FINDING BALANCE: AN EXPLORATION OF FACTORS RELATED TO BALANCE IMPAIRMENT IN CHILDREN AFTER CONCUSSION

FINDING BALANCE: AN EXPLORATION OF FACTORS RELATED TO BALANCE IMPAIRMENT IN CHILDREN AFTER CONCUSSION

By

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# ABSTRACT

**Introduction:** Balance impairment is a commonly reported symptom of concussion. Very little research has been undertaken regarding the complexities of balance impairment after concussive injury in the pediatric population.

**Purpose:** The objectives of this study were: 1) to identify the factors that are associated with balance impairments in children with concussion; 2) to review and evaluate four commonly used balance measures; and 3) to provide recommendations for the best methods of clinical evaluation of balance in children and youth after concussive injury.

**Methods**: A cross-sectional balance evaluation was completed on 104 children, ages 5-18 who had a confirmed diagnosis of concussion. Four balance measures were examined to determine which was the most appropriate for evaluating balance post-concussion.

**Results:** 37% of children were found to have balance impairment according to the BOT-2. The full logistic regression model was found to be not statistically significant however, mechanism of injury with an odds ratio of 2.1 and 95% CI [0.810, 5.027] indicates that children with sport-related injuries are twice as likely to have balance impairment than those with a non-sports-related injury. Chi-Square analyses showed a statistically significant association for mechanism of injury (χ2=11.05, p = 0.03) and age (χ2 = 0.04, p =-0.02) for children who presented with balance impairments and those who did not. Children with balance impairment may present with different symptom profiles than children without.

**Conclusion**: Using a single method of assessment may not provide an accurate representation of balance impairment in children and youth after concussion. Based on the comparison of measurement properties and application of each measure to 104 children with concussion, the BOT-2 and the CB&M when used together provide the most comprehensive assessment of balance and postural instability in children with concussive injury. Age, mechanism of injury and site of impact may be leading factors in the development of balance impairment.

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# TABLE OF CONTENTS

[Title Page i](#_Toc425700001)

[Descriptive Note iii](#_Toc425700002)

[Abstract iv](#_Toc425700003)

[Acknowledgements v](#_Toc425700004)

[Chapter One: Introduction 1](#_Toc426079550)

[Concussion in Children and Youth 2](#_Toc426079551)

[Theoretical Framework 5](#_Toc426079552)

[The Human Balance System 7](#_Toc426079553)

[Clinical Evaluation of Balance 10](#_Toc426079554)

[Balance and Concussion 14](#_Toc426079555)

[Research Plan 16](#_Toc426079556)

[References 18](#_Toc426079557)

[Chapter Two 26](#_Toc426079558)

[Title of Paper: Measuring Balance: A Comparison of Four Balance Measures for Children with Concussive Injury](#_Toc426079559)

[Abstract 26](#_Toc426079560)

[Introduction 26](#_Toc426079561)

[Methods 29](#_Toc426079562)

[Participants 29](#_Toc426079563)

[Procedures 30](#_Toc426079564)

[Measures 31](#_Toc426079565)

[Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2) 31](#_Toc426079566)

[Balance Error Scoring System (BESS) 32](#_Toc426079567)

[Sway Balance 32](#_Toc426079568)

[The Community Balance and Mobility Scale (CB&M) 33](#_Toc426079569)

[Comparison of the Measures According to *CanChild* Guideline Criteria 33](#_Toc426079570)

[Data Analysis 38](#_Toc426079571)

[Results 38](#_Toc426079572)

[Discussion 41](#_Toc426079573)

[Limitations 45](#_Toc426079574)

[Future Directions 45](#_Toc426079575)

[Conclusions 46](#_Toc426079576)

[References 47](#_Toc426079577)

[Chapter Three 52](#_Toc426079578)

[Title of Paper: Finding Balance: Exploring the Factors Related to Balance Impairment in Children with Concussion](#_Toc426079579)

[Abstract 52](#_Toc426079580)

[Introduction 52](#_Toc426079581)

[Methods 55](#_Toc426079582)

[Design 55](#_Toc426079583)

[Participants 55](#_Toc426079584)

[Procedures 56](#_Toc426079585)

[Measures 57](#_Toc426079586)

[Data Analysis 57](#_Toc426079587)

[Results 58](#_Toc426079588)

[Logistic Regression 63](#_Toc426079589)

[Injury Related Factors 64](#_Toc426079590)

[Mechanism of Injury 64](#_Toc426079591)

[Other Self-Reported Presenting Symptoms 64](#_Toc426079592)

[Non-Injury Related Factors 67](#_Toc426079593)

[Discussion 67](#_Toc426079594)

[Limitations 71](#_Toc426079595)

[Future Directions 72](#_Toc426079596)

[Conclusions 73](#_Toc426079597)

[References 74](#_Toc426079598)

[Chapter Four: Discussion and Conclusion 80](#_Toc426079599)

[Implications for Clinical Practice 84](#_Toc426079600)

[Conclusion 86](#_Toc426079601)

[References 87](#_Toc426079602)

# LIST OF TABLES

[Chapter Two:](#_Toc426109320)

[Table 1: Descriptive Characteristics of Study Population 31](#_Toc426109321)

[Table 2: Guideline Criteria and Measurement Properties of the BOT-2, modified BESS, Sway Balance and CB&M 36](#_Toc426109322)

[Table 3: Psychometric Properties of the BOT-2, modified BESS, Sway Balance, and CB&M 37](#_Toc426109323)

[Table 4: Measure Comparisons between Identified Balance Impairments and Total Sample 40](#_Toc426109324)

[Table 5: Correlation matrix for the relationship among balance assessment measures in children identified as having balance impairment 41](#_Toc426109325)

[Chapter Three:](#_Toc426109326)

[Table 1: Descriptive Characteristics of Study Sample 61](#_Toc426109327)

[Table 2: Logistic Regression Predicting Likelihood of Balance Impairment following a Concussion 65](#_Toc426109328)

[Table 3: Means of Self-Reported Other Presenting Symptoms 67](#_Toc426109329)

[Table 4: Correlation Matrix for Self Reported Balance Problems and Other Presenting Symptoms 68](#_Toc426109330)

**LIST OF APPENDICES**

[Appendix A: Ethics Approval Letters 92](#_Toc426109368)

[Appendix B: Bruininks-Oseretsky Test of Motor Proficiency (Version 2)- Balance Subtest 98](#_Toc426109369)

[Appendix C: Modified Balance Error Scoring System 99](#_Toc426109370)

[Appendix D: Sway Balance Application- Balance Output 101](#_Toc426109371)

[Appendix E: Post Concussion Symptom Scale 102](#_Toc426109372)

[Appendix F: Community Balance and Mobility Scale 103](#_Toc426109373)

# Chapter One: Introduction

There has been increased public attention surrounding the significance within the pediatric population of sustaining a so-called mild traumatic brain injury (mTBI) or concussion. In the United States, 1.6 to 3.8 million sport-related concussions occur each year (Leddy et al. 2012). According to MacPherson et al. (2014) between 2003 and 2010 in Ontario, 88,688 pediatric concussions were diagnosed and treated in either an emergency department or a physician’s office. The rate of pediatric concussive injury per 100,000 increased from 340.5 in 2003 to 601.3 in 2010 (MacPherson et al., 2014). Similarly, Quayle et al. (2014) found that approximately 14,177 injuries per year were reported between 2004 and 2006 in 25 Pediatric Emergency Care Applied Research Network emergency departments across the United States. As the awareness about the significance of concussion increases, more people are being appropriately diagnosed with this type of injury; however, there is still little understanding about both the short- and long-term effects of experiencing a concussion (Schatz & Moser, 2011). One primary symptom of concussion is balance impairment. Very little research has been undertaken regarding the complexities of balance impairment after concussive injury in the pediatric population. By exploring and gaining a better understanding of the factors associated with balance impairments, recommendations can be made regarding the best methods of clinical evaluation of balance for children and youth and its possible prognostic implications, based on their associations with relevant outcomes.

This dissertation is comprised of two manuscripts that address issues in balance impairments in children with concussive injury. The first manuscript (Chapter 2) presents a rigorous comparison of four balance measures used in four current research study protocols and provides recommendations for the best methods of clinical evaluation for children with balance impairments after concussive injury. The second manuscript (Chapter 3) presents the results of a study of balance in children and youth with concussive injury. It describes the main factors, both injury-related and non-injury-related, that are associated with balance impairments in children after concussion. The aim of this second manuscript is to create and define a profile for children presenting with balance impairments compared to children who do not, based on the findings of the specific factors related to balance impairments.

This introductory chapter provides a background regarding the complex nature of concussive injury as well as a review of the literature examining current clinical evaluations of, and factors that may affect, balance impairments in children after concussive injury. The examination of current literature provided the foundation and direction of the research questions addressed through this dissertation. In addition, an overview of relevant motor learning and neuronal damage theories is provided as a framework to help explain and understand the current clinical applications of balance impairment. Finally, this chapter offers an outline of the core study objectives as well as a summary of the research plan.

## Concussion in Children and Youth

Concussions are complex pathophysiological processes caused by a direct blow to the head, face or body that transmits impulsive forces to the head, jarring or shaking the brain inside the skull (American Association of Neurological Surgeons, 2013). Many symptoms are associated with concussion. These can vary by duration, severity, and factors within the individual. Concussions can result in symptoms that can be categorized into four main domains that include cognitive, emotional/mood, somatic, and sleep-related symptoms. The onset of symptoms associated with concussive injury can occur immediately after the injury or become apparent several minutes, hours or days after the injury (McCrory et al., 2013). Concussive injuries reflect functional rather than structural disturbances (Giza & Hovda, 2001), meaning that structural damage is not evident during computerized tomography (CT) or Magnetic Resonance Imaging (MRI) scans of the brain. No two head injuries are neuropathologically similar, as variable symptoms of concussion and primary and secondary insults to the brain differ (Liss & Willer, 1990; Aubry et al., 2002).

Recovery time for concussion varies and can be influenced by various factors such as age, sex, history of previous concussions, past medical history, pre-morbid conditions such as migraine and depression, and pre-injury level of function (Guskiewicz et al., 2003, Iverson, Gaetz, Lovell, & Collins, 2004, McCauley et al., 2001, Eisenberg et al., 2013). This study protocol defines recovery as the resolution of symptoms. Research into recovery times shows that individuals with concussion typically recover within a 7- to 10-day period (Belanger & Vanderploeg, 2005), however approximately 10% of people with sport-related and 33% of non-sport related concussive injuries will have symptoms persisting beyond 2 weeks (Willer & Leddy, 2006, Rimel et al., 1981). It is also important to realize that recovery time for children and adolescents may take longer due to different stages of brain development (McCrory et al., 2013). In studies examining symptom duration specifically in children, Barlow et al. (2010) and Babcock et al. (2013) found that up to 30% of children have persisting symptoms 3 months post-injury.

In examining the causes of concussion, age is shown to be a significant factor (Macpherson et al., 2014). Fall-related injuries account for approximately 45% of all concussive injuries admitted to Canadian hospitals (Canadian Institute for Health Information, 2006) and are the most common cause of injury in children ages 0-7 years old (Willer, 2004; Andersson et al., 2012; Faul et al., 2010). Sport-related injuries, most common in youth, account for approximately 30% of concussive injuries in children and youth (Canadian Institute for Health Information, 2006; Meehan & Mannix, 2010; Bakhos et al., 2010; Kimbler, Murphy & Dhandapani, 2011). It is difficult to create an accurate depiction of how common concussive injuries are within the pediatric population as injuries often go unreported. However, a more accurate depiction is emerging in the literature as the research focus is expanding to observe not only emergency department services but also other healthcare services such as physicians’ offices.

When a concussive injury occurs, children often experience restrictions in participation in their regular daily occupations. Participation is a core component of human development and lived experience (Law, 2002). It is through participation that skills and competencies are acquired, social networks are developed and expanded, goals are met and challenges are overcome (Desha & Ziviani, 2007). The literature on participation in meaningful occupations has shown that participation has a positive influence on quality of life and health (Freysinger, Alessio, & Mehdizadeh, 1993; Law, Steinwender, & Leclair, 1998). The hindrance of participation in both formal and informal activities can lead to social isolation, depression, deconditioning, and overall decreased quality of life (Leddy et al., 2012; Law, 2002). A study completed by Law et al. (2011) found that children with acquired brain injury, including mTBI, participate in similar types of activities compared to typically-developing children without concussion, however level of intensity and diversity of activity differ. Research has shown that level of participation in children and adolescents with concussion is restricted when compared to expected participation patterns for their age (Bedell & Dumas, 2004; Law et al., 2011). The main goal of rehabilitative practice is to encourage individuals to have full participation as active and productive members of society. The recovery of visual-motor control, balance, postural control, coordination and range of motion are all important goals after concussion and for participation in many activities, particularly in school and sports (Both, 2008; Chaplin, Deitz, & Jaffe, 1993). Appropriate management of concussive injuries can allow the child to return to their regular daily occupations in a safe and timely manner. By investigating the main factors that are associated with balance impairments, a better understanding of how to evaluate balance clinically can be determined, better informing practice and aiding in the re-establishment of pre-injury participatory patterns.

## Theoretical Framework

Understanding and evaluating the process of concussive recovery is like building an intricate puzzle. By understanding the core concepts of various theoretical frameworks valuable insights can be derived into how best to manage the complex nature of concussions. A key objective in pediatric rehabilitation is to assist in the promotion of learning or relearning functional motor skills (Larin, 1998). Motor learning theories help support the process of rehabilitation, as the main clinical goal is to facilitate the development of skills through practice and responses to environment. Motor learning refers to internal processes that connect practice or experience to long-lasting changes in motor behaviour (Schmidt, 1988). One theory that describes development and change over time is the Dynamic Systems Theory (DST). The DST is useful for explaining how movement is produced and developed through the interaction of multiple subsystems that self-organize in a specific pattern to produce a desired movement or outcome (Thelen, 1989). According to the DST, the promotion of development is influenced by complex bi-directional interactions of the individual, the environment and the task itself (Law et al., 1998). By examining which variables to manipulate and the relationships among the interacting variables, the DST encourages learning through specific environmental context and considers the meaning of the task.

There are many core concepts with the DST that attempt to explain how change occurs within development. The concept of continuity of time within the DST refers to the idea that every event and time point along a process is dependent on what has previously occurred and that all future events and time points are dependent on the current state (Thelen, 2005). It is important to apply the notion of continuity of time to the assessment and treatment of children with balance impairments after concussion because it allows for the facilitation of development by considering how the injury has already impacted the individual and how the injury and recovery process will impact future development.

Dynamic stability is another concept within the DST, defined as the process of observing a behaviour or outcome and understanding how the pattern of development is utilized or maintained in response to context (Thelen, 2005). Behaviour patterns become stable and preferred over time and with practice. It is in these periods of stability that behaviour patterns resist change. However, if patterns are disrupted, resulting in a period of instability or transition, positive change may be most easily introduced or influenced (Law et al., 1998). Dynamic stability specifically relates to understanding assessment of balance impairments in children after concussion, as previous patterns of balance ability have been disrupted, introducing periods of transition. Children with balance impairments may need to learn or re-learn new skills to complete goal-oriented tasks such as returning effectively and efficiently to sport. Rehabilitation strategies and interventions can be introduced to help a child with the learning or re-learning of skills, however the child has to express readiness for change. Without readiness for change and active participation from the child, the stability of the skill will not increase and other non-effective adaptive skills may become preferred, ultimately restricting the child’s participation in their daily activities of living and meaningful goal-oriented tasks.

The International Classification of Functioning, Disability and Health (ICF) framework can also help address the different levels of management for concussive injury. The ICF considers the impact of the bi-directional relationships among impairments in body functions and structures, limitations of activity and restrictions in participation. The ICF also considers the role of contextual factors, such as environmental and personal factors, when understanding functioning and disability. The neurological damage causing balance impairment after concussive injury falls within the body functions and structures domain of the ICF. This neurological damage influences how an individual participates in meaningful activity. By understanding the influence that each domain has within the individual, the appropriate management strategies can be established with the ultimate goal of returning the individual to pre-injury level of function.

