Relationship between presence of Clinical Oculomotor and Vestibular Impairments to Functional Mobility in Children and Adolescents in the Sub-acute stage following Mild Traumatic Brain Injury.

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December 2014

A thesis submitted to the faculty of graduate studies and research in partial fulfillment of the requirement of the degree of M.Sc in Rehabilitation Science

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ABSTRACT

Objective: The aim of this study was to (1) determine the proportion of children and adolescents, who present with clinical oculomotor and vestibular function deficits in the first week after sustaining an mTBI and (2) explore their relation to functional mobility and balance in children and adolescents. *Study Design:* A cross-sectional study included 29 children aged 8-17 years, who had sustained an mTBI in the previous 7-10 days. *Setting:* Participants were recruited from the concussion clinic of the Montreal Children's Hospital, McGill University Health Center.

Methods: Functional mobility and balance were examined using the Functional Gait Assessment (FGA) and the Biodex Balance System (BBS) respectively. Three eye movements: saccades, smooth pursuits and vergence, were assessed to characterize oculomotor function. Vestibular function was assessed using Dynamic Visual Acuity (DVA) and Subjective Visual Vertical (SVV). Participant's characteristics such as history, number of previous concussions and self reported post concussion symptoms were also noted from the medical chart. The principle analysis included descriptive statistics and multiple linear regressions. *Results:* Saccades and smooth pursuits were within normal limits while vergence was found abnormal in 20.7% of children. Approximately half the children exhibited abnormal DVA but no SVV deficits. Functional mobility problems were present with a mean FGA score of 25.7 ± 3.9 but static balance was within normal limits. Except for vergence, neither oculomotor nor vestibular function deficits were significantly related to functional mobility. *Conclusion*: Children in the sub-acute stage post mTBI present with some clinical oculomotor and vestibular impairments. Despite the fact that they were not related to functional mobility, such impairments may be responsible for a number of self-reported post-concussion symptoms and could be the object of

specific targeted intervention. We therefore recommend the inclusion of basic clinical tests for oculomotor and vestibular function to screen children and adolescents post-mTBI.

ABRÉGÉ

Objectif: L'objectif de cette étude était de (1) déterminer la proportion d'enfants et d'adolescents présentant des troubles oculomoteurs ou de fonction vestibulaire au cours de la première semaine suivant un traumatisme craniocérébral léger et (2) explorer leur relation avec la mobilité fonctionnelle et l'équilibre. Devis de l'étude: Cette étude transversale s'intéressa à 29 enfants et adolescents âgés de 8 à 17 ans, ayant subi un TCCL au cours des 7 à 10 jours précédents. Milieu: Les participants furent recrutés au sein de la clinique de commotion cérébrale de l'Hôpital de Montréal pour enfants du Centre universitaire de santé McGill. *Méthodes*: La mobilité fonctionnelle et l'équilibre furent examinés en utilisant le *Functional Gait Assessment (FGA*) et le *Biodex Balance System (BBS),* respectivement. Trois mouvements oculaires: saccades, poursuites et vergence furent évaluées afin de caractériser la fonction oculomotrice. La fonction vestibulaire fut évaluée à l'aide d'un test d'acuité visuelle dynamique et de verticale visuelle subjective. Les caractéristiques des participants telles que l'histoire, le nombre de commotions cérébrales antérieures et les symptômes post-commotionnels furent relevés à partir du dossier médical. L'analyse principale s'intéressa aux statistiques descriptives et à des régressions linéaires multiples. *Résultats*: Les saccades et poursuites visuelles étaient dans les limites de la normale tandis que des troubles de la vergence furent identifiés chez 20,7 % des participants. Environ la moitié des enfants présentaient une acuité visuelle dynamique anormale, mais aucun déficit de verticale visuelle subjective. Des problèmes de mobilité fonctionnelle étaient présents tel qu'illustré par un score moyen à la FGA de 25,7 ± 3,9, mais l'équilibre statique des participants était dans les limites de la normale. Excepté la vergence, ni la fonction oculomotrice

ni la fonction vestibulaire n'étaient significativement liées à la mobilité fonctionnelle.

Conclusion: Une grande proportion d'enfants en stade subaigu post-TCCL présentent des difficultés oculomotrices et de la fonction vestibulaire. Malgré le fait qu'ils ne soient pas liés à la mobilité fonctionnelle, ces troubles peuvent être responsables d'un certain nombre de symptômes post-commotionnels et pourraient faire l'objet d'une intervention spécifique ciblée. Nous recommandons donc l'inclusion de tests cliniques de fonction oculomotrice et de fonction vestibulaire è l'évaluation des enfants et adolescents post-TCCL.

ACKNOWLEDGMENTS

The writing of thesis, although undertaken by one person, is in reality the bringing together of ideas, concepts, and teachings developed and put forward by many individuals. In particular, for this study, I would like to thank the following people:

First and foremost, my supervisor, Dr. Isabelle Gagnon. Without her help, encouragement, persistence and eye for detail, this thesis would not be what it is. I appreciate, all her contributions of time, ideas and funding to make my M.Sc experience productive and simulating. She has always expressed interest in my work and I cannot think of a better advisor and mentor. I am grateful for my inclusion in her research group. At the same time, I express my gratitude to my supervisory committee, Lisa Grilli and Dr. Anouk Lamontagne, for their time, interest and insightful questions in the advancement of my thesis. I would like to specially thank Lisa Grilli, for her endless support and enthusiasm during the process of data collection.

I am also deeply thankful to my recruitment team at the Montreal Children's Hospital, Helen Kocilowicz, Diane Richard and Fatemeh Bahrpeyma (Fara) for always keeping me informed about eligible participants. It is because of them, I could collect my data in the designated time span. I am grateful to the participating children and their parents, for their cooperation and significant contribution in my research.

My time at McGill was made enjoyable in large part due to my colleagues and friends at the lab. In particular, I am thankful to Laurie- Ann Corbin-Berrigan, Shikha Saxena, Jérôme- Gauvin Lepage, Krithika Sambasivan and Rosemary Wagner for their constant support, ideas and words of encouragement.

I gratefully acknowledge the funding agency throughout my masters work. I was funded by Dr Gagnon's internal funds at the McGill University Health Centre. It took care of my finances, which allowed me to focus on my research work. I greatly appreciate the help of the School of P&OT, Dr.Eva Kehayia and Dr Isabelle Gelinas, for all the moral and financial support.

On a more personal note, I am and I will always be grateful to my family, my mother Smruti and my father Naresh, who raised me with unconditional love and supported me throughout all my pursuits. My sister, Vrushti, for always bringing a smile on my face. Thank you for encouraging me and supporting me. I hope, I have made you proud. For the past six years, I have had the privilege to have my two best friends, Shweta and Pooja, as my roommates. They are my support system in many aspects, thank you for accompanying me on this adventure. I look forward to our next one!

To these people and many others THANK YOU for your help and encouragement. Your support played a large part in successful completion of my thesis.

