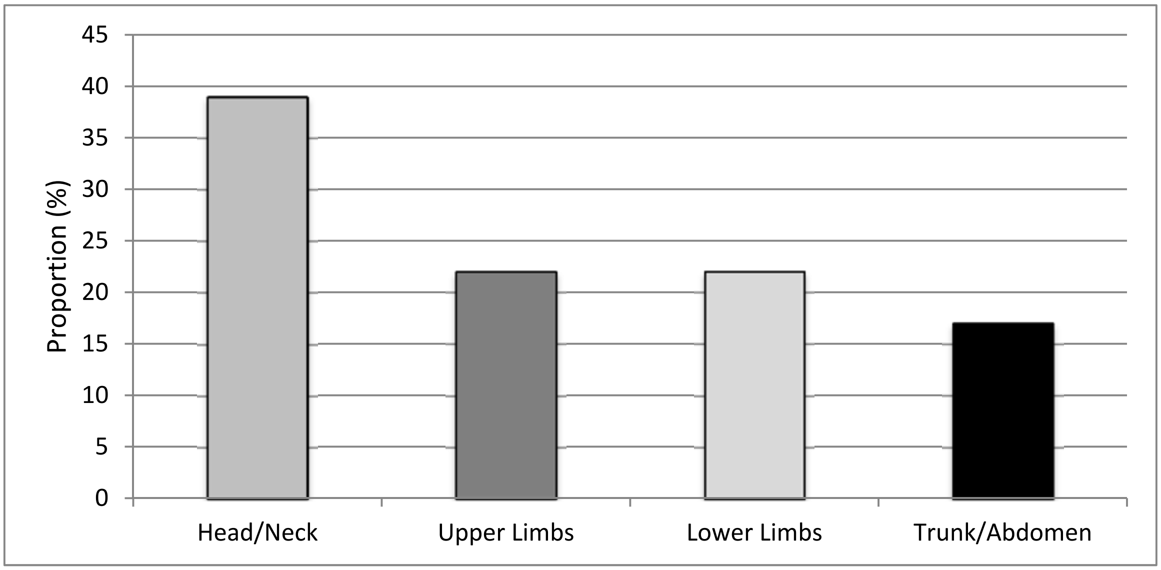

Figure 3: Injury rates by location.

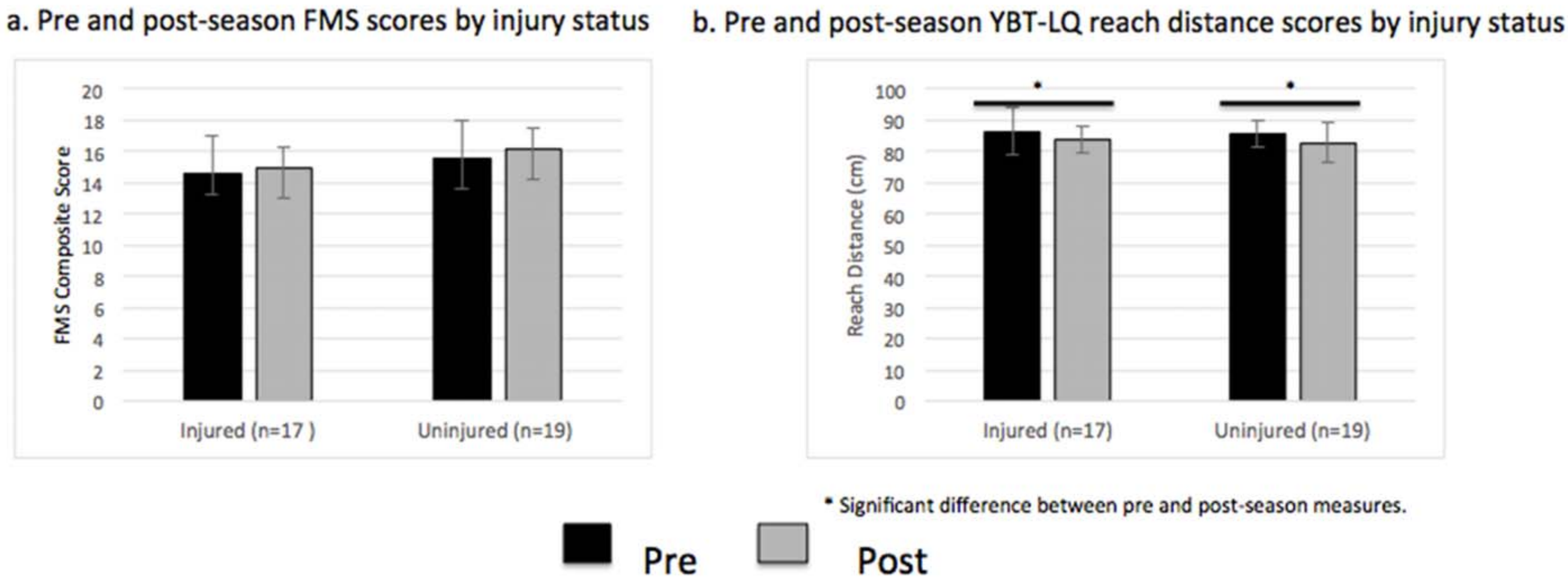

Figure 4: In-season changes of functional fitness scores by injury status.