## The Human Balance System

Balance plays an essential role in day-to-day functioning as it is required in almost all activities of daily living. Impaired balance can interfere with the participation in the activities that we want to do, need to do and are expected to do, and can increase the risk of sustaining other injuries. Balance is defined as the ability to maintain the body’s centre of mass over its base of support, regardless of static or dynamic states (Shumway-Cook & Horak, 1986). Static balance refers to the ability to maintain postural stability and orientation in a stationary position, whereas dynamic balance is the ability to maintain postural stability and orientation while in motion (Goldie, Bach & Evans, 1989). Balance plays a critical role in the maintenance of fluid dynamic movements used in daily occupations (Guskiewicz, 2011). If neurological damage has occurred after a concussive injury, balance impairments may be a result of an inappropriate interaction among the sensory input subsystems such as vision or vestibular system. This means that incorrect orientation information is being processed by the postural control system (Guskiewicz, 2011). Intersensory conflict may arise after concussive injury due to the neurological damage of some systems causing a reliance on other systems (Shumway-Cook & Horak, 1986; Nashner, 1982; Nashner, Black & Wall, 1982).

The human balance system is comprised of and maintained by a complex set of sensorimotor control and biomechanical systems that process and integrate information from vision, tactile and motor functions to produce and execute appropriate responses (Guskiewicz, 2011). The proprioceptive system is an internal regulatory system within the somatosensory system that is responsible for providing information on the position and movements of the body (Subasi, 2014). Proprioception is a very important feedback mechanism that assembles sensory input regarding motor control and posture. The proprioception system uses tactile senses such as touch, pressure and vibrations to establish relative positions and rates of movement within the body (Guskiewicz & Perrin, 1996).

The vestibular system is integral to spatial orientation and balance by providing information about head position and movement. This system is located within the inner ear and involves two types of sensors. The otoliths in the saccule and the utricle are responsible for sensing linear acceleration such as gravity and translational movements, and the semicircular canals respond to angular acceleration through rotational movements (Subashi, 2014). The receptor cells within these sensory organs send signals through vestibular nerve fibers to neural structures that produce the desired outcome (Subashi, 2014). This system is particularly important in regards to the development of balance, coordination and eye movement (Subasi, 2014). There are three main responsibilities of the vestibular system. The first is muscular control of the eyes when head position changes. This ensures that the eyes can maintain position and stay fixed on one point (Guskiewicz & Perrin, 1996). The second responsibility is to use sensory information to maintain upright posture through muscle control (Guskiewicz & Perrin, 1996). Finally, the vestibular system uses conscious awareness of body positioning and acceleration or deceleration of movement after signals have been relayed throughout the system (Guskiewicz & Perrin, 1996). It is the ability to react and respond to sudden changes through the automatic control mechanisms of the vestibular system that stabilizes gaze and body equilibrium (Guskiewicz & Perrin, 1996). When any one of these sensorimotor systems becomes compromised or inhibited due to a brain injury, the individual may experience balance issues.

Many important areas of the brain contribute to functioning of the balance system. However, the cerebellum is responsible for the coordination and learning of movements and for controlling posture and balance (Guskiewicz, 2003). Distinct regions of the cerebellum play an essential role in the control of behaviours such as voluntary limb movements, eye movements, balance and locomotion (Morton & Bastian, 2004). The cerebellum also regulates the flexibility of these behaviours. This flexibility is essential for the trial-and-error adaptation of motor behaviours in new contexts (Morton & Bastian, 2004). The adaptive trial-and-error capability of the cerebellum supports the recovery of balance impairments through facilitation of learning and/or relearning what works and what does not in order to complete a goal-oriented task.

Postural control results from all of the above systems working together to achieve balance. Maintaining position and transitioning between positions requires the generation of multiple complex motor responses (Gagnon, Friedman & Forget, 2004). These responses need to be received and translated through multiple sensory inputs within the central nervous system (Gagnon, Friedman & Forget, 2004). It is through the use of postural control after the response signals have been transmitted that allows for the maintenance or production of a desired stance, movement or response. There are two types of postural control responses: anticipatory control and feedback control. Anticipatory control is seen when a set of strategies is used to prepare for specific movements (e.g., knowing what movements need to occur in order to catch a ball) (Case-Smith & Clifford-O’Brien, 2013). Feedback control is observed when an individual receives information from the sensory input systems and reacts to changes based on the incoming information (e.g. knowing what movements need to occur in order to remove your hand from a hot stovetop). These responses are accomplished separately or in combination with each other and are adjusted based on context-specific factors and the desired task (Gagnon, Friedman & Forget, 2004). Internal and external interferences may threaten the ability to maintain balance. The ability to adapt to these interferences is dependent on the maturation and development of all systems involved (Horak, 1987).

## Clinical Evaluation of Balance

When providing specific interventions to children with balance impairments after concussive injury, it is important to choose assessments that emphasize balance and mobility skills in order to determine what skills need to be strengthened or re-learned, and what will impede participation. A number of assessments have been developed to measure both static and dynamic balance in typically developing children as well as in specialized populations such as older adults, individuals with neurological impairment and individuals with traumatic brain injuries. Most balance assessments involve having the individual who is being tested move into and maintain various stances while the assessor evaluates balance by examining various errors, or based on the effort given to complete a task. Tools such as foam or tilt boards can also be introduced to modify the support surface feedback associated with the proprioceptive system when assessing dynamic balance ability (Riemann, Guskiewicz, & Shields, 1999; Atwater et al., 1990). This provides insight into how the individual may respond or react to different environmental factors (e.g., playing field surface), allowing for specific issues to be pinpointed and interventions to become more targeted.

Many balance assessment tools are used within clinical or sport sideline settings. However a current criticism of traditional observational balance assessments is that these measures offer subjective rather than objective measurements (Guskiewicz & Perrin, 1996). In order to address the criticism of subjective measurements, the introduction of force plates or force platforms into clinical assessment can provide quantitative measurements of functional balance by analyzing postural sway (Guskiewicz & Perrin, 1996). Force plates analyze multiple aspects of postural control including the ability to keep the body motionless, the ability to distribute body weight evenly in stances, dynamic stability and dynamic balance (Goldie, Bach & Evans, 1989). However, although force plates are considered a gold standard of balance measurement, as they provide objective quantitative data, there are several limitations that prevent clinical uptake and use, minimizing clinical utility. Force plates are not readily available for clinical settings. Clinical space, cost, non-portability, duration of assessment and other resources such as software for interpretation, analyses and measurement, and trained laboratory assistants are limitations in why balance platforms were not used within the four current study protocols.

In the current study, prospective data from multiple sources have been collected for four balance measures (Appendices B-F) that have been used to gain a better understanding of the different components of balance. (i) The balance subtest of the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2) (Bruininks & Bruininks, 2005) is a standardized age and sex norm-referenced outcome measure (Gagnon et al., 1998). The BOT-2 balance subtest is comprised of nine tasks that measure trunk stability, the use of visual cues, and both static and dynamic balance abilities. The tasks within the balance subtest of the BOT-2 include standing on a line and on a balance beam with feet apart, walking forward on a line with a normal gait and with a heel-to-toe gait, standing on a line on one leg and on a balance beam. For all tasks the examinees are asked to have their hands on their hips and may be instructed to have their eyes closed. All static positions are held for a maximum of ten seconds and all dynamic positions are monitored for a maximum of six steps. Tasks end either when the defined time has lapsed or if an error occurs. Errors consist of the examinee being unable to maintain a position, by putting their non-balancing foot down, opening their eyes, and/or taking their hands off of their hips. After testing is completed, standardized scoring is interpreted through five descriptive categories ranging from well above average to well below average (Bruininks & Bruininks, 2005).

(ii) The second balance outcome measure reviewed in this study is the Balance Error Scoring System (BESS). The BESS is a three-task assessment tool designed to evaluate postural-stability deficits after concussive injury (Guskiewicz, 2001). The three tasks in the BESS include a double leg stance, a tandem stance and a single leg stance. All stances are performed twice, once on a firm surface and once on a foam surface, and individuals are instructed to have their eyes closed **(**Bell et al., 2011**)**. All stances are timed for 20 seconds and errors are counted throughout the stance (Bell et al., 2011). Errors in the BESS are defined by opening the eyes, stumbling or falling out of position, lifting of the balancing forefoot or heel, more than 30**°** abduction of the hip and/or failing to return to the testing stance for more than 5 seconds (Bell et al., 2011). Unlike the BOT-2, in which once an error is committed all timing is stopped, the examinee is instructed to try to return to the testing stance and timing is continued.

(iii) Recent work has introduced and examined the use of accelerometers in assessing postural sway and balance to replicate the force plate quantification and objectivity but in an easily implemented clinical technique. Accelerometers are non-invasive, portable and have been shown to be able to detect definite abnormalities in gait and balance (Auvinet et al., 2002; Menz, Lord, & Fitzpatrick, 2003; Cho & Kamen, 1998.)

The Sway Balance system, an accelerometer application in an iPad, is used to examine how balance is quantitatively measured compared to the subjective measurements of the three other balance assessments. The system is an application that is installed on a mobile device. It uses tri-axial accelerometers to generate a stability score based on postural sway (Patterson et al., 2014). The application provides a five-test protocol that the examinee is guided through based on prompts within the system shown on the screen. The protocol includes a bipedal stance, two tandem stances and two single leg stances (Sway Medical, 2015). All stances are performed with the examinee’s eyes closed. Completion of the protocol results in an output of a Sway score based on a 100-point scale (Sway Medical, 2015). The Sway score is an interpretation of the accelerations of the deviations within the device that is said to mimic body positioning and is determined by undisclosed calculations from Sway Medical (Patterson et al., 2014).

(iv) Finally, the fourth balance measure that is evaluated in this study is the Community Balance and Mobility Scale (CB&M) (Howe et al., 2006). The CB&M measures balance and mobility by assessing tasks that require multi-tasking, dynamic balance, sequencing, rapid directional change, coordination, and speed (Wright et al., 2010; Rocque et al., 2005). There are 19 tasks in the CB&M, and all are scored on a 0-5 scale based either on time and/or quality of performance criteria (Howe et al., 2006). Tasks include a unilateral stance, tandem walking, tandem pivoting, lateral foot scooting, hopping on one foot, crouching and walking to pick up an object, walking and looking at a target, walking, looking at a target and carrying weights, descending stairs, and speeded step-ups (Howe et al., 2006). The CB&M was designed for a young adult population with high ambulatory function after a mTBI (Rocque et al., 2005), making it a useful measure for the current study as all participants are between the ages of 5 and 18.

The purpose of outlining each outcome measure evaluated in the study is to provide the reader with an introduction to how balance is being measured. A more in-depth overview of each measure, including their reliability and validity, is provided in Chapter 2. Chapter 2 also presents a rigorous comparison of all of the measures, highlighting the strengths and limitations of each. Whether the measures used in the study can be administered individually, assessing different types of balance within one measure effectively, interchangeably, or used in combination as they measure different components of balance is also explored.

## Balance and Concussion

Balance impairment is a commonly reported primary symptom after a concussive injury (Guskiewicz, 2011; Gagnon et al., 1998; Wade et al., 1997). Balance issues become apparent soon after the injury and do not develop as secondary sequelae. When assessing individuals with concussive injury, neuropsychological testing is usually completed to evaluate the cognitive domain of functioning, and postural stability or balance assessment is completed to evaluate the motor domain of functioning (Guskiewicz, 2001). Understanding more about the importance of balance in recovery and treatment of concussion is important as balance issues may provide insights into impairments that have occurred to the neurological system after experiencing a concussion. Increased postural sway, excessive or diminished responses to perturbations, poor control of stability during motions of other body parts and atypical oscillations of the trunk are all classified as balance impairments (Morton & Bastian, 2004). Until recently, research has overlooked balance impairments after concussive injury due to the differences in presentation of neurological damage of those who have had a severe traumatic brain injury compared to those with mTBI (Gagnon, Friedman, & Forget, 2004). Between 30% and 65% of people with a mTBI will experience dizziness, disequilibrium and/or imbalance at some point in their recovery (Williams & Schache, 2010). The severity of an individual’s balance issues may vary depending on numerous factors such as how severe the brain injury was, what part of the brain was injured and whether any other injuries occurred at the time of the brain injury (Peterson & Greenwald, 2011).

After examining balance and cognitive performance in collegiate-level athletes for up to ten days after a concussive injury, Guskiewicz (2001) found that when matched to controls of non-injured athletes cognitive performance evaluation scores did not differ among groups. However after examining balance in both groups there were significantly poorer outcomes in the concussed athlete group within the first three days post-injury (Guskiewicz, 2001). In a prolonged 6-month post-injury follow-up study Geurts et al. (1996) found that postural sway in static balance stances significantly increased and weight-shifting speed during dynamic balance tasks decreased in a group of individuals with concussive injury compared to a healthy control group. When examining the presentation of other symptoms related to concussion, individuals who experienced headaches post-injury were more likely than individuals who did not experience headaches to have balance impairments (Register-Mihalik, Mihalik, & Guskiewicz, 2008). As reported by Gagnon, Freidman & Forget (2004) no similar research has been undertaken in the pediatric population with mTBI. After examining balance in children following concussive injury using standardized tests, Gagnon et al. (1998) found that approximately 40% of the children had decreased balance performance in comparison to published norms.

Gagnon, Friedman & Forget (2004) found that when completion of a task needed more refined postural control and higher levels of anticipatory control, children with mTBI did more poorly than children without an injury. These findings suggest that children with concussive injury have difficulties retrieving and applying the proper motor responses for preparing and approaching challenging balance tasks (Gagnon, Friedman & Forget, 2004). The children in that study were also challenged by the introduction of two disruptions while trying to complete the desired task, one providing a challenge to the proprioceptive system and the other providing a challenge to the vestibular system (Gagnon, Friedman, & Forget, 2004). Balance impairments were detected with each of these tasks suggesting that problems existed when trying to integrate and interpret sensory information to produce a motor response, and that there was an overreliance on different mechanisms of the sensorimotor control system. A combination of both static and dynamic balance tasks should be used when evaluating children after mTBI because as Gagnon, Friedman & Forget (2004) suggest examining these components in isolation may result in a failure to detect subtle changes.

## Research Plan

The aim of this research is to identify factors associated with balance impairments in children and adolescents ages 5-18 years of age who have sustained a recent (within 3 months) mTBI/concussion. The exploratory questions guiding this research are:

1. What type of measure is most clinically appropriate to evaluate balance impairment in children/youth after a concussive injury?
2. What factors are associated with balance impairments in children 5-18 years with recent concussive injury?

The primary objective of this study is to:

Determine the main factors associated with balance impairments in children with mTBI/concussion.

* + 1. Injury-related factors, which might include: site of impact? time since injury? other presenting symptoms? previous number of injuries? mechanism of injury?
    2. Non-injury-related factors: age? sex?

It is hypothesized that, based on the injury-related and non-injury-related factors that are examined age, mechanism of injury and site of impact will be the most significant factors affecting balance impairment.

In addition, other objectives include:

1. To conduct a rigorous comparison of the four balance measures used in the concussion research studies underway at *CanChild* Centre for Childhood Disability Research.
2. To provide recommendations regarding the best method(s) of clinical evaluation of balance in children and youth.
3. To create a profile of children with concussion who present with balance impairments and those who do not.