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December 2014

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PREFACE

Contribution Of Authors:

Completion of thesis involved several steps. First, a research proposal was written by Vishwa Buch. It was approved by supervisor Dr. Isabelle Gagnon, committee members, Lisa Grilli and Dr. Anouk Lamontagne. An extensive literature review was conducted. Following which, the research proposal was approved by the Research Ethics Board at the Montreal Children's Hospital. The next step involved the data collection at the Montreal Children's Hospital to recruit 29 children with an mTBI. The thesis was written by Vishwa Buch, under close supervision of Dr. Isabelle Gagnon and feedback from committee members.

Format of The Thesis:

The global aim of this thesis is to explore the relationship between oculomotor deficits, vestibular deficits and functional mobility in children one week following a mild traumatic brain injury (mTBI).

The objectives are addressed in the manuscript, which will be submitted to a scientific journal for publication. Following the regulations of Graduate and Post-doctoral Studies (GPS), a manuscript-based style has been adopted for this thesis. It is required by the GPS to include a literature review and a conclusion that is separate from the manuscript. Thus, it is unavoidable to have redundancy of material in this thesis.

Chapter 1 is the literature review which is divided into four sections. *Section 1* gives background information of the incidence of mTBI in children, the patho-physiology of the mTBI with its etiology as well as the sign and symptoms of mTBI. *Section 2* defines balance and sensory systems involved in maintaining balance. It also includes development of balance in children and

evidence about balance deficits observed post mTBI. *Section 3* introduces the oculomotor system and focuses on three eye movements (saccades, smooth pursuits and vergence), their anatomical pathways and eye movement deficits observed in the current literature. *Section 4* deals with the description of vestibular system, assessment of the vestibular system and vestibular deficits observed following an mTBI.

Chapter 2 highlights the rationale and objectives of the study. *Chapter 3* consists of the manuscript with a standard format: an introduction, methodology, results and discussion.

Chapter 4 is the final and concluding chapter of this thesis. It entails the summary and conclusion of the thesis. Following which, list of appendices and references is included.

CHAPTER 1

REVIEW OF THE LITERATURE

Section 1: Mild Traumatic Brain Injury

1.1.1 Definition

Mild Traumatic Brain injury (mTBI), also known as "concussion, minor head injury, minor brain injury, or minor head trauma occurs when a forceful motion of the head (with or without impact) results in a transient alteration of mental status" [1]. In 2004, the World Health Organization (WHO) collaborating task force on mTBI [2], proposed to define mTBI as "an acute brain injury resulting from mechanical energy to the head from external physical forces". According to the WHO, the operational criteria for clinical identification of mTBI include the following:

a) One or more of the following: confusion or disorientation, loss of consciousness for 30 minutes or less, post-traumatic amnesia for less than 24 hours, and/or other transient neurological abnormalities such as focal signs, seizure, and intracranial lesion not requiring surgery.
b) Glasgow Coma Scale score of 13–15 after 30 minutes post-injury or later upon presentation for healthcare.

The term mild TBI and concussion are often used interchangeably. Since 2001, sports medicine experts gather every 4 years to obtain a consensus of the definition and management guidelines for concussion [3]. The latest one developed during the 4th international conference on concussion in sport in the year 2012 [4], defined concussion as a *subset of TBI*. The team also proposed several common features that incorporate clinical, pathological and biomechanical injury constructs.

These constructs maybe utilized in defining the nature of a concussive head injury. They include:

"1) Concussion maybe caused either by a direct blow to the head, face, neck or elsewhere on the body with an "impulsive" force transmitted to the head. 2) Concussion typically results in the rapid onset of short-lived impairment of neurologic function that resolves spontaneously. 3) Concussion may result in neuro-pathological changes but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury. 4) Concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness (LOC). Resolution of the clinical and cognitive symptoms typically follows sequential course however it is important to note that a small percentage of cases, post-concussive symptoms maybe prolonged. 5.) No abnormality on standard structural neuro-imaging studies is seen in concussion" [4].

1.1.2 Incidence and Etiology

Mild Traumatic Brain Injury in the pediatric and adolescent population has generated increased attention among clinicians, researchers, parents, communities, sports and recreational professionals. Epidemiological data indicates the rate of admission and emergency department visits in hospitals, is indeed higher in children than adults [5].

A study conducted among the Ontario School children, to determine the incidence of head injury, found 1861 diagnosed concussions out of the total 11,068 injuries reported during school days. The authors also concluded that younger children (aged 16 and under) were more susceptible to the injury, falls being the primary reason [6]. Children aged 0-14 years are known to have the highest incidence of mTBI [7]. In fact, at least one head injury warranting medical attention is sustained in 16% of children by the age of 10 years [8]. The Centre for Disease Control (CDC) reports that over 1.3 million emergency room (ER) visits are due to

suspected head injury [9]. Data from the National Hospital Ambulatory Medical Care Survey suggest that 144,000 ER cases are mTBI in children aged between 0-19 years [10]. In a study that estimated ER visits for pediatric sport related concussion in 8-13 year olds versus 14-19 year-olds found, 4 in 1000 children aged 8-13 years and 6 in 1000 children aged 14-19 years sustained sports related concussion [11].

Despite the huge numbers, it is likely that the actual incidence is greatly underestimated; as children may not have sought medical attention or may fail to recognize symptoms themselves [12]. In addition; there are reports of 'lacking documentation' and 'misdiagnosis' of mTBI observed [13]. The Montreal Children's Hospital (MCH) statistics [14] show that over 17,000 children and adolescents with traumatic injuries are seen at the ER every year, of which approximately 2000 are diagnosed concussion cases.

Although the estimated number of injuries presenting to the EDs vary across the studies, sports and recreation has consistently been identified as one of the most common causes of the injury. The highest rates for both males and females are observed among those aged 10-19 years.

1.1.3 Risk factors

A variety of risk factors have been associated with the occurrence of mTBI.

1.*Age*: Younger children are more susceptible to concussion because of their anatomical and physiological make up [11]. The younger brain may be affected more and take longer to recover due to the structural development of the brain during growing years [15]. A normally developing brain in children has increased brain volume as compared to adults, as well as increased connectivity due to large amount of white matter [16]. In addition, the younger brain is shown to have decreased myelination with thinner frontal and temporal bones. This

relative immaturity along with greater head to body ratio and weaker neck muscles further make children vulnerable to injury[17,18] .

2.*Gender:* It is observed that, when comparing similar sports or environmental contexts, female athletes have higher rates of concussion than their male counterparts [19]. Women have weaker neck muscles as compared to men. This anatomic difference has been suggested as a reason for the difference in reported rates [20]. Men also tend to underreport concussion symptoms due to fear of activity restriction [20]. Other authors have also suggested that women are more honest in reporting their concussion symptoms leading to a higher reported rate [19].

3.*Previous Injury*: It has been observed that individuals who have sustained mTBI are at a risk of re-injury. Guskweicz et al [21], when evaluated collegiate athletes, noted that those with one or two previous concussions were *2.8 times* more likely to sustain re-injury. Furthermore, it was also noted, those with 3 previous concussions were *3.8 times* more likely to sustain another injury [22].