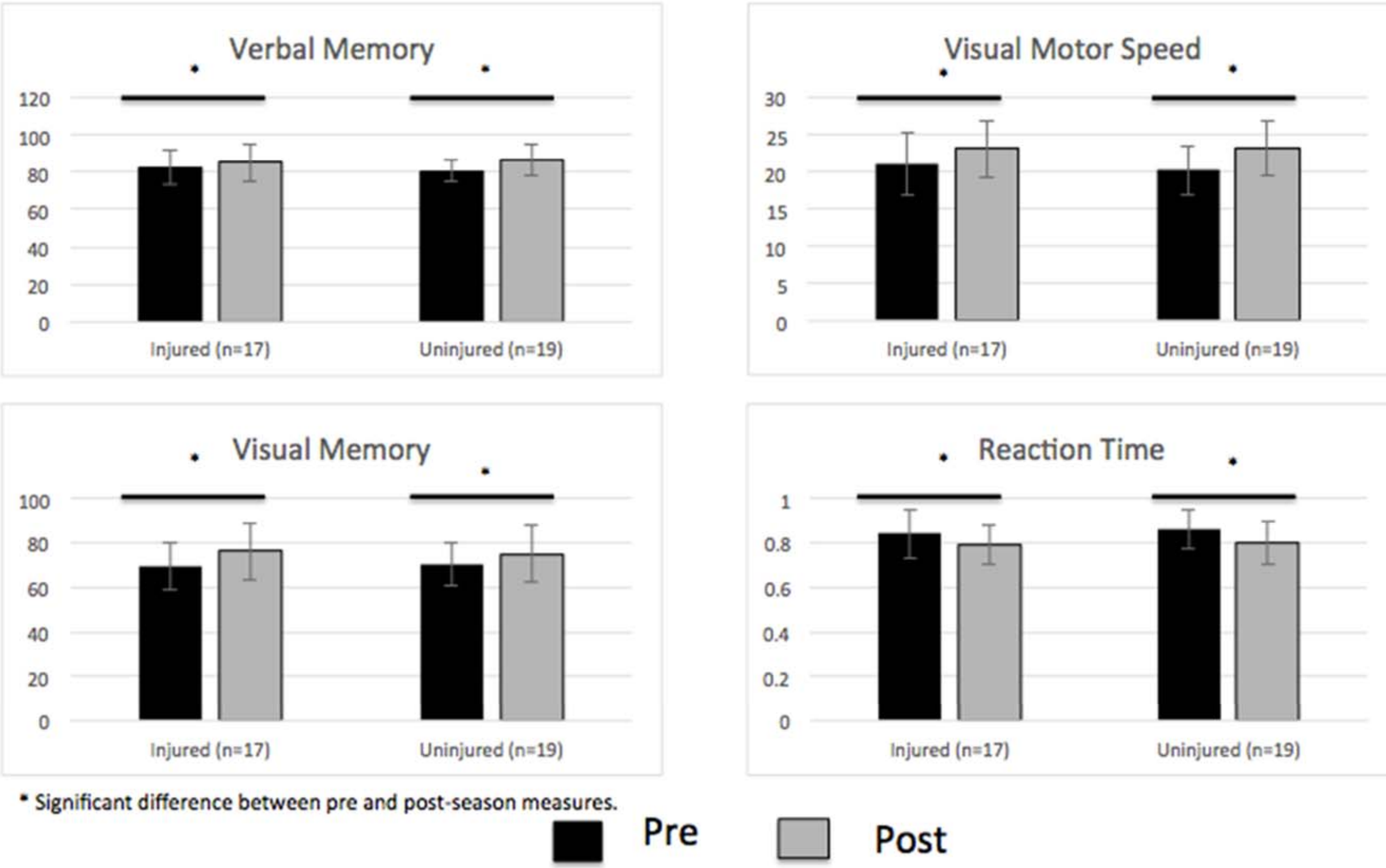

Figure 5: Pre and post-season ImPACT composite scores by injury status.

CHAPTER 4: GENERAL DISCUSSION

4.1 THESIS SUMMARY

The primary objective of this thesis was to observe and measure functional fitness and concussion status during the course of a competitive season in male youth (aged 8-11 years) ice hockey players. In addition, our goal was to examine the incidence of injury in the context of functional fitness and concussion status. The main results indicate that during the competitive season, dynamic balance decreased significantly; however, functional movement as assessed using the functional movement screen (FMS) did not change over the season. Furthermore, our results indicate that almost all neurocognitive scores improved from pre to post-season. Interestingly, this improvement was observed irrespective of the fact that a participant may have sustained an injury, including minor head injuries and concussions. A definitive understanding of the mechanisms that lead to injury remains unclear.

Functional Movement Screen

The Functional Movement Screen (FMS) was originally developed to help evaluate the quality of functional movement patterns that have the potential to expose functional limitations, which could ultimately place an athlete at an increased risk of injury (Cook, Burton, Hoogenboom, & Voight, 2014). The use of this tool has been demonstrated to be cost-effective, easily administered, as well as, reliable in evaluating the quality of functional movement (Cook, et al., 2014; Elias, 2013). Garrison et al., (2015) conducted a descriptive epidemiology study in collegiate athletes to explore the association between pre-season FMS scores and the development of injury. When comparing the mean FMS scores of injured (13.6) and uninjured participants (15.5), results indicated a statistically significant difference between the two groups (Garrison, Westrick, Johnson, & Benenson, 2015). Chorbra et al., (2010) investigated the relationship between FMS scores and injury risk in a cohort of female collegiate athletes. Results from this study also indicated that those athletes with an FMS score of 14 or less correlated with the development of injury (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010). As indicated, previous literature has demonstrated that in adult populations, a lower composite FMS score (≤14) is associated with an increased risk of injury. Given that our cohort is a unique population due to age, it was important to determine if similar observations could also be detected in a youth population therefore extending the generalizability of the effectiveness of this tool.

This study was one of the first investigations to examine potential relationships between FMS composite scores and injury in youth ice hockey players. In contrast to previous research, our results indicate that there were no significant differences in composite FMS scores when comparing injured and uninjured athletes (Garrison et al., 2015; Chobra et al., 2010); yet, our results were consistent with other studies that found no differences between mean pre and post-season measures of composite FMS scores for all athletes (Sprague, Mokha, & Gatens, 2014). In light of these statements it should be noted that our effect sizes were low (d=0.2). It is possible to speculate on these conflicting results, which may serve to partially explain our findings.