This study, designed from prospectively derived data from larger ongoing studies (Appendix A), allows for measuring balance impairment occurrence and its association with both injury- and non-injury-related factors across time. All participants in the study were diagnosed by a physician as having a concussion, and all data were collected prospectively following their injuries. The main goal of data analysis was to identify associations between injury- and non-injury-related variables in relation to the outcome of balance impairments after concussive injury. The findings of Chapters 2 and 3 are discussed in Chapter 4 as they relate to balance impairment in children post concussion, including clinical implications regarding the best methods of evaluation of balance. Recommendations for future research and strengths and limitations of the current research study are also described.

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# Chapter Two

Title of Paper: Measuring Balance: A Comparison of Four Balance Measures for Children with Concussive Injury

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## **ABSTRACT**

**Introduction:** Increased public recognition about mild traumatic brain injury or concussion and the health problems that result has encouraged research about the best way to assess and manage these injuries. Balance impairment is a commonly reported symptom of concussion and an important symptom to assess and manage in order to resume safe participation in daily activities. The purpose of this study is to critically review and evaluate four commonly used balance measures and to provide recommendations for the best methods of clinical evaluation of balance in children with concussion.

**Design**: As a part of larger prospective cohort studies evaluating recovery of children after concussion, a cross-sectional balance evaluation of 104 children with concussion was completed at first post-injury assessment.

**Methods:** The Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2), the Balance Error Scoring System (modified BESS), the Sway Balance, and the Community Balance and Mobility Scale (CB&M) were administered to children between the ages of 5-18 who had a diagnosed concussion. The guidelines developed by *CanChild* for assessing outcome measures were used to review and compare the measurement properties of each measure. The BOT-2 was used as the reference standard for comparison with the other measures.

**Results**: Correlation analyses of all measures revealed statistically significant correlations between the BOT-2 and the CB&M (r=0.517, p=0.003); the BOT-2 and the modified BESS (r=-0.588, p=0.006); the BOT-2 and the Sway Balance (r=-0.642 p=0.005); and the modified BESS and the Sway Balance (r=-0.630, p=0.007). Of the 38 children classified as having a balance problem according to the BOT-2, 18 were below the 50th percentile score of the CB&M, and both the modified BESS and the Sway Balance classified 9 children below the 50th percentile.

**Conclusion:** Using a single method of assessment may not provide an accurate representation of balance impairment in children and youth after concussion. Based on the comparison of measurement properties and application of each measure to 104 children with concussion, the BOT-2 and the CB&M together provide the most comprehensive assessment of balance and postural instability in children with concussive injury. The Sway Balance shows promise in its ability to objectively quantify postural sway and ease of administration.

## **INTRODUCTION**

Mild traumatic brain injuries (mTBI) or concussions are complex injuries that require a comprehensive, multifactorial management approach.[1-4] Rates of reported pediatric concussion are on the rise, increasing yearly[5], and concussion in children and youth has become an important public health problem. Concussive injuries can result in physical and psychosocial impairments, participation restrictions and limitations of daily activities of living.[6,7] Current management of concussive injuries includes neuropsychological testing to assess the cognitive domain of neurological function and postural stability or balance testing to assess motor function.[8] Concussive injuries are assessed based on the manifestation of symptoms throughout the individual’s recovery trajectory.[8]

Symptoms of concussion are categorized into four main domains: cognitive, emotional/mood, somatic, and sleep-related symptoms. Balance impairment is a commonly reported somatic symptom of concussion.[9-11] Measuring balance can assist with clinical evaluation, selection of appropriate therapies, outcome measurements and decisions regarding return to activity, including sports and school.[9,12] Since the human balance system is comprised of a number of complex sensorimotor control and biomechanical systems, appropriate measures for balance impairment and postural instability need to be included in the process of injury assessment and management. Balance impairment results from neurological damage within the central nervous system and specific parts of the brain. Assessing and improving balance impairments in children after a concussive injury can aid in improving functional performance, preventing further injury and increasing participation in activities of daily living.[13]

Rehabilitation specialists use measurement instruments to help describe patient characteristics, evaluate treatment decisions, measure outcomes and predict recovery trajectories.[14,15] The purpose of a measure guides the development and methodological properties of the instrument.[14] In order for a measure to be clinically useful a number of criteria need to be met. As suggested by Law (1987)[14] these criteria include: purpose of the instrument, clinical utility, construction and scaling, standardization, reliability, validity and responsiveness. The criteria used in the *CanChild* guidelines[15] help evaluate the scientific rigor and utility of a measurement instrument.[14]

Assessing balance is essential to determine accurately an individual’s ability to maintain postural stability in both static and dynamic states. A variety of measures are commonly used for assessing balance and postural sway in specific populations such as older adults, individuals with neurological impairments, stroke and acquired brain injury. Force platforms are seen as the gold standard for evaluating balance impairments and postural instability as they provide objective quantitative measurements of postural sway.[17] However, the clinical utility of balance force platforms is low due to a number of factors: space, specialized equipment required; and the costly software and trained laboratory assistants.

There are a number of balance measures available and some more commonly used in the field of concussion management. The balance subtest of the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2)[18] is a commonly used standardized, pediatric assessment tool that has age and sex-based normative data. The Balance Error Scoring System (BESS) is a popular measure amongst the athletic training community and was originally developed as a sideline tool for evaluation of postural stability after concussion.[19] The modified BESS (administered without stances on foam) is often used instead of the complete BESS due to ease of use however there is no normative research data in pediatric populations using the BESS.[20] The Sway Balance System[21] is a mobile application that measures stability using built in accelerometers of the mobile device to quantify postural sway. The Community Balance and Mobility Scale (CB&M)[22] evaluates an individual’s static and dynamic balance ability and has been validated to measure change in balance performance for children and youth with acquired brain injury.[23] Other balance measurement tools such as the Berg Balance Scale and the Functional Gait Assessment were examined before finalizing the study protocol but were not selected, as the target populations are not children and youth or mild traumatic brain injury. The purpose of this study was to review, contrast and evaluate four commonly used measures to assess balance through the comparison of measurement properties, and to evaluate the performance of these measures on 104 children with concussion.

## **METHODS**

### Participants

Participants in three prospective concussion research studies and one prospective clinical database were recruited from the McMaster Children’s Hospital Emergency Department, or via referral by their community physician, rehabilitation clinician, or self-referral. All participants had to be between the ages of 5 and 18 years, have a confirmed diagnosis of concussion from a physician and have no other significant developmental delays. Participants were excluded if their head injury was more severe than a concussive injury or they had multi-system injuries affecting their balance. Participant demographic information is provided in Table 1.

Table 1: Descriptive Characteristics of Study Population

|  |  |
| --- | --- |
| Variable | Study Population (n= 104) |
| **Gender *n(%)*** |  |
| Male | 59 (56.7) |
| Female | 45 (43.3) |
| **Age (years)** |  |
| Mean, range | 13.32 (8-17) |
| 8-12 *n(%)* | 37 (35.6) |
| 13-18 *n(%)* | 67 (64.4) |
| **Site of Impact *n(%)*** |  |
| Frontal | 34 (32.7) |
| Occipital | 32 (30.8) |
| Right Parietal | 10 (9.6) |
| Left Parietal | 6 (5.8) |
| Right Temporal | 5 (4.8) |
| Left Temporal | 7 (6.7) |
| Neck | 3 (2.9) |
| Indirect Force | 1 (1.0) |
| Other Body Part | 6 (5.8) |
| **Total Number of Head Injuries** |  |
| Mean SD; Range | 1.86 SD 1.34; 1-9 |
| **Number of Weeks Since Most Recent Injury** |  |
| Mean SD; Range | 17 SD 25; <1-158 |
| **Total Number of Participants/Measure *n(%)*** |  |
| BOT-2 | 104 (100) |
| CB&M | 88 (84.6) |
| modified BESS | 51 (49.0) |
| Sway Balance | 45 (43.3) |

The Hamilton Integrated Research Ethics Board approved all current studies and the collection of data from the acquired brain injury clinic database.

### Procedures

As a part of larger prospective cohort studies evaluating recovery of children after concussion, a cross-sectional balance evaluation of 104 children with concussion was completed at first post-injury assessment. Demographic data, medical history and current injury data were collected through self-report. Time between injury and first post-injury visit varied based on time of recruitment and family availability. The mean assessment time was 17 weeks post-injury (range <1-157 weeks). The four balance measures reviewed and administered were the BOT-2, the modified BESS, the Sway Balance and the CB&M. All four measures were administered by one of four trained research assistants. Inter-rater reliability was completed to ensure a high level of agreement among assessors; Intra-Class Correlation Coefficients (ICC) for total scores were 0.936 for the BOT-2, 0.885 for the modified BESS, and 0.852 for the CB&M. Inter-rater reliability was not completed for the Sway Balance as it is scored through the application software. To minimize potential of practice effects, the order of balance assessments was randomized by participant.

### Measures

#### Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2)

The BOT-2 is a widely used standardized assessment for measuring gross and fine motor skills of children and youth aged 4-21 years.[18] The purpose of the BOT-2 is to screen children who may have motor impairments, to assist in making program adjustments such as readiness to return to activity, and to evaluate motor interventions.[18,24]

This standardized measure with population norms is comprised of four motor area composites containing a total eight subtests, one of which is balance. The purpose of the balance subtest of the BOT-2 is to discriminate which children have balance impairments. The balance subtest is found within the body coordination motor area composite, which encompasses control and coordination of large musculature used in maintaining posture and balance.[18] The balance subtest includes nine tasks, seven of which are timed, that measure trunk stability, and balance abilities with and without vision. Standing on a line and on a balance beam with feet apart, walking forward on a line both with a normal gait and a heel-to-toe gait, standing on a line on one leg, and standing on a balance beam on one leg are all tasks included in the balance subtest. Computerized scoring uses raw point scores that are converted to scaled scores then standard scores.

#### Balance Error Scoring System (BESS)

The BESS was originally designed as a discriminative measure for collegiate athletes, to determine postural stability without the use of excessive equipment.[19,25] The BESS has since been modified and included in the Sport Concussion Assessment Tool, 3rd edition (SCAT3)[26] and the Child SCAT3.[27] The modified BESS is an observer-rated, timed test consisting of three tasks, including a double leg stance, a single leg stance, and a tandem stance. All stances are completed on a firm surface, held for 20 seconds, and are performed with the subject’s eyes closed.[28] A maximum of 30 total errors can be scored across all three trials. In contrast to the BOT-2, where a higher scores is better, a lower score, meaning fewer errors committed in the BESS, represents better postural stability.[28]

#### Sway Balance

The Sway Balance System uses tri-axial accelerometers within a mobile device to measure postural control and stability quantitatively.[29] The aim of the Sway Balance as a disrciminative measure is to replicate force platform quantification in an easily administered, non-invasive, portable manner. The system prompts the subject through a five-item timed protocol and generates a stability score based on postural sway.[29] All items included in the Sway Balance protocol are completed with the subject’s eyes closed and the items are the same stances used in the modified BESS.[21] Completion of the protocol results in an output score based on a 100-point scale.[21] The scoring of the Sway Balance is the opposite of the modified BESS, so a higher score represents less postural sway indicating higher postural stability. The Sway score is an analysis of the deviations of position within the device that mimics body positioning and is determined by undisclosed calculations from Sway Medical.[29]

#### The Community Balance and Mobility Scale (CB&M)

The CB&M was originally created as an outcome assessment for adults with acquired brain injury (ABI) or stroke and aims to assess foundational as well as functional balance, but has since been evaluated for children with acquired brain injury.[23] The purpose of the CB&M as an evaluative measure is to replicate forms of high-level balance used by individuals within the community and associated with activities of daily living[23] and to measure change over time or after intervention. Items in the CB&M involve multitasking, sequencing of movement components and complex motor skills demanding precise movements, coordination and timing.[22]

The CB&M is comprised of 19 balance items, 12 of which are timed. All items in the CB&M use a 6-point rating scale (0-5) with response option descriptors indicating errors in performance.[23] Tasks of the CB&M include a unilateral stance, tandem walking and pivoting, lateral foot scooting, hopping, crouching and walking to pick up an object, walking and looking at a target with and without carrying weights, descending stairs and speeded step-ups.[22]

#### Comparison of the Measures According to CanChild Guideline Criteria

As suggested by the outcome measure guidelines[16] it is important to understand the focus and purpose of the measurement tool to ensure that it is appropriate for the population under study and the ‘job’ it is meant to do. Using the guidelines, evaluation of the focus of the measure is structured using the International Classification of Functioning Disability and Health (ICF) Framework.

Under the ICF, the BOT-2 and the CB&M address the body structures (the brain, ocular system, vestibular, and proprioceptive systems) and functions domain (the physiological and psychological functions of the body) as well as activities (execution of a task) domain. The BOT-2 and the CB&M evaluate neuromuscular and movement related functions including control of voluntary movement, muscle and movement and gait patterns.[16] The reduced number of items in the modified BESS and Sway Balance allow for limited evaluation of the body structure and functions domains. All four tools involve tasks that engage sensori-motor control and biomechanical systems, and, if an individual is unable to complete a task or maintain a position, insight may be provided into where deficits exist. Again, however, the BOT-2 and the CB&M may be better at isolating the specific area of impairment due to the number and type of items involved in each measure.

Balance is a critical component for the ability to participate in meaningful occupations and activities involving movement against gravity. All four measures address mobility by assessing the ability to change and maintain a variety of body positions and the ability to undertake a single task.[16] The CB&M alone addresses a number of components of mobility. The CB&M examines an individual’s ability to undertake multiple tasks, the ability of walking and moving and the ability of carrying, walking and handling objects.[16] Table 2 outlines the criteria of the guidelines and provides a summary of the measurement properties of each measure. Studies that have examined the psychometric properties of each measure can be found in Table 3.

Table 2: Guideline Criteria and Measurement Properties of the BOT-2, modified BESS, Sway Balance and CB&M

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Measure | Primary Purpose | ICF Classification | Norm Reference | Clinical Utility | Standardization |
| BOT-2- balance subtest | * Discriminative | * Body Functions * Activity | * 4-21 years of age[18] | * Completion time: 10-15 minutes * Active Participation of client required and special equipment required | * Published manual for administration, scoring and interpretation |
| Modified BESS | * Discriminative | * Body Functions * Activity | * Healthy individuals, 20-60 years of age.[30] | * Completion time: 2 minutes * Active Participation of client required and special equipment required | * No manual available however administration articles can be found. |
| Sway Balance | * Discriminative | * Body Functions * Activity | * No | * Completion time: 5-10 minutes * Active Participation of client required and special equipment required | * No manual available: after downloading the application administration instructions are given. * A mobile device app using a tri-axial accelerometer to quantify postural sway. |
| CB&M | * Evaluative | * Body Functions * Activity | * Healthy individuals, 20-79 years of age[31] | * Completion time: 20-30 minutes * Active Participation of client and specialized equipment required | * Published manual for administration, scoring and interpretation |

Table 3: Psychometric Properties of the BOT-2, modified BESS, Sway Balance, and CB&M

|  |  |  |  |
| --- | --- | --- | --- |
| Measure | Reliability | Validity | Internal Consistency |
| BOT-2 | * Inter-rater reliability ICC= >.90[18] * Test-retest reliability ICC= >.80[18] | * Content Validity: item generation involved product survey and focus groups. Based on item analysis, the Rasch analysis, the factor analysis and feedback from users items were edited, retained, or removed.[18] | * Using the normal sample: Cronbach’s alpha= >.93 for the total motor composite[18]. |
| BESS | * Inter-rater reliability for total scores ICC= 0.57-0.85\*[19,32,33] * Intra-rater reliability for total scores ICC= 0.60-0.92\*[32-36] * Intra-rater reliability for total scores in youth athletes 9-14 years of age ICC=0.98[38] * Test-retest reliability for total scores in youth athletes 9-14 years of age ICC= 0.70[38] | * Construct Validity: In a healthy adult population there was an adequate correlation between the BESS and age (r=0.36) and a poor correlation between the BESS and height (r=-0.03), weight (r=0.16), and BMI (r=0.23).[37] * Content Validity: Not established for children/adolescents with ABI * Face Validity: Not established | * Not established |
| Sway Balance | * Test-retest reliability for total scores ICC >0.75[39] | * Construct Validity: a significant relationship between Sway Balance and Biodex balance system, r= 0.632, p<0.01[29] and between Sway Balance and BESS, r=-0.767, p<0.01[40] | * Not established |
| CB&M | * Inter-rater reliability for school aged adolescents with acquired brain injury ICC= 0.93 [23] * Inter-rater reliability ICC= 0.898\*[22] * Intra-rater reliability ICC= 0.977\*[22] * Test-retest reliability for school aged adolescents with acquired brain injury ICC=0.90[23] | * Construct Validity: A significant relationship between the CB&M and Activities-specific Balance Confidence Scale, r= 0.60, p<0.001[41]. * Content Validity: Item generation involved traumatic brain injury patients and experienced clinicians.[22] * Face Validity: Items were added or eliminated after item generation discussions based on expert opinion on key concepts of balance and mobility.[22] | * Traumatic brain injury: Cronbach’s alpha= >95\*[22] * School aged children and adolescents with acquired brain injury: Cronbach’s alpha= 0.89[23] |

\*populations did not include children and youth

### Data Analysis

All statistical analyses were completed using Statistical Packages for the Social Sciences (SPSS) version 22. Descriptive statistics, means and standard deviations were calculated for all participants and to characterize reference points for balance impairment in this population according to each measure. Pearson correlation analyses were used to determine the correlations between the BOT-2, the modified BESS, the Sway Balance, and the CB&M. Significance was evaluated at level of *p*<0.05 for all analyses. Sensitivity and specificity were calculated to see the accuracy of the CB&M, modified BESS, and the Sway Balance as compared to the BOT-2 reference standard. Kappa (κ) statistics were also run to examine the ‘true’ agreement beyond chance between measures when determining balance impairments.