There are specific risk factors associated to the sport itself as concussion in high school athletics are common in contact sports, team sports and collision sports. Full contact sports (e.g., football, ice hockey, rugby) have the highest rates of concussion while sports in which athlete-athlete contact occurs frequently but is not the primary focus of the sport (e.g., basketball, soccer) have moderate rates of concussion. Also, sports where athlete-athlete contact is relatively rare (e.g., volleyball, baseball, softball) have the lowest rates of concussion[23,24] .

1.1.4 Patho-physiology

An mTBI is viewed as a metabolic injury, with a disruption in glucose metabolism and regional cerebral blood flow. Describing the patho-physiology that present after an mTBI, Giza and Hovda[25,26] , concluded that cerebral physiology can be adversely affected for weeks in humans. Significant changes in cerebral glucose metabolism are observed even in head injured patients with intact sensorium (GCS score=15). This metabolic 'cascade' is characterized by a mismatch between energy supply and demand, and has been shown to extend up to 7–10 days post-injury in mice and up to weeks in humans.

The concussion injury can be categorized into two parts: a primary insult and a secondary inflammatory response [27-29]. As explained in the figure 1.1.1, in rat models, the initial insult results in pathologic release of excitatory amino acid neurotransmitters (glutamine and asparate) that lead to loss of cell wall integrity. Subsequent changes in the permeability of the cell wall allows influx of sodium and an efflux of potassium. These changes in intra cellular level of sodium and potassium alter the pH of the cell and leads to an influx of calcium. Further disruption leads to cellular damage. As severely injured cells die, they release cytokines that propel the inflammatory process [30]. This cascade of cell injury may explain the worsening of symptoms during the first 6 to 24 hours after injury.

Apart from the mentioned patho-physiological changes, Diffused Axonal Injury (DAI) also contributes to the impaired brain function following concussion [31]. There is delayed onset and the changes that are not seen immediately (initial stages) are mediated through intracellular signaling. This occurs concurrently with a cytokine mediated inflammatory response. These changes are observed in diffuse tensor imagining as shown by subtle white matter abnormalities in individuals with persistent post concussive symptoms [32].

1.1.5 Clinical symptoms

Mild TBI results in a cluster of somatic, cognitive, emotional symptoms, physical signs (e.g. loss of consciousness, amnesia), behavioral changes (e.g. irritability) and sleep disturbances (e.g. insomnia) [4,33]. Headache and dizziness are the most commonly reported symptoms followed by nausea and vision changes. Loss of consciousness (LOC) may occur in 10% of mTBI population [34]. These symptoms are prominently observed in the early period after injury[33,35] . Refer to table 1.1.1 for list of clinical symptoms and signs.

In a 2 year prospective study, where a group of children with mTBI aged 11-17 years were examined using a post concussion symptom scale, headache was the most commonly observed symptom and fatigue was the most severe [36]. Grubenhoff et al (2011) [33], examined 6-18 year old children who suffered mTBI and matched them with children with a minor extremity injury using graded symptom checklist. Children in the mTBI group exhibited symptoms such as headaches, dizziness, nausea, as well as blurred and double vision more frequently and with increased severity than the orthopedic control group. Thus, it is important to assess clinical symptoms such as headache, dizziness, blurred vision particularly in the acute period following mTBI.

Section: 2 Balance

1.2.1 Definition of Balance

Postural control involves controlling one's body position in space in order to acquire orientation and stability. Orientation refers to 'the ability to maintain an appropriate relationship between the body segments and the environment' while stability is the ability of a system to resist perturbations (external or internal) in order to maintain a desired posture such that body's centre of mass is maintained within the base of support' [37].

1.2.2 Systems involved to maintain balance

Sensory systems interact with motor systems at all levels to ensure postural stability. In order to determine the position of one's center of mass in relation to gravity, it is necessary for the nervous system to receive and interpret the incoming sensory information. Once the correct information is filtered, the motor system can act to move the center of mass to equilibrium [38]. In order to maintain an upright posture and ensure appropriate transitions between the positions, the central nervous system integrates the afferent information from various peripheral sources mainly visual, vestibular and somato-sensory and then generates complex motor responses [39]. Each of these systems have their defined (specific) roles in maintaining balance, which are discussed later in detail.

1.2.3 Development of balance

Like any other system, balance function changes with age, from infancy through childhood to adulthood. It is not until after the age of 7, that adult-like balance strategies begin to appear in children. While children aged 3-4 years show levels of somato-sensory function equivalent to adults, the visual system progresses more slowly, and it is only at the age of

14-15 years that they achieve adult-like strategies. The third system that is the vestibular system, develop the slowest, beyond the age of 15 years [40].

It is reported that balance control changes from primarily visual-vestibular to somatosensory-vestibular between 3 to 6 years of age. However, the transition to adult responses for all the sensory inputs is not achieved by the age of 6 years [41]. It is known that the ability to stabilize the head during locomotion develops between the age of 3 to 6, when the visual 'pre dominance' decreases and vestibular function increases [42,40].

In a later study that also dealt with maturation of the balance in children, Cumberworth et al [43] used computer posturography to evaluate 60 healthy children from age 5 to 17. Here as well, the authors concluded that the somato-sensory system was developed early in childhood. However, development of the visual system progressed significantly with height while the vestibular system progressed significantly with the age.

1.2.4 Assessment of balance after an m TBI

Balance can be assessed in multiple ways including instrumented and clinical balance tests. These measures can focus more on the static or on the dynamic part of balance. The use of instrumented balance testing has helped predict recovery post injury in mTBI population. One of the most commonly used is, Computer Posturography which allows examination of individual sensory systems with the help of 6 different conditions presented in *Table 1.2.1.*

Apart from posturography, the most commonly used balance tests in concussion research and management are presented in *table 1.2.2* and *table1.4.1.* The evidence suggests that injured athletes perform significantly worse than their control counterparts when examined using instrumented and score based clinical tools [44-46].

1.2.5 Balance after an mTBI

Traditionally, a person who has sustained an mTBI is thought to suffer mostly from cognitive, as opposed to motor problems[47,48] . In the last decade, however, interest in the motor outcome of people sustaining mTBI has increased, and a number of research teams have identified balance problems after mTBI. (Table 1.2.3).

A previous cohort study performed by our research group has focused on balance in mTBI population. Gagnon et al [49] studied children (n=38, age= 7-16years) with mTBI, and matched them with controls. They were assessed at 1, 4 and 12 weeks after injury with the use of following three balance measures: (1) Bruininks-Oseretsky Test of Motor Proficiency (BOTMP), (2) Paediatric Clinical Test of Sensory Integration and Balance (PCTSIB), and (3) Postural Stress Test (PST). The Analysis of Variance concluded that mTBI children performed significantly worse than healthy control children, even at 12 weeks post injury. The mTBI group exhibited balance deficits on the BOTMP balance subset (p<0.001), PST (p=0.31), and in the eyes closed condition on the P-CTSIB tandem position (p=0.05). Taken together, the difference in postural sway became most evident when visual and support surface were altered, suggesting that mTBI causes a transient sensory interaction problem.