When choosing relevant tools that can evaluate physical performance, it is important to consider an individual's maturity status. In a recent study which compared functional and static evaluation tools among adolescents, it was found that post-pubescent FMS scores were significantly higher than the FMS scores of pre-pubertal groups, suggesting that greater scores may be a result of an increase in muscular strength, flexibility, proprioception and coordination among this more mature group (Paszkewicz, McCarty, & Van Lunen, 2013). It has been proposed that these increases may allow post-pubescent youth to complete more complex movement tasks (Minick et al., 2010), and thus potentially score higher on certain screening tools. It should be noted that an adolescent's score could be influenced by a variety of possible deficits and therefore measuring functional fitness should be done with a holistic approach using a variety of evidence-based tools (Paszkewicz, 2013). A comprehensive pre-season injury risk assessment could provide important information to athletic trainers that may assist in the development of injury prevention programs.

In addition to considering the age of the athlete, the differences observed in our study may be explained by possible in-season changes in functional movement. Given that baseline measurements were taken only prior to the commencement of the 8-month competitive season, it is quite possible that the functional movement status of a participant at the time of injury during the competitive season may have changed from the pre-season status. In retrospect, conducting more frequent assessments throughout the competitive season may have been beneficial in order to have the most current information, especially considering the influence that the rate of growth may have had on this population. Furthermore, those participants who sustained an injury mid-season were not reassessed post-injury and therefore their mobility and stability may have been negatively impacted thus potentially leading to further injury risk. This may have negatively influenced those participants who sustained more than one injury. In hindsight, it would have been more appropriate to re-evaluate functional movement ability post-injury.

Changes in the quality of movement can be assessed by the FMS. This tool has been used in a variety of sports settings including professional, collegiate, high school and more recently, youth sports. This tool was developed with the intent to help screen participants and identify compromised movement patterns which may place them at an increased risk of sustaining a sports related injury. Considering that much of the existing literature has demonstrated conflicting results regarding the ability of the FMS to identify risk of injury, an understanding of the effectiveness of this tool remains unclear.

Lower Quarter Y-Balance Test (YBT-LQ)

The YBT-LQ is used as a functional test to assess dynamic balance. This test requires a combination of strength, flexibility, stability, range of motion, and balance. The assessment has been used effectively in team settings where it is required to evaluate many athletes over a short period of time (Gonell, Romero, & Soler, 2015). In a youth population, it has been found to be a consistent and objective tool with a high inter-rater reliability within session ($ICC > 0.995$) and between sessions ($0.907 \leq ICC \leq 0.974$) (Faigenbaum et al., 2014). Results from our study indicate that the reach distance scores decreased over the season, which is contradictory to previously reported research (Zech et al., 2014). The differences in dynamic balance performance may be attributed to the many variations in the maturity status of the neurological, visual, and proprioceptive systems due to the age of the participants (Mickle, Munro, & Steele, 2011). In light of the aforementioned, it is equally important to consider other contributing factors such as the rate of growth during the season as well as the ability of a participant to concentrate and mentally focus on the balance task at hand.

Results from our study demonstrate marked increases ($p=<0.001$) between pre and post-season measurements of height (cm), weight (kg), thigh circumference (cm), and leg length (cm). It is possible that these changes made the balance task more challenging post-season as participants may have had to make compensatory modifications in their movement patterns to account for changes in limb dimensions as a result of developing muscle mass and lengthening of the legs. This increase in difficulty may have led to the decrease in reach distance scores that were observed in our study. Thus, changes in motor skill performance and muscle strength may have had an influence on the dynamic balance performance in the current study.

Another possible factor that may have contributed to the decrease in balance performance was the inability of the participant to mentally engage and remain focused during the short performance task. Although the instructions for the participants were modified to account for the younger age, more recent research has suggested that in order to increase the reliability of the YBT-LQ, nine attempts should be performed, including six trial attempts and three measurements. In addition, it was recommended that the average of the three measured attempts be analyzed (Linek, Sikora, Wolny, & Saulicz, 2017). Although one of the many reported benefits of using the YBT-LQ as a field assessment is due to the short time the test takes to conduct, this may not be beneficial for all populations. It is possible that by providing a greater number of practice trials that this could allow additional time for a younger participant to become more mentally engaged and focused during the balance task and therefore could help to achieve a greater reach distance score.

Balance is a critical component of motor skills in youth athletes. Strong athletic performance requires the integration of multi-joint movements placing an emphasis on whole body movements rather than performing movements in isolation. As such, it is important that the majority of assessments used for athletes be of a dynamic nature, thus making the YBT-LQ an extremely relevant tool to use. As previously described, further modifications to the assessment protocol may allow for a more accurate assessment of dynamic balance in a youth population.

Neurocognitive Assessment

Sport-related concussion in youth is a growing public health concern (Moser, Schatz, Grosner, & Kollias, 2016). As such, there has been much discussion around how to effectively develop, administer and oversee testing programs that are aimed at evaluating neurocognitive function. Baseline assessments are administered with the goal of measuring an athlete's verbal and visual memory, attention, reaction time and processing speed, and are often used in the management and prevention of concussions (Meehan, d'Hemecourt, Collins, Taylor, & Comstock, 2012). Although there is no current legislation which mandates baseline testing of athletes, the Centers for Disease Control and Prevention (CDC) recommend baseline testing on a yearly basis (Centers for Disease Control and Prevention, 2015). The question as to how often baseline testing should be conducted, particularly in youth, still remains unanswered as much of the literature reports conflicting results (Moser et al., 2016). In our study, a computerized neurocognitive test, ImPACT, was conducted pre and post-season and results demonstrated significant improvements in the verbal, visual, word, and design memory domains as well as the speed (reaction time and visual motor speed) domains of the test for all participants. At the time, this test had not been validated for use in younger aged athletes; however, regardless of age, results still indicated improvements. In addition, perhaps even more interesting, is the fact that those participants who did sustain an injury, including those concussed, also demonstrated improvements in their domain scores. Until recently, there was no established computerized baseline test for children under the age of 10; ImPACT has now developed such a tool, however, there is minimal published research regarding the reliability and validity of the paediatric version.