As the BOT-2 is the only norm-referenced test for children and youth, it was used as the reference standard comparison for determining below average scores for all of the other measures. A below average score on the BOT-2 is a standardized scale score of 10 or lower (falling below the 17th percentile). Mean scores for the CB&M, the Sway Balance and the modified BESS were analyzed for all children scoring below average on the BOT-2 to give an estimation of which children had a balance problem on each measure as compared to the reference standard BOT-2.

Due to the differing study protocols of the three larger studies used for data collection, the four measurement tools have differing sample size for how many participants received each measure. Every participant received the BOT-2 (*n=104*) and at least one other measure, sometimes all four measures, depending on the associated study protocol*.*

### Results

The results of the administration of the BOT-2 to all 104 children with concussion revealed that 38 children were classified as having below average balance according to the BOT-2. Of these 38, 60% (18) were below the 50th percentile score of the CB&M, while 49% (43) of all the youth tested on CB&M were classified below the 50th percentile. Similarly the modified BESS found 63% (32) of the total sample of youth tested with the BESS had scores below the 50th percentile while 45% (9) were also classified by the BOT-2 as below average. The Sway Balance classified the same percentage (53%) [23] of the total sample and 53% [9] of youth with BOT-2 below average scores. The BOT-2 reference standard statistics and associated scores of each measure are displayed in Table 4.

Table 4: Measure Comparisons between Identified Balance Impairments and Total Sample

|  |  |  |
| --- | --- | --- |
| Variable | Whole Population | BOT-2 Reference-Point Sample |
| **BOT-2** | (n=104) | (n=38) |
| Mean SD; Range | 12.70 SD 4.78; 3-24 | 8.36 SD 3.86; 3-23 |
| Total Possible Score | 24.0 | 24.0 |
| Reference Point | Standard Score categorized as ‘below average’ or ‘well-below average’ | Standard Score categorized as ‘below average’ or ‘well-below average’ |
| Participants below reference *n(%)* | 38(36.5) | 38(100.0) |
| **CB&M** | (n=88) | (n=30) |
| Mean SD; Range | 84.5 SD 8.12; 62-96 | 81.93 SD 9.65; 62-96 |
| Total Possible Score | 96.0 | 96.0 |
| Reference Point | 84.0 | 84.0 |
| Participants below reference *n(%)* | 43(48.9) | 18(60.0) |
| **Modified BESS** | (n=51) | (n=20) |
| Mean SD; Range | 5.3 SD 3.83; 0-13 | 5.95 SD 3.85; 0-13 |
| Total Possible Score | 30 | 30 |
| Cut-Off Score | 6 | 6 |
| Participants below reference *n(%)* | 32(62.7) | 9(45.0) |
| **Sway Balance** | (n=45) | (n=17) |
| Mean SD; Range | 70.26 SD 16.53; 28.32-97.06 | 72.27 SD12.51; 53.51-97.06 |
| Total Possible Score | 100.0 | 100.0 |
| Reference Point | ~72 | ~72 |
| Participants below reference *n(%)* | 23(52.9) | 9(52.9) |

To compare and establish the relationship that existed between measures, bivariate Pearson correlation analyses were run on the total scores of each measure (Table 5). Of the 104 who received the BOT-2, 88 received the CB&M, 51 received the modified BESS and 45 received the Sway Balance. A moderate but statistically significant relationship was found between the BOT-2 and the CB&M (r = 0.517, *p* = 0.003). Significant negative relationships were found between both the BOT-2 and CB&M and the modified BESS (r = -0.588, *p* = 0.006) and (r= - 0.314, *p* = 0.320), respectively. A strong negative relationship was found between the modified BESS and the Sway Balance (r= - 0.630, *p* = 0.007).

The sensitivity and specificity for all measures in relation to the BOT-2 reference standard were calculated. The CB&M has a sensitivity of 60% and a specificity of 77%. The modified BESS has a sensitivity of 45% and a specificity of 61% and the Sway Balance has a sensitivity of 53% and a specificity of 79%. The associated κ statistic of agreement was low for all measures compared to the BOT-2: κ = 0.273 for the modified BESS, κ = 0.028 for the Sway Balance and κ = 0.153 for the CB&M.

Table 5: Correlation Matrix for the Relationship among Balance Assessment Measures in Children Identified as having Balance Impairment (n=38)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Measure *(95% CI)* | BOT-2 | CB&M | Modified BESS | Sway Balance |
| BOT-2 | 1 | .517\*(0.193;0.740) | -.588\*(-0.818;-0.197) | .642\* (0.233;0.858) |
| CB&M |  | 1 | -.314 (-0.752;0.317) | .445(-0.257;0.839) |
| Modified BESS |  |  | 1 | -.630\* (-0.853;-0.214) |
| Sway Balance |  |  |  | 1 |
| \*Significant at the .01 level (2-tailed) | | | | |

## **DISCUSSION**

The overall findings of this study suggest that, based on scores from four measures assessing balance, a substantial number of children present with balance problems after concussive injury. The measures are not all interchangeable, however the modified BESS and the Sway Balance are highly correlated.

The BOT-2 was the only measure that clearly indicated that the child had balance impairment and provided standardized normative values for children. For this reason it was used as a reference standard for the other 3 measures. Using this criterion, when another measure agreed with the BOT-2, this was an indicator of potential validity, in this latter measure, of accurately evaluating true balance impairment in youth post concussive injury. The CB&M showed highest sensitivity (60%) and specificity (77%) with the BOT-2, suggesting that children without balance impairment are more accurately identified by the CB&M. However the CB&M identified 49% of the total sample tested with CB&M as having impaired balance (below 50th percentile) while the BOT-2 only identified 38%. The CB&M was not highly correlated with the BOT-2 (r = 0.517, *p =* 0.003), and kappa agreement (κ = 0.153) beyond chance was low, suggesting it is evaluating another but equally important aspect of balance impairment. The correlation of the BOT-2 with the CB&M is statistically significant, which has been found in similar studies of balance issues in children after concussion.[42]

Similar to the CB&M, the modified BESS found 45% of children were also classified by the BOT-2 as below average, yet 63% of the total sample of children tested with the modified BESS had scores below the 50th percentile. Although the modified BESS is used extensively with children through the SCAT3[26], one must be cautious as research has been completed looking at performance on the modified BESS in children and adolescents with no history of concussion and has shown that mean modified BESS scores are higher in children than scores for adults.[43] The higher scores of the children’s performance suggests that, developmentally children, have more balance limitations and this requires age-specific norms before it can be accurately used as a diagnostic tool in the identification of balance impairment. The low sensitivity of 45% and a specificity of 61% support the opinion that the modified BESS is not ready to be used with children in the identification of balance impairment and interpretation of scores should remain guarded.

The modified BESS and the Sway Balance were strongly correlated with each other (r= -0.630, *p*= 0.007). Both showed a moderate correlation (r = -0.588, *p* = 0.006 and r = -0.642, *p*= 0.005, respectively) and agreement (κ = 0.273 and κ = 0.028, respectively) with the BOT-2 signifying that the same aspects of balance are assessed across all three measures. The Sway Balance did have a moderately high specificity with the BOT-2 of 79% and lower sensitivity of 53%. The moderately high specificities for each measure relates to the measures’ ability to correctly detect children without balance impairments. Like the modified BESS, the Sway Balance has no normative data to interpret impairment in balance scores. However in its favour the Sway Balance is the only objective measure that quantifies postural sway with accelerometry.

The benefit to using the BOT-2 in assessing balance in children/youth with concussion is that it challenges increased levels of anticipatory control and static vestibular-based balance[44] proving to be clinically relevant for the assessment of complex concussive injuries and recovery patterns. And most importantly it has normative data for the identification of children with balance impairment when compared to an aged-based control sample.

Although the modified BESS and the Sway Balance require less time to administer and score in comparison to the BOT-2 and the CB&M, static balance is the only component measured in the modified BESS and Sway Balance and true comprehensive balance assessment should evaluate both static and dynamic balance.[42] The CB&M and BOT-2 can be used together as the CB&M aims to be a useful tool assessing higher order balance and includes items involving multitasking, sequencing of movement components and complex motor skills demanding precise movements, coordination and timing.[22,23,42] The CB&M is an important measure for assessing balance problems in children with concussion, as the tasks are more reflective of activities that children actually participate in. The negative correlation of the BOT-2 and CB&M, yet its moderate sensitivity, suggest that the different components of balance are assessed allowing for more informed clinical recommendations to be made.

When examining a measure’s ability to identify balance and impairment it is important to look first to their measurement properties and include this in the ultimate decision of what is the best measure to assess balance in children with concussive injury. The BOT-2, the CB&M and the modified BESS have all been examined for their test-retest reliability in pediatric populations. The CB&M has specifically been examined for children and youth with acquired brain injury. Both the CB&M and the BOT-2 have strong test-retest reliability values at ICC = 0.90[23] and ICC >0.80[18], respectively. The modified BESS has a test-retest reliability value of ICC = 0.70.[38] Content validity was established for both the BOT-2 and the CB&M for individuals with traumatic brain injury[18,22] however, this has not been established specifically for children and youth with concussion. Construct validity has been established between the Sway Balance and the Biodex Balance System, a computerized balance force plate as well as the modified BESS.[29] Having a moderate significant relationship with the Biodex Balance System is a major strength of the Sway Balance as it is the only measure that objectively quantifies postural sway. The limitation of the Sway Balance is the lack of normative data. The CB&M has been shown to be more sensitive to change in motor abilities and balance when compared to the Gross Motor Function Measure (GMFM)[45]. As longitudinal studies reporting change over time are important in monitoring concussion recovery, the fact that the CB&M is the only measure of the four examined in which responsiveness was reported adds strength to inclusion of CB&M in clinical and research protocols.

The modified BESS stands alone in the need for non-specialized equipment to administer the assessment. The only equipment needed for the modified BESS is a stopwatch. The other three measures all require specialized equipment or procedures, making the modified BESS practical for its common use as a sideline assessment tool. However, due to the increased use of mobile devices the Sway Balance may be quickly recognized as a convenient sideline assessment tool, as the application can be downloaded for free and accounts can be used on multiple devices.

In comparing the reliability and validity of the modified BESS and the Sway Balance, the Sway Balance seems to be a stronger measurement tool as the test-retest reliability is higher than that of the modified BESS. The modified BESS has also been reported to be unreliable with children younger than 10 years of age.[43] Scoring and reporting biases are less likely to occur due to the consistent accelerometry measurements in the mobile device. Due to the similarities of items on the modified BESS and the Sway Balance, the Sway Balance may replace the modified BESS, as the objectively measured accelerometry score is more reliable and sensitive to detecting balance deficits.

A discrepancy between measures identifying balance impairment or not does not mean that one is incorrect; it may simply imply that certain items within measures are more sensitive to detecting different areas of balance impairment than others. For the children whose BOT-2 balance scores did not agree with the CB&M, modified BESS or Sway Balance scores but were still identified as having balance issues on these respective measures, these observations may indicate that these measures detect different types or profiles of balance impairment in children. More in-depth evaluation of the measures on more children will be needed before conclusions can be drawn about whether this is true.

### *Limitations*

This study has a number of limitations. Since this study is a part of larger prospective cohort studies and also used prospectively derived data from a clinical database, convenience sampling occurred potentially leading to the under- or over-representation of specific characteristics of children with concussion. However by including both acute and complex concussive injury an apparently more representative sample of concussive injuries in children is included. A methodological limitation of this study was that there were multiple evaluators increasing the chances of inconsistency when assessing and scoring. As a means of controlling for this, inter-rater reliability was completed for each measure. A further limitation was that as data were included from four sources with slightly differing protocols, not every participant received every measure during their balance assessment, limiting the sample size when comparing all four measures together. Analyses comparing all measures specifically examined only those individuals (n=31) who received all four measures. All children had the reference standard and at least one other measure. One thing that was ensured between studies was that the application of each measure was the same. This nested study only looked at the balance subtest for the BOT-2; it is possible that the other subtests in the BOT-2, addressing similar tasks and functions included in the CB&M may be able to provide further insight into a stronger relationship between the CB&M and the BOT-2.

### *Future Directions*

This study has applied four measures to the specific, specialized population of children and youth with concussion. To replicate this approach with a larger sample of children with equal cells each having all four measures, would increase the information regarding validity of the evaluation of impairment and determine which measures are most helpful clinically. Further investigation of the responsiveness of each measure in this population could determine the validity of each measure for evaluating recovery of balance impairment after concussive injury over time. The comparison of similar individual items across measures could also be evaluated to examine which items are more sensitive for detecting balance issues for both static and dynamic balance.

## **CONCLUSIONS**

Assessing balance is a challenging task that requires evaluating multiple components. Using a single method of assessment may not provide an accurate representation of balance impairment in children and youth after concussion. Based on the comparison of measurement properties and application of each measure to 104 children with concussion, the BOT-2 and the CB&M provide the most comprehensive assessment of balance and postural instability in children with concussive injury. The Sway Balance shows promise in its ability to objectively quantify postural sway and ease of administration.

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# Chapter Three

Title of Paper: Finding Balance: Exploring the Factors Related to Balance Impairment in Children with Concussion

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## **ABSTRACT**

**Objective:** Balance impairment is a commonly reported symptom after concussion. This study explored both injury- and non-injury-related factors that may be associated with balance impairment in children after concussion.

**Methods:** As part of larger prospective cohort studies evaluating recovery of children after concussion, balance data were collected on 104 children using the BOT-2. Correlations, chi-square statistics, and logistic regression were used to examine the associations between balance scores and both injury- and non-injury-related factors.

**Results:** Balance impairments were found in 37% of children (BOT-2 balance scaled score of ≤10). The results of the logistic regression show that the full model using five predictor variables was non-significant. The model explained 6% of the variance in balance impairments and correctly classified 68.3% of cases. Although the variables were found to be not statistically significant, mechanism of injury had a high odds ratio (OR=2.1) suggesting that children with sports-related injury and motor vehicle accidents were more likely to have balance impairment.