Section 3: Oculomotor function

1.3.1 Visual system and Eye movements

Visual system [50]*:* The visual system is the primary sensory information used to maintain balance. The visual system registers movements of the objects in the environment and the body's movements within the environment. The system consists of mainly three components: central, ambient (peripheral) and retinal slip. The central vision specializes in object motion perception and object recognition; whereas peripheral vision is sensitive to

movement scene and is thought to dominate both perception of self-motion and postural control. The peripheral vision compared to central vision, plays an essential role in maintaining quiet stance. Peripheral vision is particularly sensitive to moving scenes, with movement influencing the extremes of a periphery. The retinal slip is used as a feedback for a compensatory sway. Inputs from the visual system are important for integration of vestibular inputs. In addition, the visual system acts in the following ways:

1. The eyes function to detect a focal point on an object until it gains a clear image of that point.

2. The eyes integrate with the vestibular system with the help of the vestibular-oculomotor reflex (VOR) to maintain the stable image on the fovea. When VOR is impaired, it causes blurred vision and subsequent difficulty to focus on the target.

To summarize, the Visual and Vestibular systems interact synergistically to provide spatial orientation and position feedback in order to maintain gaze and stability during a movement. Both the Visual and Vestibular systems gather sensory information (mechanical from the vestibular system and photo-optic from the visual system) and transfer it to the central processing areas of the brain, which then decodes and generates appropriate motor responses of the eye, head or body [51].

Although the visual system is complex, one of its immediate contribution to postural control is mediated through three different eye movements: Smooth Pursuits, Saccades and Vergence [52]. Smooth pursuit eye movements are slow eye movements that stabilize images of smoothly moving targets on the fovea. Saccades are responsible for rapid, small movements of both eyes simultaneously in changing a point of fixation. Vergence is closely connected to the accommodation of the eye.

Smooth Pursuit: Smooth pursuits are slow eye movements that approximate the velocity of the moving object in order to focus the visual image on the fovea. The smooth-pursuit system is distinct from the saccades system. Smooth pursuits help us catch a ball speeding towards us, it helps us cross the street without getting run over by a moving vehicle. It differs from the rapid eye movements in the saccade system.

Saccades: When the body is moving and the object to be viewed is stationary, the ocular system generates saccades in order to fix the image of the viewing object on the fovea. Saccades can be spontaneous, voluntary or reflexive. Voluntary saccades are used to change fixation between two stationary objects [53]. In everyday life, we typically make approximately three saccadic eye movements every second. [54] The characteristics of children's eye movements differ than in case of adults. Pre-school children exhibit more frequent small saccades, saccades latency is usually longer and saccade accuracy is usually less precise to that of an adult when scanning a scene [55].

Vergence: Vergence is defined as "simultaneous movements of both eyes in opposite direction to maintain a clear binocular vision" [52]. Vergence has two components; convergence and divergence [52]. Convergence is the inward movements of the eyes towards each other to maintain a single binocular vision when viewing the object, while divergence refers to outward movement of the eyes away from each other [52].

1.3.2 Eye movement pathways

In the Frontal lobe, three main areas are concerned with control of eye movements 1.Frontal Eye Field (FEF) 2.Supplimentary Eye Field (SEF) 3.Dorsolateral Pre Frontal Cortex (DPFC) [56].

Saccades:

Neurons in the Frontal Eye Field (FEF) initiate voluntary conjugate horizontal gaze (saccades and micro-saccades). Activation of the right FEF will cause the eyes to look to the left and active left FEF which in turn cause the eyes to look to the right. Projections from the FEF go directly and indirectly (via the superior colliculus) to the contralateral paramedian pontine reticular formation (PPRF). The PPRF is situated ventral to the abducens nucleus (Cranial Nerve VI) and contains neurons that are responsible for generating saccades. Projections from the PPRF go to the ipsilateral abducens nucleus and, through the medial longitudinal fasciculus (MLF), to the contralateral oculomotor nucleus. This results in conjugate eye movement away from the FEF that started the process and towards the side of the PPRF that was involved in the movement (here from right to the left). Damage to the left PPRF, for example, will completely prevent the movement of either eye to the left. The MLF is the link that yokes the medial movement of one eye to the lateral movement of the other eye during lateral gaze. Damage to the MLF permits the abducting eye to move, while preventing the adducting eye from following [56-58].

Smooth Pursuit:

Smooth pursuit eye movements utilize some of the vestibulo-ocular reflex pathways (discussed later in *section 4.2*) and require a visual input to the occipital cortex in order to view the target.

The occipital eye fields are not as well defined as the FEF. They are located in the region near the junction of the occipital lobes with the posterior parietal and temporal lobes, including visual association areas that are involved in detecting motion. The occipital eye fields project directly and indirectly to the pontine nuclei. Pontocerebellar fibers carry these signals to the flocculus of the cerebellum. The flocculus is part of the vestibulo-ocular circuitry. The flocculus, in turn, is connected to the vestibular complex which is capable of generating smooth eye movements in all directions via connections to the extraocular nuclei[56,59] .

Vergence:

Vergence requires the occipital lobes to be intact. The pathway involves the midbrain reticular formation (adjacent to the oculomotor nuclei), which contains neurons that are active during vergence activities. The details of this pathway are less well understood than the other eye movement pathways, although it is wired in parallel with accommodation. This linkage appears due to interconnections between midbrain neurons projecting to the nucleus (responsible for accommodation) and neurons projecting to the oculomotor nucleus to adduct (converge) the eyes [60].

1.3.3 Assessment of Eye movements

Eye movements can be assessed in several different ways as shown in Table 1.3.1. Eye tracking systems that are currently in use rely on surface electrodes that are placed around the eyes and recordings are made using software.

Despite their clinical utility; these available tools are not only expensive but also require a skilled person to administer and demand knowledge of this technology. For example, electro-oculography administration requires wearing electrodes along with a computer

laboratory setup, which may not be feasible for a rehabilitation centre. Therefore, in this study we aim to use inexpensive and easy to administer valid clinical tests administered by a trained physical therapist. The physical therapist will assess saccades, smooth pursuits and vergence.

1.3.4 Eye movements deficits after mTBI

Common visual sequels are impaired eye movements (fixation, pursuit, saccade), and binocular dysfunctions (convergence) [61]. More specifically, mild head injury is shown to have *impaired saccades* and *prolonged smooth pursuits* [62]. A pilot study by Szymanowicz et al [63](2012) assessed vergence in 21 adult subjects who suffered mTBI. After comparing subjects with 10 controls, he observed *reduced convergence* and restricted ranges for *near vergence* in subjects with mTBI.