Since youth athletes continue to mature cognitively, it is likely that their performance would vary more than that of adult populations and thus, more frequent assessments of concussion status may be warranted in this population. In addition, given that much of the data from previous studies show variations in reliability using the computerized neurocognitive testing (Elbin et al. 2011; Moser et al., 2016; Register-Mihalik et al., 2012; Schatz & Ferris, 2013), it warrants the question as to whether other methods of assessing baseline concussion status should be considered.

In addition to computerized neurocognitive assessments, recommendations have been made by the Zurich Consensus Statement on Concussion in Sport, that components of the Sport Concussion Assessment Tool for children 5-13 years of age (ChildSCAT3) should be used in younger athletes (Davis et al., 2017). These components are child and parent symptom reports; cognitive assessments including orientation, immediate memory and concentration; balance exams using the Balance Error Scoring System (BESS); and delayed recall. Although neurocognitive assessments are frequently used in the evaluation of concussion status, it should also be used in conjunction with assessing symptoms, and measuring balance and vision.

General Conclusion

Screening tests allow participants to have a variety of physical and psychological parameters evaluated. Some tests demonstrate a statistically significant association with risk of injury thus providing insight into possible causative factors (Bahr, 2016). Therefore, the question remains as to whether screening tests are able to effectively predict injuries especially given the unpredictable nature of sport itself. There is a variety of literature demonstrating conflicting evidence to support the utility and validity of screening tests (Bahr, 2016; Grant et al., 2015; Kennedy et al., 2012; Moran, Schneiders, Mason, & Sullivan, 2017). The majority of these studies have been conducted in adult and collegiate age populations. As discussed previously, youth present a unique set of characteristics given their less mature physical and psychological profiles making the task of injury prediction even more complex. It is difficult to ascertain whether the tools used in the current study have been able to effectively assess risk of injury. Nonetheless, movement proficiency was evaluated and this information could be used to help develop targeted intervention programs aimed at improving such limitations.

4.2 LIMITATIONS

Sample Size

It is common for cohort studies to typically require larger samples sizes than those that were used during the present study (Fuller et al., 2006). Previous studies that have investigated the relationship between functional movement scores, including balance, and injury in other athletic populations have often used larger sample sizes (Bardenett et al., 2015; Kiesel, Plisky, & Voight, 2007; Letafatkar, Hadadnezhad, Shojaedin, & Mohamadi, 2014). It is possible that in the current study the sample size (n=36) was too small in order to determine a true significant relationship between the observed variables. As per an estimate using effect sizes calculated from the present study (d=0.25), a sample of approximately 500 would be needed for an alpha of 0.05, a beta of 80% to compare between injured and uninjured athletes. In order to develop a more robust investigation an increase in the number of participants involved in the study would be beneficial. An increase in numbers would also require an increase in the number of individuals involved in the study to assist with data collection and analysis. To make this more feasible, an increase in project funding could potentially provide a solution to this problem.

Inter vs. Intra-rater Reliability

In the current study, inter and intra-rater reliability were not calculated for the FMS. The primary investigator (MA) conducted all but one FMS assessment from both the pre and post-season screening, and she had FMS training. Previous literature has reported excellent inter-rater reliability of the FMS, with intra-class correlation coefficients (ICC) for the FMS composite score ranging from 0.87 (Smith, Chimera, Wright, & Warren, 2013) to 0.91 (Elias, 2013). Similarly, intra-rater reliability has been reported to be excellent, with ICCs of 0.95 reported (Gribble, Brigle, Pietrosimone, Pfile, & Webster, 2013). More recently, a reliability study was conducted in a group of young elite ice hockey players using video raters which indicated excellent intra-rater reliability for the total FMS score, with an ICC of 0.96 (95% CI; 0.92-0.98) and 0.96 (95% CI; 0.91-0.98) and field raters demonstrating excellent inter-rater reliability for the total score, with an ICC of 0.96 (95% CI; 0.92-0.98) (Parenteau et al., 2014).

Homogeneity of the Participant Pool

Although the participants were of a variety of ages from 8 to 11 years, all were considered to be pre-pubertal males, and all participants were homogeneous in terms of level of play, that is, representative hockey players from an ‘A’ centre. It is possible that studying a more diverse pool of participants, including female athletes, and athletes from a variety of levels of play would allow for more robust experimental findings and allow for results to be more generalizable to a greater proportion of Canadian youth ice hockey players.

Injury Definition and Classification

Following guidelines described in previous research (Fuller et al., 2006), our study used a broad definition of injury. As such, an injury was defined as "any physical complaint sustained by a player that results from a hockey game or hockey training, irrespective of the need for medical attention or time-loss from hockey activities." Our results indicated that 47% of participants sustained at least one injury. Our injury description is limited by the fact that it doesn't allow for further classification such as those injuries requiring medical attention or those that may have led to a player being unable to participate in future hockey training; consequently, injury rates may have been overestimated.

According to Emery (2010), in youth sports the rate of estimated injury varies significantly in the literature, indicating differences in the classifications of injury, skill level of players, age, as well as methodological discrepancies and inconsistent reporting. In a recent systematic review and meta-analysis which examined risk factors for injury and severe injury in youth ice hockey, the authors reported high injury rates occurring which ranged from 11.7 injuries per 1000 player hours to 34.4 per 1000 player hours player hours to 43.99 injuries per 100 players (Emery, Hagel, Decloe, & Carly, 2010). A limitation of the current study was that players' exposure hours were not recorded, which did not allow for us to explore any potential relationships between the incidence of injury as a result of actual exposure times for each player. In retrospect, future prospective cohort studies should record each specific type of event such as practice, game, off-ice training sessions or other, along with the exposure time recorded in hours. It should be noted however, that in order to implement these suggestions in future studies it would require higher time-demands on those investigators involved in the study and therefore may require more support and funding to make such recommendations possible.

4.3 FUTURE RESEARCH

The nature of injury risk in sport is multifactorial, especially for athletes who participate in high-risk sports such as hockey, and therefore a more comprehensive injury risk assessment is warranted. Functional movement patterns, balance ability and concussion status are only a few measures that have the potential to identify at risk participants; a more complete pre-season assessment that also includes other risk factors such as injury history, vestibular function, and scores from standardized tests of physiologic function, may help to further identify those at risk for injury.