**Conclusion:** Balance impairment is an issue in children after concussion. Children with balance impairment show a different symptom profile than children without balance problems, with higher scores in symptoms of headaches, fatigue, feeling slowed down, difficulty in concentrating and visual problems. The tracking and monitoring of balance performance after concussion is an important part of concussion management and is necessary for planning safe return to play and full participation in activity for children and youth.

## **INTRODUCTION**

A number of symptoms can result from a concussion or mild traumatic brain injury (mTBI). One primary symptom of concussion is balance impairment. Balance, simply defined, is the ability to maintain one’s centre of mass over its base1. The assessment of balance after a concussion is important because it is an indicator of functional recovery2. According to Gagnon et al.3-5 a significant number of children after concussion present with some form of postural instability during the first 3 months post-injury and, compared to published norms, have decreased balance performance scores upon evaluation with standardized measures. Similarly, Dahl and Emanuelson (2013)6 found that when compared to non-injured children, children with a concussion had significantly worse balance, yet their results were still in the normal range. The complexities of the human balance system make assessing balance after concussive injury a challenging task. A variety of factors need to be assessed to provide a comprehensive post-concussive evaluation and to inform appropriate clinical decisions. Current clinical evaluations of concussion assess a combination of neurological and cognitive as well as motor functions7. Both injury- and non-injury-related factors may be associated with the presentation of balance impairment after concussive injury in children.

The reporting of pediatric concussive injuries is increasing; between 2003 and 2010, 88,688 concussions were reported in Ontario for emergency department or physicians’ office visits8. Age has been shown to be a significant factor in regard to causes of concussion or mechanism of injury9-13. Sixty-six percent of traumatic brain injuries occur in children and adolescents under 20 years of age9 and 30% of pediatric concussive injuries are sport-related10. Children aged 0-7 years typically present with concussion after a fall or non-sport-related injury11-13. It has also been shown that when testing balance after a concussion, younger children typically make more errors, indicating less postural stability14. Because children and adults may have differing recovery trajectories based on developmental stage and maturation, age is an important factor in regard to children with balance impairments after concussion.

Participation in many of the meaningful physical activities of childhood requires well functioning systems of balance, spatial orientation, stable vision and adequate motor control15. The vestibular and proprioceptive systems are responsible for the sensorimotor and biomechanical controls that process and integrate information through the senses, producing and executing appropriate responses such as coordination7. These systems contribute to a number of functions involved in the maintenance of balance and postural control including the stabilization of the head and gaze, sensing and perceiving motion, muscular control of the eyes, controlling upright posture and sensing linear acceleration16-18.

In the assessment and management of concussion, individuals are commonly asked to self-report symptoms. Symptoms of concussion can be divided into four main domains including cognitive, somatic, sleep-related and emotional mood. Symptoms typically resolve spontaneously, leading to full recovery within seven to ten days post-injury19. However, depending on mechanism of injury, 10-33% of individuals will have symptoms persisting beyond two weeks20,21. Furthermore, since children and adolescents may take longer to recover after concussive injury22 up to 50% of children experience symptoms for longer than one month23 and symptoms can persist longer than 3 months post-injury in up to 30% of children24,25. In a study comparing postural stability in children with mTBI to non-injured children, Gagnon et al. (2004)5 found that a significant number of injured children present some form of balance deficit up to 3 months post injury. Depending on the combination of symptom presentation, physical symptoms such as balance impairment present early in the concussive injury trajectory and resolve earlier, whereas emotional and cognitive symptoms can develop and persist longer than the other symptom domains23. Symptoms of dizziness, headache, sensitivity to light and noise, and troubles with vision including blurred or double vision are all commonly reported and associated with the functions of the vestibular and proprioceptive systems which if experienced, could result in postural instability or balance problems7, 26-28.

The factors of age9-13, gender29-34, mechanism of injury35, site of impact36-38, time since injury2,5,20-23, number of previous injuries39-47, and presentation of other concussive symptoms7,15,23,26-28,48 have all previously been evaluated in varying populations in the hopes of gaining better insight into the specifics of concussive injuries. Very little research has been completed looking at these factors in relation to children between the ages of 5 and 18 who experience balance impairment after concussion.

The purpose of this analysis was to explore the prevalence of balance impairments in children after concussive injury, in order to gain a better understanding of the risk factors associated with developing a balance problem post-concussion. These factors will help to highlight the differences between children who present with balance impairments and those who do not. It was hypothesized that balance impairment would be associated with mechanism of injury and site of impact. It was also hypothesized that presentation of balance impairment would differ by gender and age, with higher rates of balance impairment among younger boys (aged 8-12 years). Lastly, other injury-related factors (number of head injuries, total symptom scores, and time since injury) would increase the likelihood of balance impairment.

## **METHODS**

### *Design*

The data used in this study were collected through three prospective cohort studies currently underway at *CanChild* Centre for Childhood Disability Research and from a prospective clinical database from a pediatric acquired brain injury clinic at a local children’s hospital. Data collection from the three prospective cohort studies occurred from July 2014 through to May 2015. The population of children in this study presented with a spectrum of acute to chronic concussive symptoms. All children/adolescents in the current studies were recruited through the Emergency Department or wards at McMaster Children’s Hospital, through referral by their physician or family health team or through self-referral.

### *Participants*

A child/adolescent was eligible for the study if he/she:

1. was between the ages of 5 and 18 (inclusive),
2. had a confirmed diagnosis of mTBI/concussion by a physician, and
3. had no other significant developmental delays

Participants were excluded from the study if they had a confirmed significant brain injury requiring resuscitation, hospitalization or surgical intervention. Lastly, children were excluded if they had multi-system injuries or were unable to complete balance measures due to pre-existing conditions or co-morbidities.

The Hamilton Integrated Research Ethics Board approved all current studies and the collection of data from the acquired brain injury clinic database.

### *Procedures*

A cross-sectional balance evaluation of 104 children with concussion was completed at the first post-injury visit assessment. Time between injury and first post-injury visit varied depending on time of recruitment and family availability. Demographic information, medical history, and previous and current concussive injury data about the children were obtained by self-report from both the child and the parent. Post-Concussion Symptom Scale (PCSS)32,49 was used to document symptoms and was completed by both the parent and the child. All balance measures and related protocols were administered in a clinical assessment room or in the research building at McMaster University.

After the completion of all study questionnaires, a balance assessment was completed independently by one of four trained research assistants using the balance subtest of the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2)50. Each assessor undertook training through administration, observation and independent scoring of each balance measure. Inter-rater reliability was completed to ensure a high level of agreement among assessors: Intra-Class Correlation Coefficient (ICC) for total balance scores was 0.94 for the BOT-2. The scoring for each measure was followed as described in the procedure manual associated with the measure.

### *Measures*

The PCSS is an efficient and clinically useful self-reported symptom inventory that measures intensity of symptoms on a 7-point Likert scale. The PCSS is comprised of 22 symptoms representing each of the four domains of concussive symptoms: cognitive, emotional/mood, somatic, and sleep-related. In this study, symptoms experienced within the past 48-hours of the PCSS administration are reported.

The BOT-2 is an observer-rated, standardized age- and norm-referenced outcome measure3,6 used for assessing gross and fine motor skills for children ages 4-2150. The purpose of the balance subtest of the BOT-2, using 9 items, 7 of which are timed, is to discriminate which children have balance impairments. These items were designed to measure trunk stability and balance ability with and without vision. Balance abilities are evaluated based on the completion of timed items and the errors that are committed. Observer-rated raw scores are converted to standardized scale scores. Standardized scaled scores below 10, falling below the 17th percentile, are considered below average50.

## **DATA ANALYSIS**

Descriptive statistics were calculated for all participant demographic data. Our sample of 104 children is sufficient to provide a valid model to estimate risk in logistic regression, as Peduzzi et al. (1997)51 suggest that less than ten events per independent variable may not reflect true values. Balance impairment is the primary outcome of the regression model indicated by a below average score (a standardized scale score of 10) on the balance subtest of the BOT-2. Logistic regression was performed to ascertain the effects of non-injury related factors – age and gender – and injury-related factors – mechanism of injury, time since injury, site of impact, total number of previous injuries, and other presenting somatic, cognitive, emotional/mood and sleep-related symptoms – on the likelihood that children with concussions will have balance impairments. The injury- and non-injury-related predictive variables used within the logistic regression model were selected based on past research, our hypotheses, and results from descriptive statistics. The data did not violate the assumption of multi-collinearity and all other assumptions of logistic regression were met.

Children were categorized into the dichotomous categories of balance impairment, yes or no. This categorization was based on the standardized BOT-2 balance subtest score of ≤10   
(≤ 17th percentile), indicating a potential balance impairment, or >10, indicating no balance impairment. Due to the non-normally distributed data, commonly found in brain injury research, Spearman’s Rho statistics were used for correlations among balance impairment and both injury and non-injury related factors. To test for group differences between those who had balance impairments and those who did not, chi-square test statistics were conducted on all of the chosen predictor variables. Significance was evaluated at the level of p<0.05 for all analyses. All statistical analyses were completed using Statistical Packages for the Social Sciences (SPSS) version 22.

## **RESULTS**

The study sample consisted of 104 children aged 8-18 (59 boys and 49 girls) with a mean age of 13 years. Table 1 provides the descriptive characteristics of the study population. Thirty-seven percent of children (N=38) had balance impairment as defined above. Of all of the children, 76 (73%) had sport-related injuries and of those 24 (31%) had balance impairment. Overall more males were involved in the study, however when looking at balance impairment both the male and female groups were similar. There was also a difference between the age groups of children: there were more older children (ages 13-18 years) (64%) than younger children (ages 8-12 years) (36%). The mean assessment time was 17 weeks post-injury (range <1-157 weeks). Most children (63%) had either a frontal or occipital site of impact.

Table 1: Descriptive Characteristics of Study Sample

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Study Sample**  **(n= 104)** | | **BOT-2 ≤10**  **Balance Impairment**  **(n=38)** | **BOT-2 >10**  **No Balance Impairment**  **(n=66)** | **Test Statistic** |
| **Gender *n (%)*** |  | |  |  | χ2=2.14, df= 1, p=0.14 |
| Male | 59 (56.7) | | 18 (47.4) | 41 (62.1) |  |
| Female | 45 (43.3) | | 20 (52.6) | 25 (37.9) |  |
| **Age (years)** |  | |  |  | χ2=0.04, df=1,  p=-0.02 |
| Mean, range | 13.3 (8-17) | | 13.65 (9.6-17.9) | 13.12 (8.3-17.5) |  |
| 8-12 *n(%)* | 37 (35.6) | | 14 (36.8) | 23 (34.8) |  |
| 13-18 *n(%)* | 67 (64.4) | | 24 (63.2) | 43 (65.2) |  |
| **Mechanism of Most Recent Injury n(%)** |  | |  |  | χ2=11.05, df=1,  p = .023 |
| Sports/Recreational Play | 76 (73.1) | | 24 (63.2) | 52 (78.8) |  |
| Hockey/Ringette | 37 (48.1) | | 10 (26.3) | 27 (40.9) |  |
| Football/Rugby | 7 (9.1) | | 2 (5.3) | 5 (7.6) |  |
| Basketball | 5 (6.5) | | 3 (7.9) | 2 (3.0) |  |
| Soccer | 4 (5.2) | | 1 (2.6) | 3 (4.5) |  |
| Cycling | 3 (3.9) | | 0 (0.0) | 3 (4.5) |  |
| Winter Sports | 4 (5.2) | | 2 (5.3) | 2 (3.0) |  |
| Other Sports | 17 (22.1) | | 6 (15.8) | 10 (15.2) |  |
| Non-Sport Related Injury/Non-Sport Related Fall | 19 (18.3) | | 8 (21.1) | 11 (16.7) |  |
| Motor Vehicle Accident | 5 (4.8) | | 5 (13.2) | 0 (0.0) |  |
| Assault | 2 (1.9) | | 1 (2.6) | 1 (1.5) |  |
| Other | 2 (1.9) | | 0 (0.0) | 2 (3.0) |  |
| **Site of Impact *n(%)*** |  | |  |  | χ2=3.7, df=1, p=0.88 |
| Frontal | 34 (32.7) | | 14 (36.8) | 20 (30.3) |  |
| Occipital | 32 (30.8) | | 11 (28.9) | 21 (31.8) |  |
| Right Parietal | 10 (9.6) | | 4 (10.5) | 6 (9.1) |  |
| Left Parietal | 6 (5.8) | | 2 (5.3) | 4 (6.1) |  |
| Right Temporal | 5 (4.8) | | 3 (7.9) | 2 (3.0) |  |
| Left Temporal | 7 (6.7) | | 1 (2.6) | 6 (9.1) |  |
| Neck | 3 (2.9) | | 1 (2.6) | 2 (3.0) |  |
| Indirect Force | 1 (1.0) | | 0 (0.0) | 1 (1.5) |  |
| Other Body Part | 6 (5.8) | | 2 (5.3) | 4 (6.1) |  |
| **Total Number of Head Injuries** |  | |  |  |  |
| Mean SD; Range | 1.86 SD 1.34; 1-9 | | 1.92 SD 1.32; 1-6 | 1.83 SD 1.36; 1-9 | χ2=2.9, df=1, p=0.81 |
| **Number of Weeks at Time of Assessment Since Most Recent Injury** |  | |  |  | F(1,103)=.74, p=0.39 |
| Mean SD; Range | 16.65 SD 24.53;  .29-157.57 | | 13.93 SD 21.83;  .29-90.86 | 18.22 SD 26.00; .57-157.57 |  |
| **Number of Youth Reporting Post-Concussive Symptoms at Time of Assessment *n(%)*** | | |  |  |  |
| Fatigue | | 65 (62.5) | 28 (73.7) | 37 (56.1) |  |
| Headache | | 62 (59.6) | 28 (73.7) | 34 (51.5) |  |
| Difficulty Concentrating | | 59 (56.7) | 26 (68.4) | 33 (50.0) |  |
| Irritability | | 55 (52.9) | 23 (60.5) | 32 (48.5) |  |
| Trouble Falling Asleep | | 44 (42.3) | 19 (50.0) | 25 (37.9) |  |
| Dizziness | | 43 (41.3) | 18 (47.4) | 25 (37.9) |  |
| Sensitivity to Light | | 43 (41.3) | 21 (55.3) | 22 (33.3) |  |
| Drowsiness | | 42 (40.4) | 19 (50.0) | 23 (34.8) |  |
| Sensitivity to Noise | | 41 (39.4) | 17 (44.7) | 24 (36.4) |  |
| Difficulty Remembering | | 39 (37.5) | 15 (39.5) | 23 (34.8) |  |
| Feeling Slowed Down | | 38 (36.5) | 20 (52.6) | 18 (27.3) |  |
| Feeling Mentally Foggy | | 36 (34.6) | 16 (42.1) | 20 (30.3) |  |
| Balance Problems | | 35 (33.7) | 17 (44.7) | 18 (27.2) |  |
| Feeling More Emotional | | 31 (29.8) | 11 (28.9) | 20 (30.3) |  |
| Sleeping Less Than Usual | | 27 (26.0) | 8 (21.1) | 19 (28.8) |  |
| Sadness | | 26 (25.0) | 13 (34.2) | 13 (19.7) |  |
| Nausea | | 25 (24.0) | 12 (31.6) | 20 (30.3) |  |
| Visual Problems | | 25 (24.0) | 14 (36.8) | 11 (16.7) |  |
| Sleeping More Than Usual | | 21 (20.2) | 11 (28.9) | 10 (15.2) |  |
| Numbness or Tingling | | 7 (6.7) | 4 (10.5) | 3 (4.5) |  |
| Vomiting | | 2 (1.90) | 2 (5.3) | 0 (0.0) |  |
|  | |  |  |  |  |
| Mean Number of Symptoms Reported Per Person | | 7.70 SD 5.74; range 0-20 | 9.42 SD 5.46; range 0-20 | 6.71 SD 5.69; range 0-19 |  |

### *Logistic Regression*

The full logistic regression model, using the five independent variables of age, gender, mechanism of injury, number of injuries, and site of impact, was found to be not statistically significant, χ2(5) = 4.9, p = 0.42. The model explained 6% of the variance in balance impairments and correctly classified 68.3% of cases. Goodness of fit was evaluated using the Hosmer and Lemeshow test χ2(8) = 4.13, p<0.845 which suggested the model fits the data well. Of the five predictor variables, the Wald criterion demonstrated that none was statistically significant. Table 2 presents the logistic regression model including standardized coefficient Beta, Wald statistic, significance, odds ratios and 95% confidence intervals for each variable. Although the variables were found to be not statistically significant, many had moderate odds, ratios, suggesting that children with these variables were more likely to have balance impairment. Statistical significance of these variables may be influenced by sample size, increasing the chances of a type II error. Age and site of impact, each with an odds ratio of 1.1 and 95% CI [.447,2.577 and 0.783, 1.437] respectively , show a weak association with the development of balance problems. However mechanism of injury, with an odds ratio of 2.1 and 95% CI [0.810, 5.027], indicates a stronger association meaning that those with sports-related injuries are twice as likely to have balance impairment as those with a non-sports related injury.