Presence of linear, rotational and angular forces associated with concussion, not only causes brain trauma but also affects cranial nerves (nerves II, III, IV and VI), which help control eye movements [64,65] . These cranial nerves originate from the mid brain and diencephalon which is observed to be one of the most affected regions of the central nervous system due to rotational forces associated with concussion [66].

In a study performed on veterans with mTBI, the authors observed visual dysfunctions in approximately 40% of their population. Most affected were oculomotor deficits such as impaired smooth pursuits and saccades. Although the subjects suffered blast induced mTBI, considering the similar mechanism involved, the results here can be extrapolated [67].

Heitger and colleagues have closely studied eye movements; with his consecutive studies, he concluded that defective saccades are sensitive markers of cerebral dysfunction caused by mTBI [68]. In another study [62], he found oculomotor deficits (saccades) in 30 subjects with

mild closed head injury (Glasgow coma score 13-15) using an IRIS infrared tracker. Heitger, thereafter used the same methods on subjects with post concussion symptoms (PCS), to identify if oculomotor deficits could be sensitive markers to predict the PCS. He and his group assessed 37 subjects with mTBI within 1 week after injury and noted that early eye movement function was 'the most effective' in distinguishing PCS and non PCS subjects [69]. In a later study, he examined if the patients who continue to report PCS at 3-5 months post injury show similar ongoing oculomotor deficits. He compared 36 subjects to that of matched controls and found that the PCS group performed worse on saccades and smooth pursuits which provided additional evidence of ongoing cerebral dysfunction following an injury [61].

Section 4: Vestibular function

1.4.1 Components of vestibular system

Vestibular system [53]: The vestibular system consists of three semi-circular canals and two otolith organs namely utricle and saccule. Together they provide sensory information with respect to head rotation and gravitational changes, which is helpful when the eyes are closed and the subject must rely on vestibular input. The organs and semi circular canals integrate with the help of three reflexes. 1) The Vestibulo-Ocular Reflex (VOR) acts to provide stable vision during a head movement and helps perceive spatial information regarding the environment around the person. The VOR response is a movement of the eyes in equal and opposite direction to that of the head movement. When input from the vestibular system is disturbed, the eyes exhibit nystagmus in an effort to fixate a reference point in the environment. 2) The Vestibulo-Collic reflex (VCR) stabilizes the head by acting on neck musculature and 3) Vestibulo-Spinal reflex (VSR) generates compensatory body movements in order to maintain head and body stability. It coordinates head and neck

movement with the trunk and body so as to maintain the head in upright position. The VSR acts upon with the help of lateral and medial vestibule-spinal tracts. The lateral vestibulo-spinal tract corresponds to postural changes to compensate for body movements. It relays signals to the antigravity muscles (extensor muscles in the leg) that help maintain upright and balanced posture; whereas the medial-vestibulo spinal tract promotes the stabilization of head position by innervating neck muscles, which help with head co-ordination and eye movements.

The vestibular system also coordinates with the cerebellum in order to maintain postural control. The cerebellum deals with various motor functions including postural control and co-ordination. It is concerned with equilibrium and regulation of muscle tone.

The vestibular system is likely to provide resolution when the other inter-sensory information is misinterpreted. In other words, the vestibular system resolves the conflicts that may occur while interpreting information from visual system and somato-sensory system[70].

Labyrinths and hair cells form an integral part of the vestibular system. They are located on either side of the head in the temporal bones of the skull. The labyrinth is made up of hollow bony system of tubes or ducts, inside which the three semi circular canals are found. The semi circular canals are connected to two membranous sacs forming a continuous tubular system. In reference to their position with respect to each other, the semicircular canals are called horizontal, superior and inferior semicircular canals. One of the membranous sacs is called the utricle and the other is called the saccule. Together these sacs are known as otolith organs[53,71].

Each semicircular canal is widened towards the end to form an Ampulla which accommodates for specialized hair cells. Otoliths and their hair cells together contribute as biological sensors that convert the displacements due to head motion into neural discharges directed to the specific areas of the brain stem and the cerebellum [53].

The utricle and saccule detect gravity, linear movement, and contribute to the sense of verticality. The semicircular canals detect rotational head movements and are located at right angles to each other. When these organs, on both sides of the head, are functioning properly, they send symmetrical signals to the brain which is integrated via sensory-neural pathways resulting in three reflexes mentioned previously- the VOR, VCR and VSR[52,53] .

1.4.2 Vestibular pathways

Vestibular-Ocular Reflex(VOR): The reflex has two components: Angular VOR and linear VOR. The angular VOR is mediated by the semi circular canals, compensates for head rotation while the linear VOR, mediated by the otoliths, compensates for translation. The angular VOR is important for gaze stabilization while linear VOR acts when the near targets are being viewed at a relatively high frequencies[53,71] .

The VOR consists of simple three neuron pathway. The receptor is located in the semi-circular canals. When the head is turned to the right, the endolymph in the right horizontal canal presses against the ampulla resulting in the increased firing rate in the right vestibular nerve. Excitatory impulses are then transmitted to the ipsilateral oculomotor nuclei, which then activates right (ipsilateral) medial rectus muscle and left (contra lateral) lateral rectus to contract, pulling the eye to the right[53,71] .

Vestibulo-spinal Reflex (VSR): The major function of the VSRs is to interact with the visual and somato-sensory systems to control postural stability in stance and ambulation. The

VSR stabilizes the body in space during head movements and during the activities of daily living. The vestibular apparatus, pheripheral sensory apparatus detects the movement and position of the head, sends messages centrally to activate vestibular (cranial nerve)and vestibular nuclei. Impulses are then transmitted via the lateral and medial vestibulo-spinal tract to the spinal cord. Extensor activity is induced on the side to which head is inclined and flexor activity is induced on the opposite side thus generating compensatory postural responses [53].

1.4.3 Assessment of vestibular function

Considering the complexity of the vestibular system, a thorough evaluation of the inner ear function of semicircular canals and otoliths organs is needed. For the context of our study, we will focus on Subjective Visual Vertical (SVV) and Dynamic Visual Acuity (DVA) as a part of vestibular functional examination. For other commonly used measures to evaluate vestibular function refer to table 1.4.1.

Subjective Visual Vertical (SVV): The SVV has been used as a test to examine utricular function. The SVV angle is the angle between gravitational axis (true earth vertical) and the position of a visual linear marker adjusted vertically by a subject. The otoliths contribute to the sense of verticality, and healthy subjects align vertical within 2 degrees of true vertical (0 degrees) [72]. Evidence suggests that otholith function may be compromised by a head trauma [73]. In an experiment, Schuknecht and Davison [74] reported damage to the otoliths along with degenerative changes in a cat. The experiment involved injury to the cat with a pattern of acceleration and deacceleration of the head which is similar to the injury mechanism observed in concussion. There is paucity of evidence of impaired SVV with respect to concussion, but as discussed earlier, mTBI can involve injury to the peripheral and central vestibular pathways which therefore may also affect the SVV.