If pre-season screening were able to detect individuals at greater risk of injury, then these participants could be provided exercises aimed at improving identified limitations. Bahr (2016) stated that while there are a number of tests that have the capability to identify risk factors for injury, these tests are unlikely to accurately *predict* injury. To determine if these targeted intervention programs are successful, the progress of athletes should be evaluated more frequently. Results should be recorded and analyzed to determine whether these *targeted* programs are more beneficial than the intervention programs provided to all other athletes (Bahr, 2016).

Future research and program development conducted in a youth population must be cognizant of the fact that the ability to perform sound functional movement patterns is continually evolving in this population. Variations in biological maturation due to developing proprioceptive systems, alterations in muscle mass, and changes in hormonal profiles all have the ability to influence physical performance (Lloyd et al., 2015). In light of this, it is important to recognize that each assessment type comes with its own limitations and individual differences and responses to tests may vary. As such, results should be interpreted carefully, and done so in the context of the overall focus or goal of the assessment itself, while keeping in mind that youth in particular have a wide range of skills and ability levels.

Conclusion

It is likely that with the evolution of youth sports there will be an increase in sport related injuries, including a rise in concussive events (Schatz & Moser, 2011). Although the science for identifying risk factors for injury in athletes has progressed dramatically over the last decade, the existing literature on its relationship to reduce injury is still evolving. The findings from our study have implications for coaches, health care practitioners, neuropsychologists, and educators who will need to unite using a multidisciplinary approach in order to continue to examine the underlying causes of sport injury while simultaneously addressing how to reduce an athlete's risk of injury.

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APPENDICES

Appendix A1: Sports Injury Tracking Form

SPORTSINJURYTRACKER
www.sportsinjurytracker.com.au

Name of patient: ____________________ **DOB** __/__/__ **Sex: Male ☐ Female ☐**

Date of Injury: __/__/__ **Time** ___:___ **am/pm** **Is the injured person : Player / Referee / Coach / Spectator**

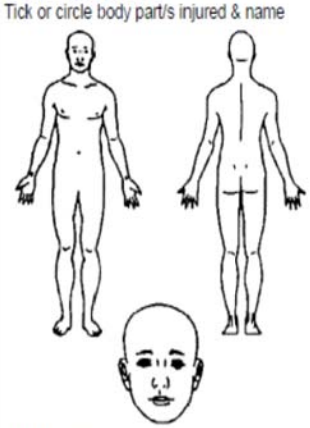
Patient Address: ____________________ Patient Phone Number: ____________________

Sport____________________ Venue____________________ Event/match: ____________________

Type of activity at time of injury
- ☐ training
- ☐ warm-up
- ☐ competition
- ☐ cool-down
- ☐ other ____________

Reason for Presentation
- ☐ new injury
- ☐ exacerbated/aggravated injury
- ☐ recurrent injury
- ☐ illness
- ☐ other ____________

Body Region Injured
Tick or circle body part/s injured & name



Body part/s
____
____
____
____

Nature of Injury/Illness
- ☐ abrasion/graze
- ☐ sprain eg ligament tear
- ☐ strain eg muscle tear
- ☐ open wound/laceration/cut
- ☐ bruise/contusion
- ☐ inflammation/swelling
- ☐ fracture (including suspected)
- ☐ dislocation/subluxation
- ☐ overuse injury to muscle or tendon
- ☐ blisters
- ☐ concussion
- ☐ cardiac problem
- ☐ respiratory problem
- ☐ loss of consciousness
- ☐ unspecified medical condition
- ☐ other ____________

Provisional diagnosis/es
____

CAUSE OF INJURY

Mechanism of Injury
- ☐ struck by other player
- ☐ struck by ball or object
- ☐ collision with other player/referee
- ☐ collision with fixed object
- ☐ fall/stumble on same level
- ☐ jumping to shoot or defend
- ☐ fall from height/awkward landing
- ☐ overexertion (eg muscle tear)
- ☐ overuse
- ☐ slip/trip
- ☐ temperature related eg heat stress
- ☐ other____________

Explain exactly how the incident occurred
____
____
____
____
____
____
____
____

Were there any contributing factors to the incident, unsuitable footwear, playing surface, equipment, foul play?
____
____
____

Protective Equipment
Was protective equipment worn on the injured body part? ☐ yes ☐ no

If yes, what type eg mouthguard, ankle brace, taping.
____

Initial Treatment
- ☐ none given (not required)
- ☐ RICER ☐ dressing
- ☐ sling, splint ☐ crutches
- ☐ CPR ☐ stretch/exercises
- ☐ taping only
- ☐ none given - referred elsewhere
- ☐ other ____________

Advice Given
- ☐ immediate return unrestricted activity
- ☐ able to return with restriction
- ☐ unable to return at present time
- ☐ Able to return but the player chose not to
- ☐ Referred for further assessment before returning to activity

Referral
- ☐ no referral
- ☐ medical practitioner
- ☐ physiotherapist
- ☐ ambulance transport
- ☐ hospital
- ☐ other ____________

Provisional severity assessment
- ☐ mild (1-7 days modified activity)
- ☐ moderate (8-21 days modified activity)
- ☐ severe (>21 days modified or lost)

Treating person
- ☐ medical practitioner
- ☐ sports trainer
- ☐ other ____________

☐ I have provided the patient with a copy of this report and told them that this record will be kept for insurance purposes. The injury information (not including patient name, address or phone number) will be entered into the Sports Injury Tracker Tool as part of the statistical analysis of injuries that occurred during the event. Patients are anonymous in these statistical records which help to create a safer sporting environment for future events.