Table 2: Logistic Regression Predicting Likelihood of Balance Impairment following a Concussion

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | | | | | | | | | | |
|  | B | | S.E. | | Wald | | df | | Sig. | Exp(B) | | 95% C.I.for EXP(B) | | | | |
|  |  | |  | |  | |  | | |  | | Lower | Upper | |
| Age Category | .071 | | .447 | | .025 | | 1 | | .875 | 1.073 | | .447 | | | 2.577 | |
| Sex | -.590 | | .425 | | 1.922 | | 1 | | .166 | .554 | | .241 | | | 1.276 | |
| Mechanism of Injury, sports related versus all other categories | .702 | | .466 | | 2.270 | | 1 | | .132 | 2.017 | | .810 | | | 5.027 | |
| Number of Injuries | -.153 | | .443 | | .120 | | 1 | | .729 | .858 | | .360 | | | 2.044 | |
| Site of impact: frontal and occipital versus rest | .059 | | .155 | | .145 | | 1 | | .703 | 1.061 | | .783 | | | 1.437 | |
| Constant | -.510 | | .473 | | 1.159 | | 1 | | .282 | .601 | |  | | |  | |

### *Injury Related Factors*

Chi-square and ANOVA analyses showed no significant differences in type of sport-related injury (χ2 = 8.4, df = 1, *p* = 0.39), site of impact (χ2 = 3.7, df = 1, *p* =0.88), time since injury (F(1,103) =.74, *p* = 0.39), and number of injuries (χ2 = 2.9, df = 1, *p* = 0.81) for children with balance impairment versus children without balance-impairment.

#### Mechanism of Injury

Mechanism of injury results (sports-related and non-sports-related including, slips, trips and falls, motor vehicle accidents, and assault) suggested a statistically significant association, (χ2=11.05, *p* = 0.023, Cramer’s V = .33, *p* = 0.03). Thirty-two percent of children with sports-related injury and 42% with non-sport-related injury had balance impairment. All children who had a motor vehicle accident demonstrated balance impairment.

#### Other Self-Reported Presenting Symptoms

A one-way between-subjects ANOVA was conducted to compare the relationship of other self-reported presenting symptoms on children with and without balance impairment. There was a significant effect of headache [F(2, 103) = 4.9, *p* = 0.03], balance problems [F(2, 103) = 10, *p* = 0.002], fatigue [F(2, 103) = 5.16, *p* = 0.02], feeling slowed down [F(2, 103) = 8, *p* = 0.02], difficulty concentrating [F(2, 103) = 4.86, *p* = 0.03], and visual problems [F(2, 103) = 5.2, *p* = 0.02]. No other presenting symptoms were significant. For the symptoms that were significantly different for children with and without balance impairment, the means show children with balance impairment scored consistently higher than children without balance impairments (table 3). Correlational analyses using Spearman’s rho between self-reported balance problems on the PCSS and all other self-reported symptoms showed positive associations (table 4). The symptoms of headache, dizziness, feeling slowed down, fatigue, difficulty remembering, difficulty concentrating, and sensitivity to light and noise all presented with moderate to strong associations.

Table 3: Means of Other Self-Reported Presenting Symptoms

|  |  |  |  |
| --- | --- | --- | --- |
|  | Mean (SD) | | Test Statistic |
| Symptom | No Balance Impairment | Balance Impairment |  |
| Headache | 1.41(1.73) | 2.24(2.01) | [F(2, 103) = 4.9, p = 0.03] |
| Nausea | 0.42(.98) | 0.74(1.45) |  |
| Vomiting | 0.00(.00) | 0.13(.58) |  |
| Balance | 0.48(.92) | 1.32(1.76) | [F(2, 103) = 10, p = 0.002] |
| Dizziness | 0.80(1.23) | 1.21(1.65) |  |
| Fatigue | 1.42(1.65) | 2.21(1.79) | [F(2, 103) = 5.2, p = 0.02] |
| Trouble Falling Asleep | 1.03(1.63) | 1.47(1.86) |  |
| Sleeping More | 0.39(1.04) | 0.71(1.35) |  |
| Sleeping Less | 0.65(1.25) | 0.74(1.61) |  |
| Drowsiness | 0.76(1.22) | 1.32(1.69) |  |
| Sensitivity to Light | 0.89(1.51) | 1.37(1.58) |  |
| Sensitivity to Noise | 0.97(1.56) | 1.29(1.77) |  |
| Irritability | 1.24(1.60) | 1.61(1.82) |  |
| Sadness | 0.52(1.24) | 0.84(1.37) |  |
| Nervousness | 0.53(1.03) | 0.87(1.34) |  |
| Feeling More Emotional | 0.70(1.34) | 0.79(1.44) |  |
| Numbness/Tingling | 0.14(.63) | 0.26(1.03) |  |
| Feeling Slowed Down | 0.53(.98) | 1.11(1.43) | [F(2, 103) = 8, p = 0.02] |
| Mentally Foggy | 0.76(1.36) | 1.24(1.78) |  |
| Concentrating | 1.24(1.58) | 2.03(2.01) | [F(2, 103) = 4.9, p = 0.03] |
| Remembering | 0.92(1.52) | 1.18(1.86) |  |
| Visual Problems | 0.30(.76) | 0.74(1.18) | [F(2, 103) = 5.2, p = 0.02] |

Table 4: Correlation Matrix for Self-Reported Balance Problems

and Other Presenting Symptoms

|  |  |
| --- | --- |
|  | |
|  | Balance Problems |
| Headache | .576\*\* |
| Nausea | .332\*\* |
| Vomiting | .166 |
| Dizziness | .624\*\* |
| Fatigue | .504\*\* |
| Trouble Falling Asleep | .447\*\* |
| Sleeping More Than Usual | .349\*\* |
| Sleeping Less Than Usual | .294\*\* |
| Drowsiness | .472\*\* |
| Sensitivity to Light | .507\*\* |
| Sensitivity to Noise | .579\*\* |
| Irritability | .418\*\* |
| Sadness | .196\* |
| Nervousness | .278\*\* |
| Feeling More Emotional | .239\* |
| Numbness or Tingling | .281\*\* |
| Feeling Slowed Down | .652\*\* |
| Mentally Foggy | .724\*\* |
| Difficulty Concentrating | .633\*\* |
| Difficulty Remembering | .524\*\* |
| Visual Problems | .335\*\* |
| \*Correlation is significant at the 0.05 level (2-tailed)  \*\* Correlation is significant at the 0.01 level (2-tailed) | |

### *Non-Injury Related Factors*

Comparing children who were classified as having balance impairment to those without balance impairment (Chi-Square analysis), there were no significant differences in regard to gender of the child (χ2 = 2.14, df = 1, *p* = 0.14). A significant difference did, however, exist between age and the presentation of balance impairment (χ2 = 0.04, df = 1, *p* =-0.02). Older children ages 13-18 years experienced balanced impairments more frequently after concussive injury than younger children (ages 8-12 years).

## **DISCUSSION**

The purpose of this study was to explore and gain a better understanding of factors associated with balance impairments in children with concussion. Balance impairments were found in 37% of the children after concussive injury using a standardized population-based norm-reference standard for balance impairment in children and youth as compared to 33% on the self-report balance symptom score. This prevalence of 37% is similar to other studies that examine balance impairments in children after mild traumatic brain injury. Gagnon et al. (1998)3 found that 40% of children presented with ‘below average’ standard scores for the balance subtest of the BOT-2 up to three months post-injury. No significant predictive factors related to balance impairments were found. The odds ratio of mechanism of injury suggests that children with sports-related injury (OR=2.1, 95% CI [0.810, 5.027]) were more likely to have balance impairment but this was the most common mechanism (73%) in this sample. Children who present with balance impairment post-concussion show significantly different profiles with higher scores on symptoms of headaches, fatigue, feeling slowed down, having difficulty concentrating and remembering, and experiencing visual problems compared to children without balance impairments. The symptoms of feeling mentally foggy (r = 0.72, *p*<0.001), feeling slowed down (r = 0.65, *p*<0.001), having difficulty concentrating (r = 0.63, *p*<0.001) and dizziness (r = 0.62, *p*<0.001) were highly correlated with self-reported balance problems.

The association between balance impairments and visual problems, dizziness, and headache has been found in similar studies examining vestibular function after sport-related concussion15,48. Kontos et al. (2012)48 found that when examining balance impairment in a factor analysis post-concussion, balance problems loaded across multiple factors, suggesting that balance impairment was associated with the presence of other symptoms related to the vestibular and proprioceptive systems. Previous research in sport-related concussion in adult populations has shown dizziness, headache, sensitivity to light and noise, and troubles with vision to be associated with balance impairment7,28. Headache, fatigue, feeling slowed down, difficulty concentrating, and visual problems were all significant when examining children who presented with balance impairment compared to those who did not. The correlation between the self-reporting of balance problems and dizziness (r = 0.62, *p*<0.001), difficulty concentrating (r = 0.63, *p*<0.001), mental fogginess (r = 0.72, *p*<0.001) and headache (r = 0.58, *p*<0.001) also makes biological sense considering the inter-relatedness of functioning for the vestibular, motor and visual systems7,15,17,23,26-28. Identifying balance problems and the related somatic and physical symptoms of the PCSS may help with a more comprehensive assessment including all potentially affected systems and the overall clinical management of concussion recovery26,28. More targeted assessment and intervention can help guide the safe return to participation in activity including contact sports18,28.

The BOT-2 identified both the children who reported they felt they had a balance problem on the PCSS and children who reported they did not have a balance problem. According to the BOT-2 standardized scores for below-average balance, 38 (37%) children in the sample population had balance impairment. An interesting observation was that 35 (34%) children reported they felt they had balance problems on the PCSS. Of these children, 17 had below average BOT-2 scale scores of ≤10 indicating balance impairment and 18 with BOT-2 scores >10 indicating they did not have a problem. This reflects that some children may feel that their balance has worsened post-injury and that the measure is not capturing this phenomenon. It is important to consider the child’s perceived balance abilities or feelings of unsteadiness during activities to ensure that the child is returned to activity safely. A difference between the BOT-2 identification of a balance problem and a perceived balance problem could be explained by the subjective nature of self-reported symptom checklists and symptoms may be under- or over-reported52,53.

Age significantly differentiated between children who had balance impairment and those who did not (*p*=-0.02). Balance abilities have been shown to increase with age in non-injured primary school children54 and when comparing high-school athletes to collegiate-level athletes55. In our results children aged 13-18 years had a higher percentage (63.2%) of balance impairment compared to younger children ages 8-12 years (36.8%). Balance impairments may be more difficult to identify in younger children as expectations of performance are lower developmentally and test items are the same for all ages. Balance impairments may be easier to identify in older children due to the items in each measure, which may be more able to capture the different aspects and range of performance of balance in older populations.

Other factors frequently associated with concussive injuries, including gender29-34, site of impact36-38, mechanism of injury35 and history of multiple concussions,39-47 had no significant relationship with balance impairment in this study. It is interesting that gender did not show a significant relationship with balance impairment in concussed children in our sample. When examining a population of primary school-aged children without mTBI it was found that boys showed greater postural instability and made more errors than girls on static balance tasks54. In contrast the results of the present study identified that more girls had balance impairments than boys, however this was not found to be statistically significant.

The most commonly reported mechanism of injury in this study was sport-related injury, involving 76 (73%) children. Twenty four (63%) of the 38 children who were classified by the BOT-2 as having balance impairment had a sport-related injury. No significant association was shown between type of sport for sport-related injury between children with and without balance impairment. Five (4.8%) of the children received their injury from motor vehicle accidents (MVA) and all had balance impairment. The fact that all of the children with injuries resulting from a MVA had balance impairments is not surprising as these are typically more serious injuries.

Evidence has shown that a history of multiple concussions significantly increases ratings on symptom scales when compared to individuals with no previous injuries, including balance impairment47. The existing literature does not report on the effects of multiple concussions on children, only on adult athlete populations. The data of the current study did not reflect an effect of multiple concussions on balance impairment in children post-injury.

This research presents many interesting results that require further exploration. Age, mechanism of injury and site of impact may, upon further investigation, be key factors in predicting which children will present with balance impairment, post-concussion. Age may be a key factor due to developmental stage of the child; it has been shown that balance abilities increase with age in school-aged children54. Mechanism of injury may be a key factor because different mechanisms produce different levels of impact35. Finally, site of impact may also be a key factor as different areas of the brain have differing roles and functions for which they are responsible. As balance is a commonly reported symptom of concussion, balance assessment should remain as an important part of the systematic clinical evaluation for concussive injury. Identifying balance impairment can provide important clinical information to guide intervention and return to safe activity.

### *Limitations*

This study has several limitations. Sample size is a major limitation as the total number of children with balance impairments was moderate, potentially influencing the power of the regression model to detect significance. Some categories within the factors had too few data points. Site of impact was one such variable; the majority of children had frontal and occipital injuries influencing the model. A low sample size also limits the generalizability of the study and may have resulted in a type II error in the model, missing a true difference due to lack of statistical power. However due to the nature of recruitment, participants came from three larger prospective cohort studies and a clinical database, allowing for a spectrum of acute and complex concussive injuries to be examined, providing a more representative sample of concussive injuries in children. The variety of participants did, however, include differing injury and assessment time frames for each child, creating an inability to standardize the time when balance assessments occurred. The cross-sectional nature of this study also means the differing assessment times may potentially influence the presentation of balance impairment and create the inability to follow the development, consistency, and disappearance of balance impairment after concussive injury. Lack of baseline testing is a limitation to this study, as it cannot be concluded that children had a balance impairment based solely as a result of their concussive injury. Although the BOT-2 is a standardized norm-referenced measurement tool specifically for children a limitation is introduced due to the subjective observer-rated nature of the tool; however, the inter-rater reliability for total balance scores was high with an ICC of 0.94.

### *Future Directions*

More research needs to be undertaken concerning the effects of balance impairments in children with concussion. Future studies should consider longitudinal methodologies when examining the factors associated with balance impairment in children with concussion to explore the presentation, the duration and the resolution of the balance impairment. Similarly, consistent standardized assessment time points should also be included in future study designs. As age has been showed to be a significant factor between children with balance impairment and those without, collecting more data for a younger age group would provide further insight into the developmental differences of multiple age groups in children, as similar research has been completed for differing age intervals for adults and other specialized populations.

## **CONCLUSIONS**

Inthis exploratory study examining balance impairment in children after concussion 37% of children had balance impairment (perhaps more if self-report is considered), contributing to the evidence that balance is significantly affected after concussion for many children and youth. Age, mechanism of injury and site of impact may be influential in the development of balance impairment. Children with balance impairment show a different symptom profile than children without balance problems, with higher scores in symptoms of headaches, fatigue, feeling slowed down, difficulty in concentrating and visual problems. The tracking and monitoring of balance performance after concussion is an important part of concussion management and necessary for planning safe return to play and full participation in activity for children and youth.