Visual Acuity tests: They (static and dynamic) are standard tests to measure visual acuity with an optotype test card. Static visual acuity is measured first, with the patient's head stationary. Dynamic visual acuity is then measured during small head oscillations of 2 Hz. This frequency of head movement exceeds the range over which visual system can respond, thus isolating vestibular system. In case of children, Lea symbols are used as an optotype. The symbols include apple, square, circle and house. *Visual Acuity score* are calculated by taking the difference between the SVA scores and DVA scores. Rine et al [75], reported that the DVA test is reliable for children as young as 3 years, and that sensitivity, specificity, positive predictive value and negative predictive value were found to be excellent (100%). In addition, Rine et al has found excellent test-retest (ICC=0.94) and inter-tester (ICC=0.84) reliability to detect bilateral vestibular hypo function in children.

In a recent study conducted by Christy et al [76], to determine the reliability and diagnostic accuracy of clinical tests for vestibular function in children. Children with vestibular hypo function were compared to typically developed children aged 6 to 12 years. *Visual Acuity and Subjective Visual Vertical* were among the other tests, which according to author, are 'accurate' to identify children with vesitbular hypofunction.

1.4.4 Vestibular function deficits after mTBI

Dizziness, headache, nausea, and blurred vision are commonly observed post-concussion symptoms and it is hypothesized that their etiology may relate partially or completely to a vestibular functional impairment[77,78] . However, it remains unclear the effects of physical damage particularly to the vestibular system post concussion. Two theories have been proposed. First, acute and long term damage to the peripheral vestibular system- the hair cells, can disturb afferent information, thus reducing brain's ability to orient in space.

Second, damage the central vestibular system can affect the central nervous system's ability to effectively integrate this information. Either way, the output is disturbed equilibrium [79]. Presence of vestibular functional deficits such as dizziness and/or headache after six months of injury, is an 'adverse prognostic indicator'. Although headache and fatigue have been shown to be one of the common symptoms post mTBI, persistent dizziness appears to a better prognosticator that affects clinical outcome as well as diseases course[35,80].

Regardless of severity or mechanism of injury, 30 to 80% individuals report dizziness and impaired balance as common complaints following mTBI [81-83]. With mTBI, visual and/or vestibular systems may be damaged, which can ultimately lead to disequilibrium and dizziness. Other symptoms reported are vertigo, spinning, or blurred and/ or double vision [84].

Vestibular Impairments can be classified either as peripheral and central vestibular disorders. Injury to vestibular nerve and labyrinth results in peripheral vestibular disorders while trauma to the cerebellum, brain cortex or the vestibular cortical network is a central vestibular disorders. As mentioned, these structures process sensory information to generate appropriate motor output. Therefore, when injured impaired gaze and postural responses are observed. With respect to mTBI, the central vestibular system is observed to be more affected than peripheral [85]. However, in some cases, both the systems can be involved. With peripheral vestibular disorders, most commonly observed deficits are blurred vision with head movements (impaired VOR), severe vertigo and imbalance. Central vestibular disorders can also present with vertigo, imbalance and double vision in conjunction with impaired saccades and smooth pursuits, nystagmus or opto-kinetic abnormalities.

Apart from the deficits listed, as described in *section 1.2.5*, the role of vestibular system in postural instability observed post mTBI is evident. Scientists suspect that one of the reasons for the imbalance could be impaired sensory integration between the visual and/or vestibular system.

Alsalaheen et al [86], in 2012, studied the effectiveness of vestibular rehabilitation on concussed athletes (n=67, age=8-18 years) presenting with dizziness and balance dysfunction . The study found that vestibular rehabilitation reduced dizziness and improved balance function; therefore the authors recommended that vestibular rehabilitation should be considered in the management of individuals post concussion.

Figures and Tables

Figure 1.1.1: Injury cascade and different stages of the injury.

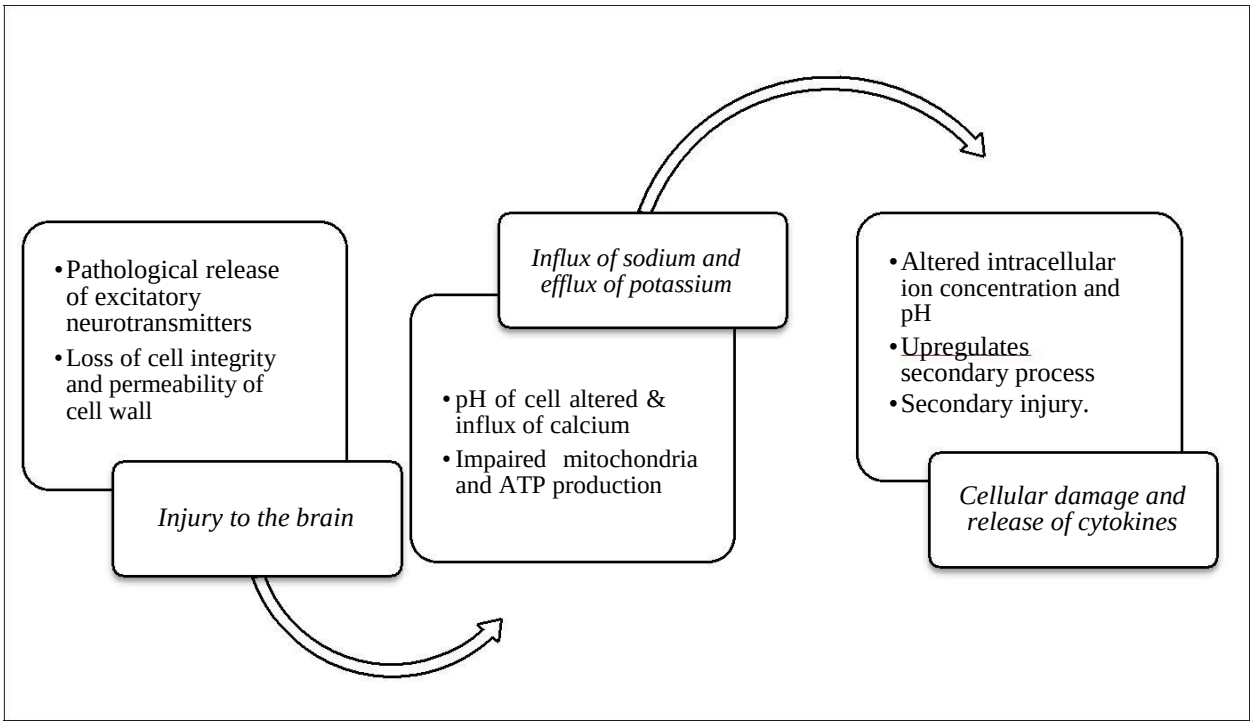

Table 1.1.1 Clinical symptoms and signs

Concussion Symptoms	Concussion Signs
Headache or "pressure" in head Nausea or vomiting Balance Problems or Dizziness Double or blurred vision Sensitivity to light Sensitivity to sound Feeling sluggish, hazy, foggy. Concentration or memory problems Confusion Does not feel 'right' or is 'feeling down'.	Appears dazed or stunned, Is confused about assignment or position Forgets an instruction, is unsure of game score or opponent Moves clumsily Answers questions slowly Loses consciousness (even briefly) Shows mood behavior or personality changes Can't recall events *prior* after hit or fall (retrograde amnesia) Can't recall events *after* hit or fall (ante grade amnesia)

Adapted from Centre of Disease Control Heads Up concussion campaign [87].