Name
____

Signature
____

Today's Date: __/__/__

Sports Trainer ID
____

Appendix 2: Hockey Development Centre Medical Information Sheet

HDCO
HOCKEY DEVELOPMENT CENTRE ONTARIO

HTCP

MEDICAL INFORMATION SHEET

Name: ____________________

Date of birth: Day ________ Month ________ Year ________

Address: ____________________

Postal Code: ____________ Telephone: (____) ________________ Cell: (___) __________

Mother's Name: ________________ Father's Name: ________________

Business Telephone Numbers: Mother ________________ Father ________________

Alternate emergency contact (if parents are not available)

Name: ________________ Telephone: ____________

Relationship to player: ________________

Address: ____________________

Doctor's Name: ________________ Telephone: (____) ____________

Dentist's Name: ________________ Telephone: (____) ____________

Date of last complete physical examination: ________________
* Before a player participates in a hockey program, any medical condition or injury problem should be checked by that individual's family physician.

Please circle the appropriate response and provide details below if you answer "Yes" to any of the questions.

Yes	No	Medication
Yes	No	Allergies
Yes	No	Previous history of concussions
Yes	No	Fainting episodes during exercise
Yes	No	Seizures and/or Epilepsy
Yes	No	Wears glasses
Yes	No	Are lenses shatterproof
Yes	No	Wears contact lenses
Yes	No	Wears dental appliance
Yes	No	Hearing problem
Yes	No	Asthma
Yes	No	Trouble breathing during exercise
Yes	No	Heart Condition
Yes	No	Family History of Heart Disease
Yes	No	Diabetes Type 1 ______ Type 2 ______
Yes	No	Wears a medical information bracelet or necklace For what purpose? ______________

HOCKEY TRAINERS CERTIFICATION PROGRAM

Yes No Has any health problem that would interfere with participation on a hockey team

Yes No Has had an illness that lasted more than a week and required medical attention in the past year

Yes No Has had injuries requiring medical attention in the past year

Yes No Has been admitted to hospital in the last year

Yes No Surgery in the last year

Yes No Presently injured. Injured body part: ________________

Yes No Vaccinations up to date
Date of last Tetanus Shot:______________

Yes No Hepatitis B vaccination

Please give details if you answered "Yes" to any of the above. Use separate sheet if necessary

____

____

____

Medications:____

Allergies: ____

Medical conditions: ____

Recent injuries: ____

Any information not covered above:_____________________________________

I understand that it is my responsibility to keep the team Hockey Trainer advised of any change in the above information as soon as possible. In the event of a medical emergency and that no one can be contacted, team management will arrange to take my child to the hospital or a physician if deemed necessary.

I hereby authorize the physician and nursing staff to undertake examination, investigation and necessary treatment of my child.

I also authorize release of information to appropriate people (coach, physician) as deemed necessary.

Date:_________________ Signature of Player:____________________________________

Date:__________________Signature of Parent or Guardian:__________________________

Disclaimer: Personal information used, disclosed, secured or retained will be held solely for the purposes for which it is collected and in accordance with the National Privacy Principles contained in the Personal Information Protection and Electronic Documents Act.

Appendix A3: Hockey Canada Injury Report Form

HOCKEY CANADA INJURY REPORT

PAGE 2/2

PHYSICIAN'S STATEMENT

Physician: ______________________ Address: ______________________ Tel: (____) ______________

Name of Hospital / Clinic: ______________________ Address: ______________________

Nature of Injury: ______________________ Date of First Attendance: ______________________

Claimant will be totally disabled:

From: ____________ To: ____________

Is the injury permanent and irrecoverable? ☐ No ☐ Yes

Give the details of injury (degree): ______________________

Prognosis for recovery: ______________________

Did any disease or previous injury contribute to the current injury? ☐ No ☐ Yes (describe): ______________________

Was the claimant hospitalized? ☐ No ☐ Yes (give hospital name, address and date admitted): ______________________

Names and addresses of other physicians or surgeons, if any, who attended claimant: ______________________

I certify that the above information is correct and to the best of my knowledge,

Signed: ______________________ Date: ______________________

DENTIST STATEMENT

Limits of coverage: $1,250 per tooth, $2,500 per accident
Treatment must be completed within 52 weeks of accident

UNIQUE NO. SPEC. PATIENT'S OFFICIAL ACCOUNT NO.

Patient

Last name Given name

Address

City / Town Province Postal Code

Dentist

PHONE NO

I HEREBY ASSIGN MY BENEFITS PAYABLE FROM THIS CLAIM DIRECTLY TO THE NAMED DENTIST AND AUTHORIZE PAYMENT DIRECTLY TO HIM / HER

SIGNATURE OF SUBSCRIBER

FOR DENTIST USE ONLY – FOR ADDITIONAL INFORMATION, DIAGNOSIS, PROCEDURES OR SPECIAL CONSIDERATION.

DUPLICATE FORM ☐

I UNDERSTAND THAT THE FEES LISTED IN THIS CLAIM MAY NOT BE COVERED BY OR MAY EXCEED MY PLAN BENEFITS. I UNDERSTAND THAT I AM FINANCIALLY RESPONSIBLE TO MY DENTIST FOR THE ENTIRE TREATMENT.
I ACKNOWLEGDE THAT THE TOTAL FEE OF $________ IS ACCURATE AND HAS BEEN CHARGED TO ME FOR THE SERVICES RENDERED.
I AUTHORIZE RELEASE OF THE INFORMATION CONTAINED IN THIS CLAIM FORM TO MY INSURING COMPANY/PLAN ADMINISTRATOR.

SIGNATURE OF (PATIENT/GUARDIAN) OFFICE VERIFICATION

DATE OF SERVICE DAY / MO. / YR.	PROCEDURE	INITIAL TOOTH CODE	TOOTH SURFACE	DENTIST'S FEE	LAB CHARGE	TOTAL CHARGE

THIS IS AN ACCURATE STATEMENT OF SERVICES PERFORMED AND THE TOTAL FEE DUE AND PAYABLE & OE.
NOTE: All benefits subject to insurer payor status, provisions of the policy, Hockey Canada sanctioned events.