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# Chapter Four: Discussion and Conclusion

As determined in the preceding chapters and seen in past literature, balance impairment is a common symptom after concussive injury and if left unidentified, can lead to longer recovery, hindrance of return to participation and potential longer-term consequences such as anxiety and depression (Gagnon et al., 1998; 2015; Dahl & Emanuelson, 2013; Guskiewicz, 2007; Wade et al., 1997). Assessment of balance is an important aspect of clinical evaluation as it is an indicator of functional recovery and can aid in the identification of impairments in the neurological system (Gagnon et al., 2015). The purpose of this thesis was first to gain a better understanding of the existing tools for measuring balance in children and second, to explore what factors may be associated with balance impairment in children and youth after concussion.

As a part of larger prospective cohort studies evaluating recovery of children after concussion, a cross-sectional study was conducted to review and evaluate four commonly used balance measures and to provide recommendations for the best methods of clinical evaluation of balance in children with concussion based on this evaluation.

The balance results of 104 children and youth were analyzed to explore injury-related and non-injury-related factors to determine whether any factors were predictive of balance impairments after concussive injury. Further analyses were completed to examine the differences between children who presented with balance impairments and those who did not. The results from the comparison of balance measures add to the existing literature surrounding the strengths and limitations of each measure when specifically applied to this population. The analyses of predictive factors and differences between groups of children provide new information related to the prevalence of balance impairment in children after concussive injury, post concussive symptoms associated with balance impairment, and profiles of children who develop balance problems post concussion and those who do not.

In Chapter Two, four measures, the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2), the Modified Balance Error Scoring System (BESS), the Sway Balance System and the Community Balance and Mobility Scale (CB&M), were reviewed and evaluated based on the measurement properties of each and the ability to detect balance impairments in children with concussion. The BOT-2 was specifically developed for use with children, as its purpose is to evaluate and characterize motor performance through the measurement of fine and gross motor skills (Bruininks & Bruininks, 2005). It was used as the reference standard as it was the only measure that provided norm-referenced values for children, thus being able to indicate, based on standard scores that a child does or does not have balance impairment. Because of these strengths the BOT-2 was found to be the strongest measure for evaluating balance impairment. The CB&M has also been specifically evaluated in children with mTBI as a measure of change over time that requires minimal equipment, is freely available, takes approximately 30 minutes to complete but lacks normative data. Although the CB&M was not strongly correlated with the BOT-2, there was a statistically significant relationship (ICC=0.392, p<0.001). The low strength of the correlation suggests that each measure evaluates different aspects of balance. If used together, these measures may provide a more informed, descriptive assessment of where balance impairments exist. The BESS is a popular sideline assessment tool, requiring very little equipment, and is easily administered and scored to aid in the return-to-activity decision making after concussive injury. This measure, however, only assesses static balance and has been developed for use with older populations with concussions, so normative data for pediatrics have not yet been established. Similar to the BESS, the Sway Balance application is easily administered, but lacks normative data and only measures static balance. However the Sway Balance was the only measure that objectively quantified postural sway through accelerometry. When examining the measurement properties of both the BESS and the Sway Balance, the Sway Balance is a stronger measurement tool as it is more reliable in detecting balance deficits.

In Chapter Three, a prospective cohort of children was examined to identify who presented with balance impairments and who did not. An exploratory analysis was conducted of both injury and non-injury factors to examine the association between balance impairment and these factors. The prevalence of balance impairment (37%) in this cross sectional balance evaluation was similar to other studies evaluating balance impairment in children after mTBI. Gagnon et al. (1998) found 40% of children had ‘below average’ scores on the balance subtest of the BOT-2 up to 3-months post-injury.

The logistic regression model using the dichotomous outcome variable of balance impairment – yes or no – included five predictor variables: age, gender, mechanism of injury, site of impact and number of injuries. Although none of the variables in the model was significant, the univariate odds ratios for mechanism of injury and site of impact provide interesting results. Children with sports-related injuries were 2.1times more likely to present with balance impairment than children with non-sport related injuries. Sport-related injuries occur quite frequently in the pediatric population and tend to result in increased impact hits compared to a non-sport related injury such as a fall (Kirkwood, Yeates & Wilson, 2006).

Chi-square analyses were completed to examine whether differences existed between children with balance impairments and those without. The age of the child may be a key factor for predicting children who present with balance impairment compared to those who do not, as children within our population between the ages of 13-18 years were more likely than children ages 8-12 to experience balance impairment. Age may be an important factor due to the developmental stage of the child as it has been shown that balance abilities increase with age in school-aged children (Mickle, Munro, & Steele, 2011). As our results differ from what has been found previously in non-injured children, further research needs to be completed examining the relationship between age and injured children. Mechanism of injury and site of impact were also shown to be significant factors that differed between the balance impaired and non-impaired group. Mechanism of injury may be a key factor because different mechanisms produce different levels of impact (Dick, 2009). Finally, site of impact may also be a key factor as the different areas of the brain have different functions. It is interesting that in our study population gender differences were not found to be significant, as previous research has shown that boys demonstrated greater postural instability and made more errors than girls on static balance tasks in non-injured primary school aged children (Mickle, Munro, & Steele, 2011). While some of the factors that may be related to the presentation of balance impairment in children after concussion are emerging, the causal mechanism of balance impairment post-injury remains unknown.

Children with balance impairment show a different symptom profile than children without balance problems, with higher scores in symptoms of headaches, fatigue, feeling slowed down, difficulty in concentrating and visual problems. Studies have shown that postural stability and balance impairment can be a result of the presence of other symptoms associated with the functions of the vestibular and proprioceptive systems such as dizziness, headache, sensitivity to light and noise, and troubles with vision including blurred or double vision (Greenwald et al., 2001; Campbell & Parry, 2005; Guskiewicz, Ross & Marshall, 2001; Guskiewicz, 2011). Balance problems can be related to the presence of vestibular and somatic symptoms or can be present as a symptom on their own. A good clinical post-injury assessment should include an examination of all of these areas for a complete picture of the concussive injury. This comprehensive assessment with targeted interventions may better guide the safe return to participation in activity including contact sport for children and youth.

## **Implications for Clinical Practice**

As balance problems in children and youth post-concussion are both common and debilitating, they must be given serious attention. Clinicians, parents, coaches and the children themselves must all do their part in detecting and managing deficiencies in balance, which is the prerequisite to proper and safe function while moving against gravity through one’s environment.

This work emphasizes the importance of including balance assessment in the clinical evaluation of children with concussion because it provides insight into the bi-directional relationship between the limitations of activities and restrictions in participation that may result from the presentation of post-concussive symptoms such as balance impairment. Drawing on a key concept from the Dynamic Systems Theory, the learning or re-learning of specific motor skills such as balance is encouraged through specific environmental context and considers the meaning of the task. Using a measure that is appropriate for children and youth provides valid information and adds to the clinical value by involving tasks that are reflective of activities in which children participate. Participation in meaningful physical activities of childhood requires well-functioning systems of balance, spatial orientation and adequate motor control (Valovich-McLeod & Hale, 2015).

Having the ability validly to identify and improve balance impairment resulting from neurological damage in a child after concussive injury is the first step. Only then can an informed balance intervention be implemented that may contribute to improving functional performance, preventing further injury, and increasing meaningful participation through a safer and quicker return to activity (Gagnon et al., 2004). Identifying balance impairment and monitoring the recovery process acts as a prevention strategy for further injury during the vulnerable healing time. Including balance assessment in a multi-factorial approach incorporating physical, neurological and neuropsychological assessments may aid in the identification of the full effects of the concussive injury and in the optimal strategies for safe return to activity decisions (Guskiewicz et al., 2007; Gagnon et al., 2015). Recovery and expectations surrounding occupational participation need to be more conservative for children because of the dynamic periods of development experienced in childhood (DeMatteo et al., 2015). It is this need for conservative management that highlights the importance of using population appropriate measures.

Using theoretical and research evidence as a guide, the case for paying close attention to balance performance is strongly supported. This study was completed to try to enhance the current research surrounding balance impairment specifically in children after concussive injury by identifying the best way to detect and measure such impairment. Without measurement tools that properly detect balance impairment there is an inability to create an appropriate treatment plans, preventing or prolonging return to participation, and potentially prevent further injuries. Without considering the other factors that may be associated with or may play a key role in the presentation of balance impairment and using appropriate measurement tools the complete concussive injury puzzle cannot be unraveled.

## **CONCLUSION**

The goal of this research was to identify and understand the factors that are associated with balance impairment in children with concussion. This thesis adds to the growing literature that balance impairment is a significant issue in the pediatric population and emphasizes the importance of tracking and monitoring balance performance in the clinical evaluation of concussion. Using population-appropriate measures that accurately determine if the child has significant balance impairment is imperative. The BOT-2 was the only measure for children that can do this. Balance evaluation should include both static and dynamic evaluation. Although there are no clear predictors of balance performance, symptoms of dizziness, headache, fatigue, feeling slowed down, difficulty in concentrating and visual problems are clearly associated with balance problems. The profile including increased age, sport or MVA injury and impact to front or back of the head seems to distinguish children who have balance impairments from those who do not. Comprehensive evaluation and monitoring of balance in a child post concussive injury can contribute to a well-informed treatment plan for safe return to play and full participation in activity for children and youth and possibly the prevention of another injury.

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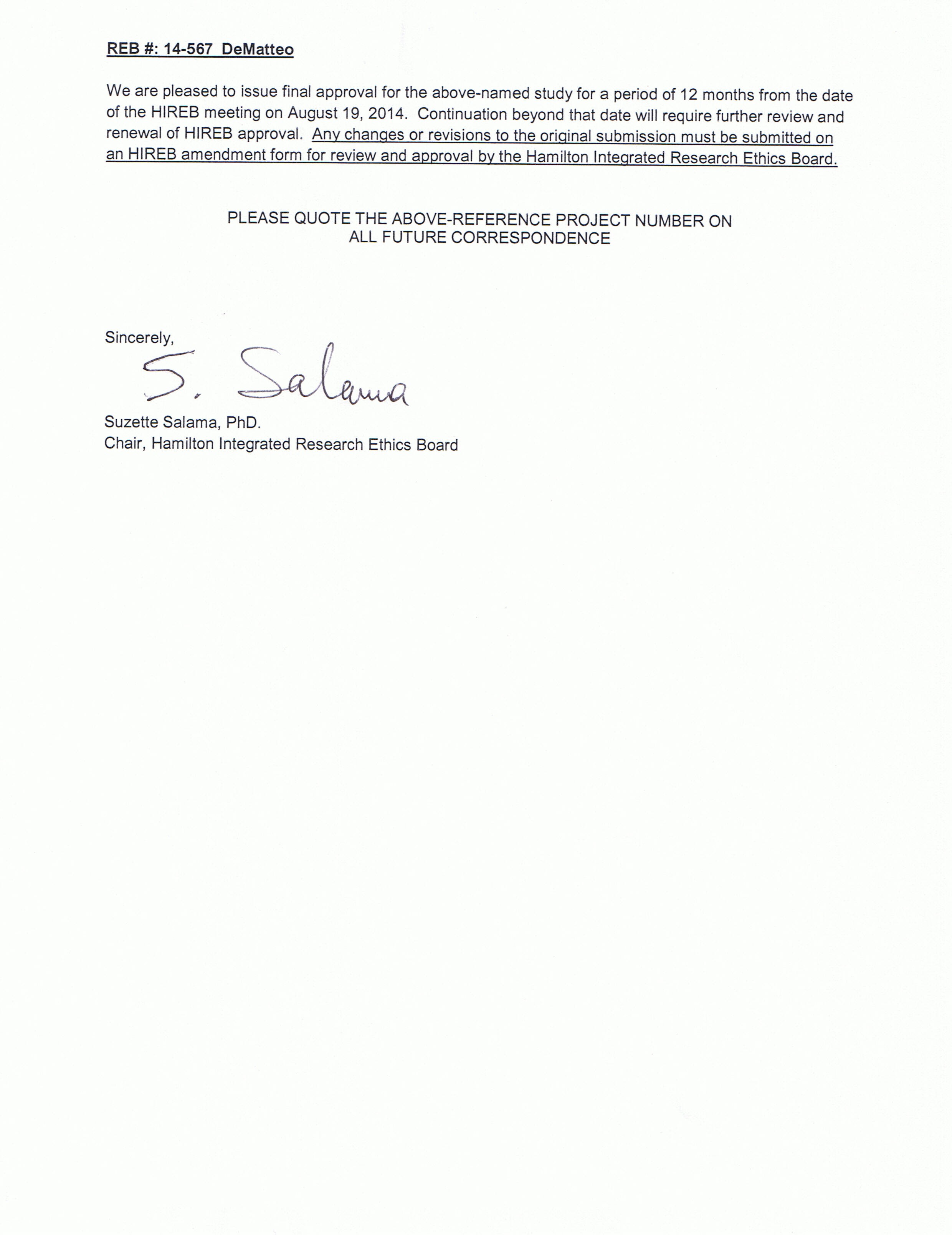
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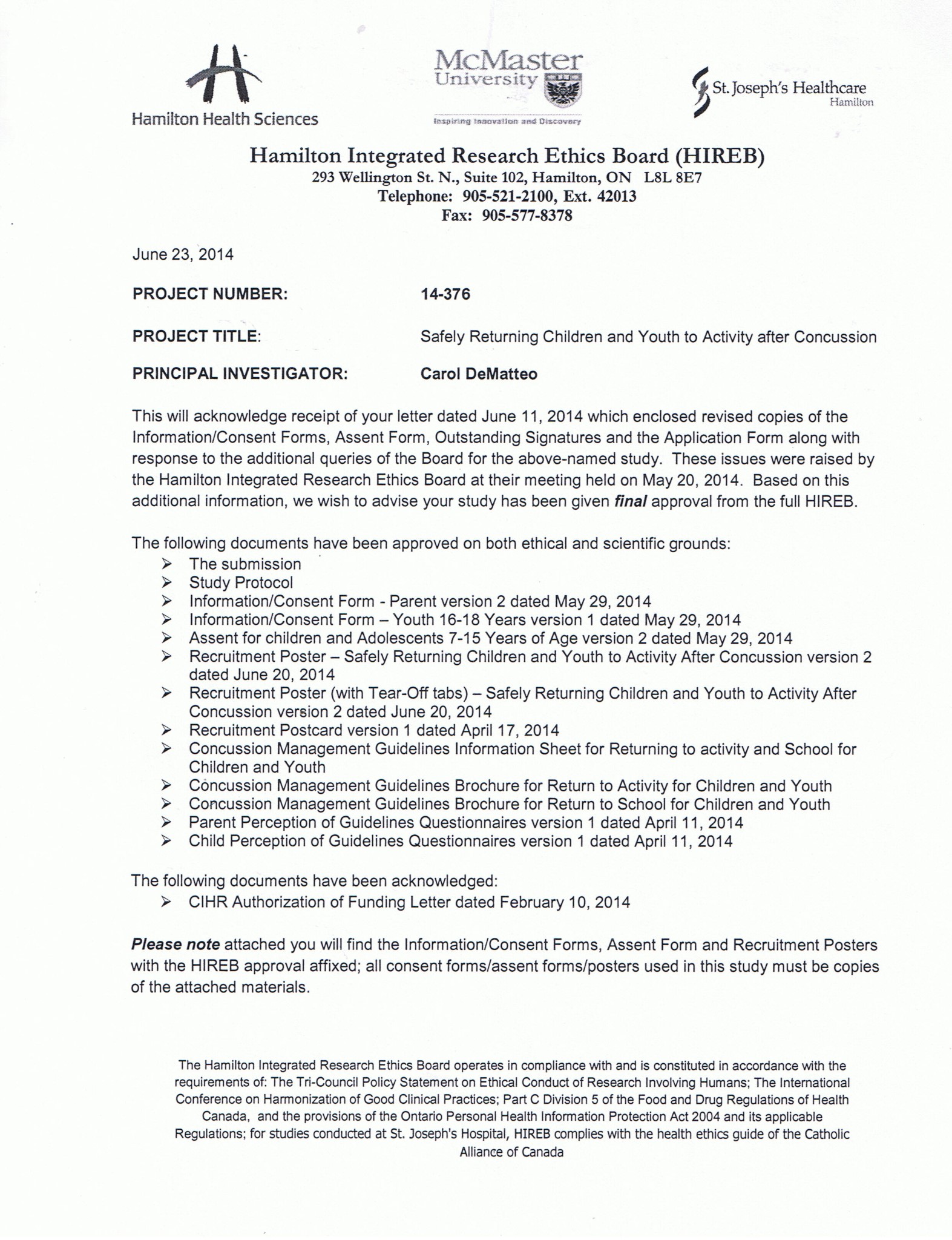
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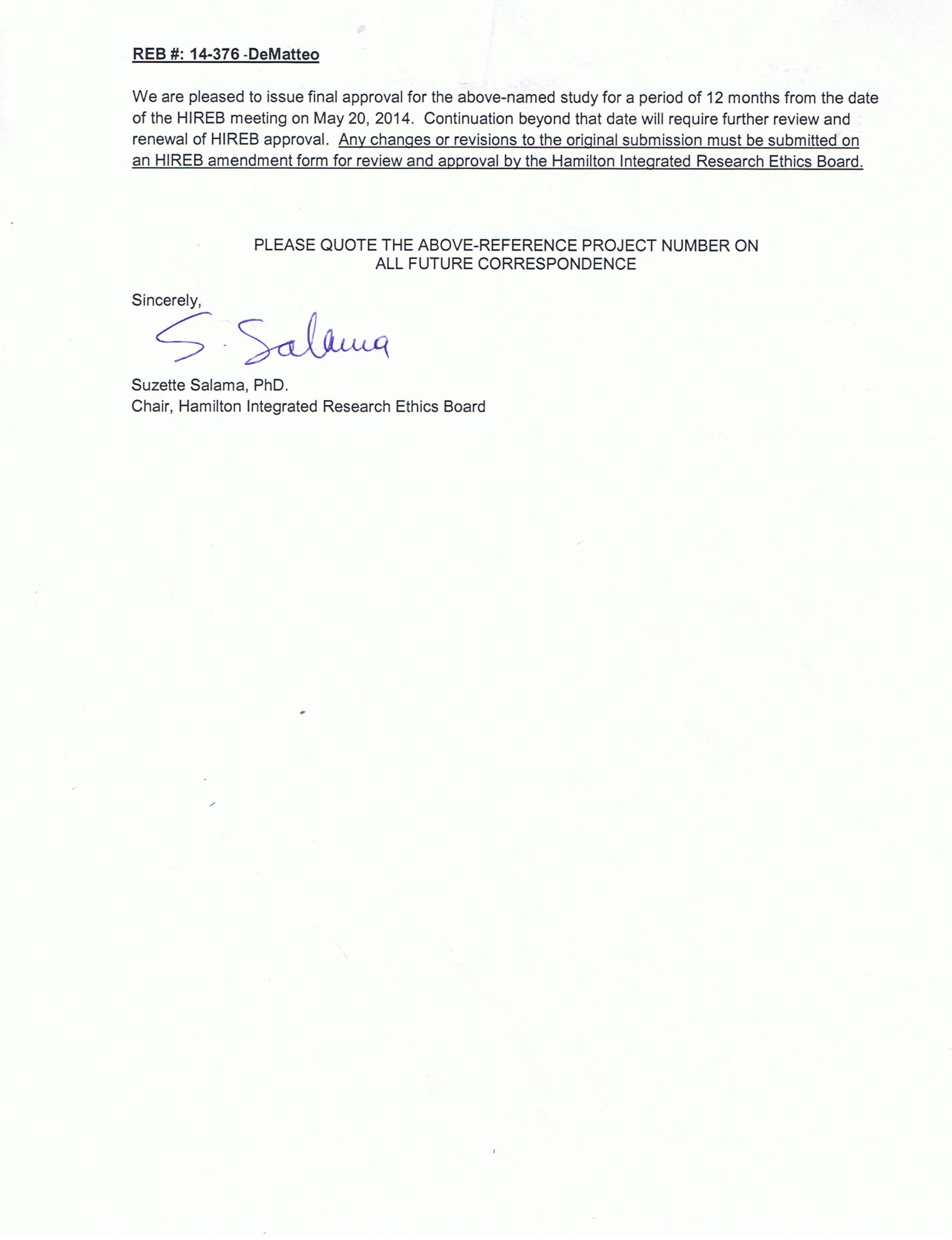
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# Appendix A: Ethics Approval Letters