Table 1.2.1: Standard conditions to evaluate balance.

Conditions	**Description**	**Sensory signals *disrupted***	**Sensory signals *available***
1	Eyes open, surround and platform stable	None	Visual, vestibular and Somato-sensory
2	Eyes closed, surround and platform stable	Visual signals removed	Somato-sensory, vestibular.
3	Eyes open, sway referenced surround	Conflicting Visual Signals	Somato-sensory, vestibular.
4	Eyes open, sway referenced platform	Conflicting Somato-sensory signals.	Visual and Vestibular
5	Eyes closed, sway referenced platform	Visual signal removed and conflicting somato-sensory signals.	Visual
6	Eyes open, sway referenced platform and surround.	Conflicting visual and somato-sensory signals.	Visual

Table 1.2.2: Measures available for balance assessment in mild TBI population (Pediatric)

Test	Test Criterion	Psychometric Properties
Modified Clinical Test of Sensory Interaction and balance(mCTSIB) [88] Pediatric mCTSIB [89]	Quantify postural control under various conditions Mean Centre of Gravity(COG), COG alignment, The score obtained are compared to normative data.	Excellent test- retest reliability *(r=0.99)* for healthy adults. Excellent test-retest reliability for pediatric mTBI : ICC=(0.79-0.82) across 12 sensory conditions.
The Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2) Motor component [90].		ICC= 0.80 for total motor composite and short form reliability. Inter rater reliability from 0.92 to 0.99
Balance Error Scoring System [91]	Based on 6 standard conditions. Total score = 60, lower scores indicate better balance and less errors.	Adequate test-retest reliability in youth aged 9-14 years(ICC=0.70).

Table 1.2.3 : Studies evaluating postural control post mild TBI.

Study	Population/Participants Age group (Mean)	Intervention	Results/Conclusions
Kleffelgaard,Roe et al [92]	N=52 individuals who suffered mTBI	Rivermead-Postconcussion symptoms questionnaire, Dynamic Gait Index, Computer Posturography, Walking Speed tests and 6 minute walk test	Balance problems are long term consequences of mTBI in adult population.
Rubin et al [93]	N=29 mTBI compared to N=51 symptom free individuals	Centre of Pressure in anterior posterior and medial, lateral directions.	mTBI group exhibited significantly *greater anterior-posterior sway* and *greater movement displacement* on four

			of the six standard conditions.
R Mihalik et al [94]	N=108 concussed athletes Age=18.83±1.27 year	Sensory Organization Test.	Increased postural deficits found in concussed athletes with PTH.
Slobunov et al [44]	N=60 student-athletes	Virtual Reality environment in conjunction with a force plate.	Balance deficits present for up to 30 days post injury due to presence of 'residual sensory integration dysfunction'.
Guskiewicz et al 1996 [95]	N= 10 mTBI matched with 10 controls.	Modified Clinical test of Sensory integration of Balance (mCTSIB).	Increase in postural sway in acute mTBI athletes. (most evident on an unstable/foam surface)
Guskiewicz et al 2001 [46]	N= 36 Concussed athletes with 36 matched controls.	Sensory Organization Test and Balance Error Scoring System (BESS)	Acute balance deficits and sensory interaction problems. May be due to 'lack of visual and vestibular information processing'.
Gagnon et al 1998 [96]	N= 28 aged 5 to 15 years	Bruininks-Oseretsky Test of Motor Proficiency	Motor performance was significantly lower in terms of *balance.* (p<0.01)
Gagnon et al 2001 [97]	Single case study	Bruininks-Oseretsky Test of Motor Proficiency the Pediatric Clinical Test of Sensory Interaction for Balance, and the Postural Stress Test.	Balance deficits were observed in all three tests.
Gagnon et al 2004 [49]	N=38 aged 7 to 16 years matched with controls	Bruininks-Oseretsky Test of Motor Proficiency the Pediatric Clinical	Children with mTBI showed balance deficits at 12 weeks after injury.

		Test of Sensory Interaction for Balance, and the Postural Stress Test.	

Table 1.3.1: Commonly used instruments to examine eye movements.

Instrument	Description
Electro-oculography [98]	Use of surface electrodes near each eye helps determine a particular eye movement. The eye acts as a dipole
Infra red reflective devices [99]	Records eye movements based on the principle of reflection of infra-red light by iris/sclera boundary. Difference obtained is used to measure eye movements.
Video-oculography	Uses pupil tracking and/or corneal reflection tracking.

Table 1.4.1: Instruments available to examine vestibular function

Clinical Test	Test Criterion	Psychometric Properties
Rotation Tests [100]	Records eye movements while the head moves at various speeds.	Test retest reliability is *poor*
Computerized Dynamic Posturography [101] • Sensory Organization Test [102]	Evaluates individual sensory system that contribute to the balance (Table: Abnormal score if 95% below the normative data/matched controls	'Good' Test-retest reliability with 70 to 100% percent agreement. Sensitivity: 54% Specificity:37%
Vestibulo-evoked Myogenic Potential (VEMP) [103]	Evaluates if saccule and/or vestibular nerve are intact. (Visual-vestibular interactions)	Excellent reliability
Hall-Pike Dix Test [104]	Upward and mixed torsional nystagmus with symptoms of vertigo, helps diagnose Benign Paraxosymal Vertigo. (BPPV)	Sensitivity: 79% Specificity: 75%
Head Thrust Test [105]	Head is pitched down to 30 degrees, and a quick head turn in either direction.	Sensitivity:71% Specificity:82%
Dynamic Visual Acuity Test [106]	3 or more lines change on static and dynamic visual acuity test; on the Snellen's chart is considered	Vestibular Population: Sensitivity: 94.5% Specificity:95.2%

	abnormal.	In children as young as 3 years , sensitivity, specificity and negative predicative value found to be excellent (100%) with use of Lea's symbol optotypes [75].
Functional Gait Assessment [107]	10 item gait test, score 0 (severe impairment) to 3 (normal ambulation). Highest possible score- 30	Internal consistency- 0.79 Spearman rank correlation coefficient: 0.11-0.67
Sensory Organization Test [102]	Abnormal score if 95% below the normative data/matched controls	Sensitivity: 54% Specificity:37%
Motor-control Test [108]	Abnormal score if 95% below the normative data/matched controls	Test-retest Reliability: (ICCs=0.66-0.98)
Berg Balance Scale [109]	Increased fall risk with cut off less than or equal to 29	Sensitivity: 82.5% Specificity: 93%

CHAPTER 2

Rationale and objectives for Manuscript

Concussion in adolescents is a common sports and recreational injury. Traditional management of concussion in this age group has focused on return to play and/or regular activities. Despite the tremendous improvements in understanding mTBI, most of the research has been done in young adults. The lack of prospective studies in the pediatric/adolescent age group limits the definitive management required post injury.