TOTAL FEE SUBMITTED

Mail completed form to: **BC HOCKEY**
6671 Oldfield Road
Saanichton, BC V8M 2A1
Tel: (250) 652-2978
Fax: (250) 652-4536
www.bchockey.net

Appendix A4: History/Demographics Form

HISTORY

When your child comes for the baseline testing, he or she will enter history information into the computer program we utilize for the neurocognitive testing portion. In order to help prepare the participant and improve accuracy, we have included a history/demographics form to complete. This information will be maintained in a confidential file along with the consent forms and may be used if your son or daughter suffers a concussion and information needs to be shared with a medical provider. Please have your child bring these with you when they come for baseline testing.

________ Height (ft./inches) ________ Weight (lbs)

Gender: ____ Male or ____ Female

Handedness: ____ Right ____ Left ____ Ambidextrous (both right and left)

1. Ethnicity: (optional)

   ____ American Indian
   ____ Asian
   ____ Black or African American
   ____ Hispanic or Latino
   ____ Native Hawaiian or other Pacific Islander
   ____ White
2. ____ Years of Education completed excluding Kindergarten

3. Check any of the following that apply:
   ____ Received Speech Therapy
   ____ Attended special education class
   ____ repeated one or more years at school
   ____ diagnosed with a learning disability
   ____ diagnosed with attention deficit disorder or hyperactivity
4. While in school, what type of grades to you earn:
   ____ < C average
   ____ Mostly C
   ____ Mostly A/B
5. Current Sport: ____________________________________.
6. Years of Experience at this sport: ________________ (yrs).
7. Number of times diagnosed with a concussion: _________________.
8. If you have been diagnosed with a concussion: _________________.

   ____ Total number of concussion that resulted in loss of consciousness
   ____ Total number of concussion that resulted in confusion
   ____ Total number of concussions that resulted in difficulty remembering events occurring immediately after the injury
   ____ Total number of concussions that resulted in difficulty remembering events occurring immediately before the injury
   ____ Total number of games missed as a direct result of all concussions combined

9. Please list your (five) most recent concussions, if applicable. You may use approximate dates:

   Concussion 1: ________________ (month) ________________ (year)

   Concussion 2: ________________ (month) ________________ (year)

   Concussion 3: ________________ (month) ________________ (year)

   Concussion 4: ________________ (month) ________________ (year)

   Concussion 5: ________________ (month) ________________ (year)

Appendix A5. Informed Consent

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY

Study Title: Seasonal Changes in Functional Fitness and Neurocognitive Performance in Youth Ice Hockey Players

Name of Principal Investigator: Michelle Avery (UOIT)
Name of Supervisor: Dr. Shilpa Dogra, PhD, CSEP-CEP (UOIT)

Study Information and Consent Form

Introduction:
You are invited to have your child participate in a research study that is being conducted by the University of Ontario Institute of Technology (UOIT). Throughout this document you will find the study purpose, procedure, benefits and risks, as well as your right to refuse your child to participate or withdraw from the study. Please thoroughly read and understand all sections of this document before you agree to have your child participate in this study. This is known as the informed consent process. Should you have any questions concerning any of the information, words, or your rights, please contact the researchers above to gain full understanding before signing this consent form.

Purpose and Explanation of the Study:

The primary purpose of the study is to determine whether baseline assessment of functional fitness, including muscle imbalances, mobility, instability, and concussion status, can influence injury during seasonal play in a specific population of youth ice hockey players. To do so, we will establish baseline data on injury and measure functional fitness as well as concussion status, and new injuries developed over the 8 month hockey season will be monitored and recorded by coaches, parents and the researcher. At the end of the season we will compare your child's baseline measurements with their injury rate to determine if there were any significant relationships between the two.

In order for your child to be eligible, they must be between the ages of 8-11 and be part of a rep Novice, Minor Atom or Major Atom hockey team. They may be excluded if they have sustained a fracture in the previous 3 months, or experienced a concussion (as diagnosed from a qualified health care practitioner) within the previous 3 months.

Forms:
In order to gather demographic information, parents of the participants will be given a contact information and history form to complete prior to their pre-screening session.

Assessment Procedures:
Having your child as a participant in this study will require him/her to attend 1 pre-screening session. Each baseline assessment session will take a maximum of 60 minutes per participant. All individuals that assist with data collection will be trained exercise professionals and certified in first aid and basic CPR. Participants will be instructed not to engage in any other vigorous physical activity in the 24 hours preceding the assessments, and not to consume a

heavy meal or caffeinated beverages approximately 4 hours prior to the assessment. The assessments will be held in the gymnasium and computer laboratory of the local high school, Uxbridge Secondary School. Stable room temperatures (18-20^{o}C) will remain constant for each testing session. At least one parent of the participant will be present during data collection. During the session, we will be taking a variety of measures which are described below:

Anthropometrics
Height, weight, flexed bicep, thigh and waist circumference will be assessed using a standard medical scale and a tape measure to the nearest 0.5 cm, 0.1 kg and 0.1cm respectively. Body mass index (BMI) will be calculated as weight (kg)/height^2 (m).

Balance
All participants will complete the Lower Quarter Y-Balance Test (YBT-LQ) for assessment of dynamic balance. This test requires a participant to balance on one foot while reaching as far as they can in three different directions with their other foot while at the same time maintaining their balance. Their reach distances will be measured for each direction.

Functional Movement
The Functional Movement Screen (FMS) will be used to rank and grade movement patterns. There are seven tests: 1) the deep squat which assess functional mobility of the hips, knees and ankles, (2) the hurdle step which assesses stride mechanic, (3) the in-line lunge which assesses mobility and stability of the hip and trunk, quadriceps flexibility and ankle and knee stability, (4) shoulder mobility and scapular stability, (5) active straight leg raise to assess posterior chain flexibility, (6) trunk stability push up, and (7) the rotary stability test to evaluate multi-plane trunk stability.

Concussion Status
The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT^{TM}) is a computerized test which takes approximately 25 minutes to complete. This test will be administered to evaluate multiple aspects of neurocognitive function including memory, attention, brain processing speed, and reaction time.