Date: May 24, 2013

To: Carol DeMatteo

Associate Clinical Professor

From: Mary Bedek

Director, Privacy & Freedom of Information

HHS

Cc: Tina Arnosti, REB Office

**Re: Research Ethics Board Application**

**13-307-D - Acquired Brain Injury (ABI) Clinical Database**

**Final Approval**

Dear Carol DeMatteo:

The above application for Creation of a Research Database has been reviewed by the REB Chair and the Chief Privacy Officer and has received Final Approval. The Privacy and Freedom of Information office does not notify co-applicants of the decision taken, we ask that you please inform those individuals involved of the outcome of this application.

Once you have the chart identifiers, please submit the listing to Helen Heimbecker, Coordinator, Health Records. If you require access to the patient’s health record, you may contact Helen as well.

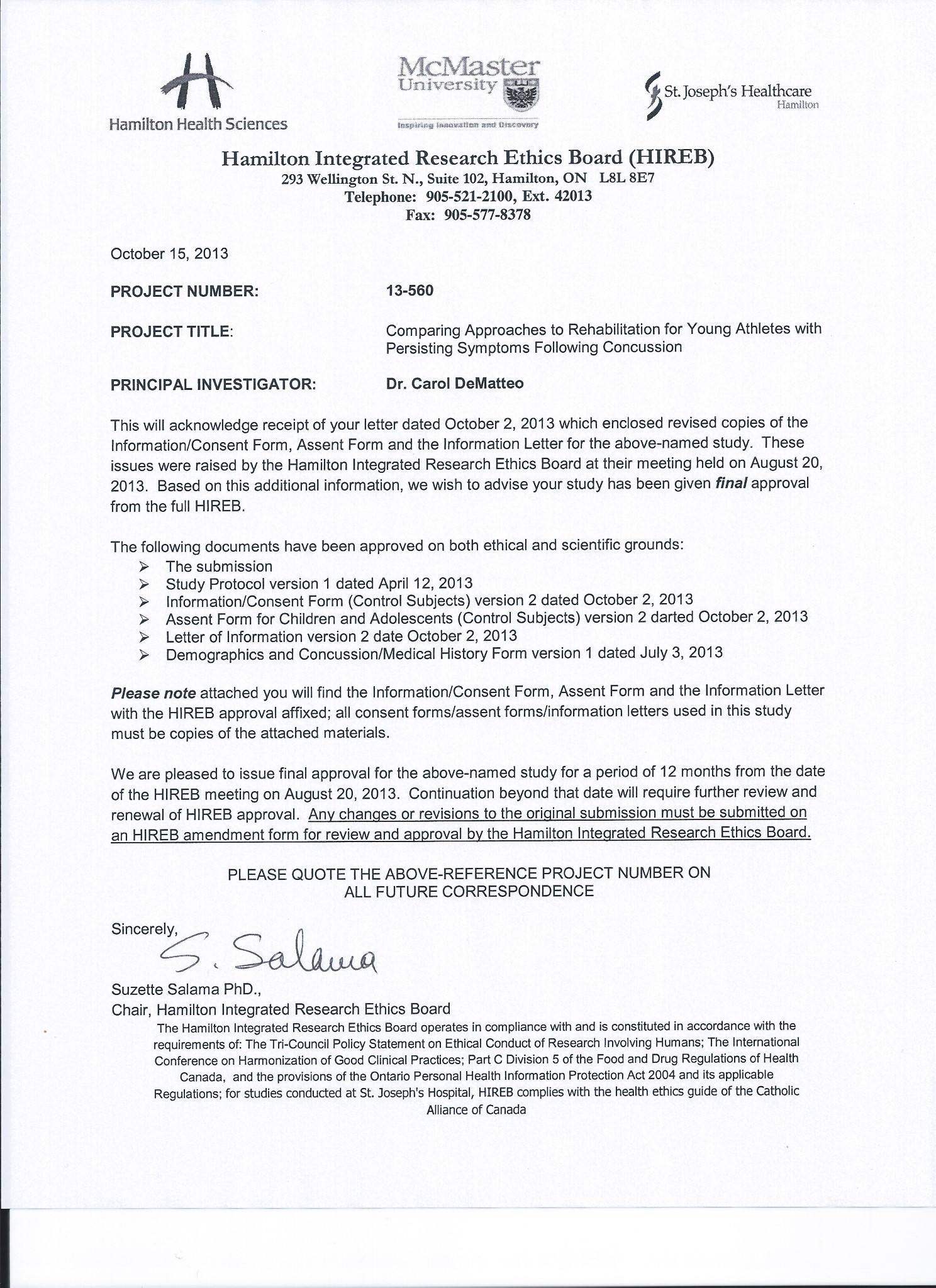
If you require any type of computer assistance, including passwords, please contact the Hamilton Health Sciences ICT department at ext 43000.

Sincerely,



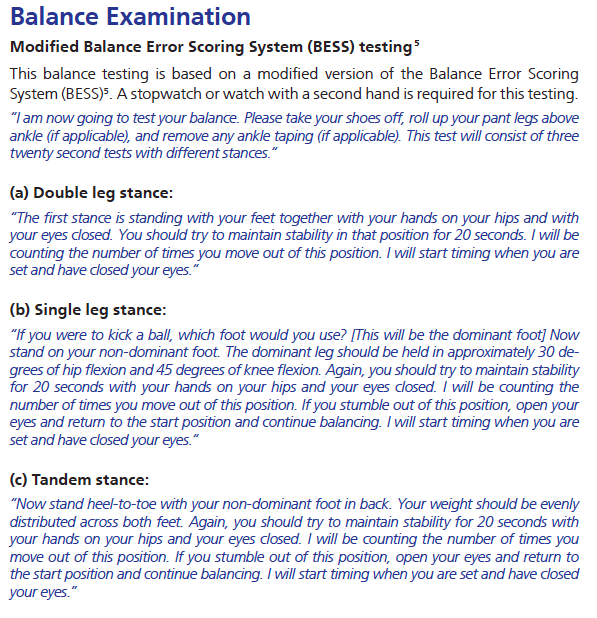
Mary Bedek

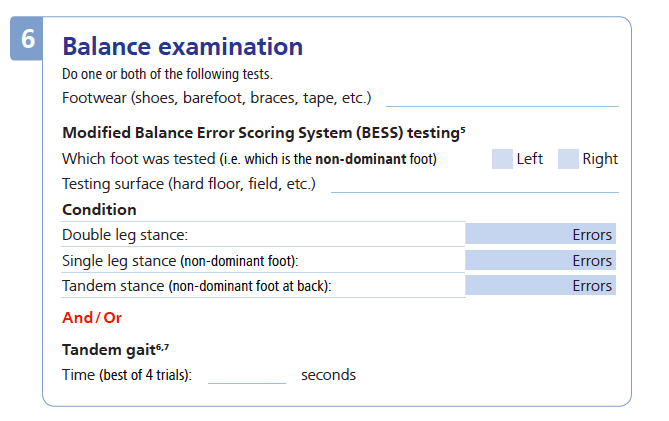
Director, Privacy and Freedom of Information



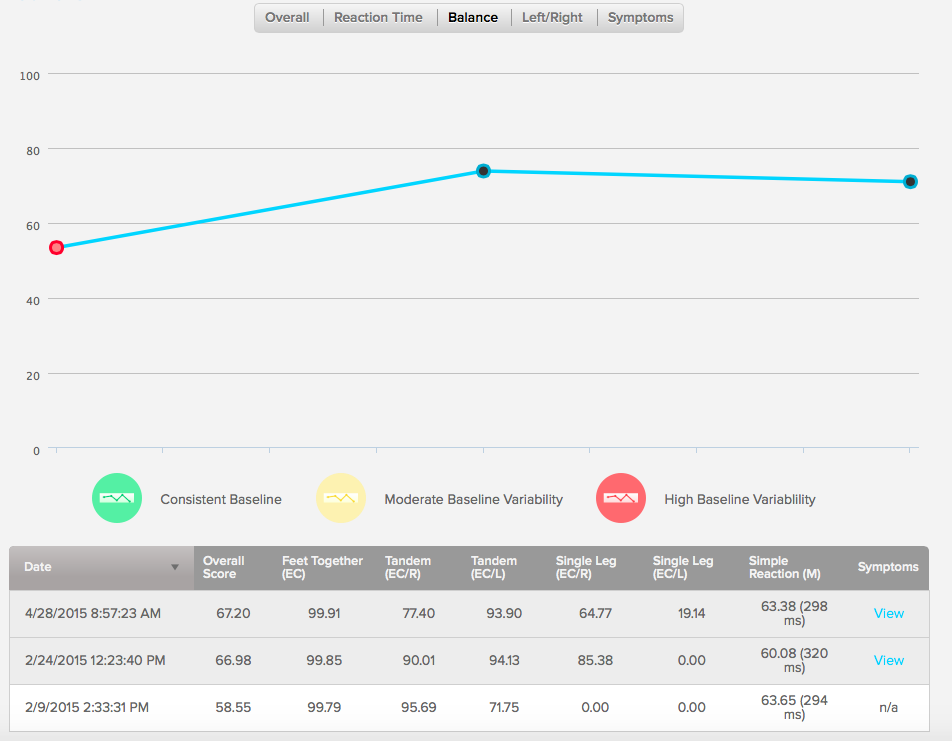
# Appendix B: Bruininks-Oseretsky Test of Motor Proficiency (Version 2)- Balance Subtest

# Appendix C: Modified Balance Error Scoring System

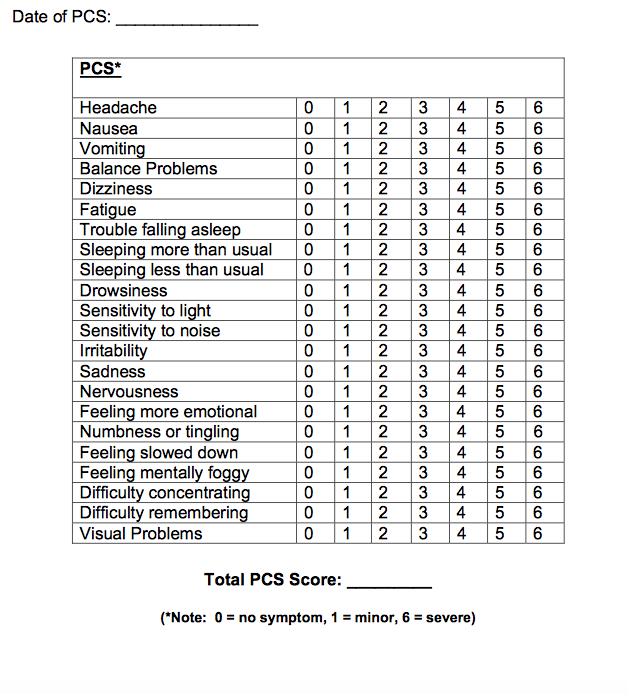




# Appendix D: Sway Balance Application- Balance Output



# Appendix E: Post Concussion Symptom Scale



# Appendix F: Community Balance and Mobility Scale

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