Participant Compensation:
You will not be paid for your child's participation in this study; however, you have much to gain. You will be sent your child's personal results from the pre-screening session in the form of an email at the end of the study. This data will provide you with an in-depth understanding of your child's current level of functional fitness and concussion status. Additionally, upon completion of the study, suggested exercises will be recommended to assist in the correction of any identified limitations pertaining to balance, mobility and/or instability.

Risks and Participant Safety:
There are minimal physical risks associated with participation in this study, as it is observational. There are some inherent risks to fitness assessments. The participant may expereince loss of balance or minor discomfort when asked to perform a balance task or a particular movement pattern (eg. deep squat, lunge, shoulder mobility assessment). None of the assessments included in the baseline assessment are expected to cause muscle soreness. Electronic neurocognitive testing using the ImPACT^{TM} test is a common and accepted procedure in the assessment and management of concussions. Risk is no greater than minimal for participants testing for their baseline scores. If the participant completes an invalid test,

they will be asked to re-test to earn a valid baseline score. This will take an additional 20-30 minutes.

There are minimal psychological risks associated with participation in this study. The particpant may experience feelings of psychological distress based on their inability to execute a particular movement pattern or perform a particular balance task. To minimize this risk, private areas will be set up to ensure that children performing the test are not being watched by their peers.

Benefits:
There are many benefits to your child as a participant in this study. First, participants stand to gain knowledge from the results of their baseline tests. These baseline measurements of balance, functional movement patterns, and concussion status are essential in determining where an athlete may have deficits. These evaluations can help provide valuable information to a clinician or coach and can be used to help guide the design and implementation of programs containing corrective exercises that may assist in improving identified limitations and potentially reducing the risk of sustaining a sports related injury. Second, at the end of the data collection period, participants will be provided their results indicating the number of injuries sustained as well as average numbers for their peers. Together, these results can be used to help provide exercise recommendations.

Cost of Participating:
There are no costs associated with participation in this study. There will be no reimbursement for any costs incurred for participating in this study (e.g. transportation fees etc.).

Withdrawal:
You have the right to withdraw your child from the study without any consequence and will be allowed to do so at any point during the study. In addition, any data collected from your child can be withdrawn and destroyed. If you choose to withdraw your child at any point, we will ask you whether we can use their basic demographic data or baseline data for analysis. If you do not consent to this, their data will be destroyed.

Participant Confidentiality:
Your child's data will be kept confidential and will be coded (therefore stored anonymously). All hard copies of your data will be stored in a locked cabinet in a laboratory at UOIT. Furthermore, identifier codes will be stored in a separate office. The data will be saved on the laptop of the Principal Investigator (Michelle Avery), as well as the supervisor's laptop (Dr. Shilpa Dogra) and will backed up on an external hard-drive. All computerized devices used throughout this study are password protected to reinforce confidentiality.

CONSENT

I understand the procedures, potential risk and benefits of this study. Any questions regarding this study have been answered to my satisfaction.

I understand my consent to have my child participate, or to not participate in this study is voluntary. I also understand my right to withdraw my child from any part or all of this study for any reason. I waive no legal rights by participating in this study.

Should you have any questions regarding the rights of your child as a research participant, or about any issues relating to this study please contact Dr. Shilpa Dogra at (905)721-8668 ext. 6240 or Michelle Avery at (905) 904-0830.

I hereby consent to participate in this study.

___________________________ _____________________ ______/______/________
Participant (Print Name) Signature Date

For a member of the research study: I have ensured the named participant above has thoroughly understood all aspects of this research study, and have answered all questions to their satisfaction.

___________________________ _____________________ ______/______/________
Research Member (Print Name) Signature Date

This research has been reviewed and approved by the Research Ethics Board of the University of Ontario Institute of Technology and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines.

If you have any concerns regarding this research, you can contact the Ethics and Compliance Officer, Sascha Tuuha, at the following:
Email: compliance@uoit.ca
Tel.: (905) 721 8668 x3693

Appendix A6: Assent Form

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY

Study Title: Seasonal Changes in Functional Fitness and Neurocognitive Performance in Youth Ice Hockey Players

Name of Principal Investigator: Michelle Avery (UOIT)
Name of Supervisor: Dr. Shilpa Dogra, PhD, CSEP-CEP (UOIT)

Participant Information and Consent Form

We want to tell you about a research study we are doing. A research study is a way to learn more about something. We would like to find out more about the functional fitness levels and concussion status in children who play hockey. You are being asked to join the study because you play hockey.

If you agree to join this study, you will be asked to fill in a questionnaire at home with your parents. Filling in the questionnaires will take about 30 minutes of your time.

We hope that the information we learn from this study will help us learn about how we can make it safer for you as an athlete so that you are less likely to get hurt while playing sports or playing with your friends.

You do not have to join this study. It is up to you. You can say okay now and change your mind later. All you have to do is tell us you want to stop. No one will be mad at you if you don't want to be in the study or if you join the study and change your mind later and stop. Before you say yes or no to being in this study, we will answer any questions you have. If you join the study, you can ask questions at any time. Just tell the researcher that you have a question.

If you have any questions about this study please feel free to contact Michelle Avery (905) 904-0830, youthhockey.uoit@gmail.com or Shilpa Dogra (905) 721-8668 ext. 6240, shilpa.dogra@uoit.ca

By signing below you are agreeing to be in this study. If you are under the age of 18 years old, your parent(s) or legal guardian will have to give their permission also for you to join this study.

Name of Participant (Print) **Signature of Participant** **Date** (yyyy-mm-dd)

Name of Parent/Guardian (Print) **Signature of Parent/Guardian** **Date** (yyyy-mm-dd)

Person Obtaining Informed Consent:
My signature below signifies that I have explained the nature and purpose of the study and the risks involved to the study participant, and I have answered all questions to the best of my ability.

Name of Person (print) Obtaining Informed Consent	**Signature of Person Obtaining Informed Consent**	**Date** (yyyy-mm-dd)