Additionally, with numerous studies it is now evident that balance deficits are hallmark sign of mTBI[46,49,95] . However, the cause of imbalance remains unclear during the course of recovery. Scientists suspect that decreased cerebral connectivity or impaired sensory integration could be one of the many reasons for postural instability in mTBI. Despite many studies in the area of postural control after mTBI, controversy still exists pertaining to the precise role of each individual sensory system of balance.

This study will focus on ascertaining the proportion of children presenting with impairments of 2 individual sensory systems, namely visual and vestibular, in the sub-acute period post-concussion, and on exploring the contribution of these sensory systems to the balance deficits observed post-injury. There is a dearth of literature associating oculomotor and vestibular function to balance post mTBI in children. Therefore, with this study, we aim to contribute to the existing literature by helping identify areas that could be the focus of rehabilitation post-injury.

Objectives and Hypothesis:

The objective of this study is to (i) characterize the proportion of children presenting with oculomotor and vestibular deficits after injury and (ii) to estimate the extent to which the presence of clinical oculomotor and vestibular impairments affect functional mobility and balance in children and adolescents one week after a mTBI.

We hypothesize that:

The presence of clinical oculomotor and/or vestibular impairments in children and adolescents in the sub acute stage after an mTBI will relate to the presence of balance impairments.

CHAPTER 3

MANUSCRIPT

***Relationship between Oculomotor and Vestibular Impairments to Functional Mobility in Children following Mild Traumatic Brain Injury*.**

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Manuscript prepared for the submission to Brain Injury Journal.

Running Title: Relationship between Oculomotor and Vestibular Impairments to Functional Mobility in Children following Mild Traumatic Brain Injury.

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3.1 Introduction

Traumatic Brain Injury (TBI) is a significant global public health problem as a major cause of morbidity and disability [1,2]. It is also, one of the most prevalent, acquired neurological conditions occurring in children and young adults [3]. The range of severity of TBI varies, but most TBIs are classified as mild TBI (mTBI) based on standard diagnostic criteria [4]. The annual incidence of mTBI is reported as 100-300 per 100,000 persons [4]. Considering the similarity in mechanisms, the terms mTBI and concussion are often used interchangeably. The deleterious effects of concussion are prominent in the areas of neurocognitive functioning [5-7], balance control [8,9] and self reported symptoms[10,11] .

Balance deficits are hallmark sign of mTBI. Balance control involves the integration of sensory inputs from three systems namely visual, vestibular and somato sensory systems [12]. Numerous investigators have identified postural instability following concussion [9,13-15]. Several hypotheses have been put forward to explain the mechanisms of decreased balance such as impaired visual perception, problems with gaze stability or decreased cerebral connectivity in relation to the sensory information [9,16]. Yet, the incidences of oculomotor and vestibular impairments post mTBI are unknown. Anatomically and physiologically, the oculomotor and vestibular systems are interrelated [17]. The postural deficits observed may relate to the integration of oculomotor and vestibular systems. However, the extent to which oculomotor and vestibular systems could be responsible for the imbalance is not well established. Furthermore, most of the studies have focused on young adults, aged 18 or above[9,14,18] thus, providing little information with respect to pediatric population.

From a rehabilitation perspective, an understanding of the relationship between these two systems to that of balance impairments is important for several reasons. It may help in

designing adaptive management strategies and personalized rehabilitation which in turn can help reduce prolonged recovery. Currently, oculomotor and/or vestibular function testing are not part of common recommended standardized mTBI or concussion assessments, such as the Sport Concussion Assessment Tool-3 (SCAT3). Impairments could therefore go unnoticed making interventions geared to improving balance non-specific and less effective.

The purpose of this study was therefore to (1) determine the proportion of children and adolescents, who present with clinical oculomotor and vestibular function deficits in the first week after sustaining mTBI and (2) explore their relation to functional mobility and balance in children and adolescents.

3.2 Methodology

Participants:

A group of 29 children with an average age of 14.49 year (SD ±1.36), who had sustained an mTBI in the previous week, were recruited from the concussion clinic of the Montreal Children's Hospital, McGill University Health Centre (MCH-MUHC). Table 3.2.1 shows the subjects' characteristics. Of the 29 participants, 75.9% (22) were boys, 75.8% presented with sport-related concussion, and 72.4% had no history of previous concussions. Participants are representative of the population seeking services at the concussion clinic of MCH-MUHC. Children were included if (i) they were aged between 8 to 17 years, and (ii) had sustained an mTBI in the week prior to their visit. Participants were excluded if they (i) presented with any co-morbidities such as a diagnosed cognitive impairment, orthopedic or neuromuscular injuries, (ii) had a pre-injury diagnosis of Attention Deficits Hyperactivity

Disorder (ADHD) or Developmental Co-ordination disorder (DCD), (iii) had a history of concussion in the previous year or (iv) had a history of three or more life time concussions.

Children were recruited on a voluntary basis from the MCH-MUHC concussion clinic, children are usually referred to this clinic after presentation to the Emergency Department of the MCH-MUHC or by their primary care providers. A clinical coordinator introduced the study to the families during their first appointment to the concussion clinic. If the family showed interest, a research assistant; further explained the study in detail and obtained consent. The parents signed a written informed consent, and the children provided written assent. The study was approved by the Research Ethics Board committee (REB) of the MUHC.

Procedure:

Testing took approximately an hour to complete. Children were examined in a quiet room for balance, oculomotor function and vestibular function on the same day and in that order. A single assessor (VB), a trained Physical Therapist who was blind to the clinical exam of the participants, conducted the examination. Information regarding the clinical visit was collected from the child's record after testing was complete. The child was asked to notify the assessor of any discomfort or excessive symptoms during the procedure.

Measures:

Functional mobility was assessed using the Functional Gait Assessment (FGA). The FGA assesses postural stability during various daily walking tasks [19] with items such as 'gait with narrow base of support' , 'ambulating backwards' and 'gait with eyes closed'. We chose the FGA as a measure of functional mobility, because its items involve challenges exceeding those in static balance, especially horizontal and vertical head turns, that could be related to

oculomotor and vestibular impairments. There is a total of 10 items, where each item is scored on an ordinal scale from 0 (severe impairment) to 3 (normal ambulation), with a highest possible score of 30[19,20] . The FGA has shown good psychometric properties and has been previously used in people with vestibular disorders[19,21,22] .

To control for levels of static balance, the child was then asked to stand on the Biodex Balance system (BBS) platform to complete a stability balance assessment. the BBS provides visual feedback of a person's ability to control their center of gravity (COG). The BBS uses a circular platform that is free to move in the anterior–posterior and medial–lateral axes simultaneously, which permits three measures to be obtained: an Overall Stability Index (OSI), an Anterior–posterior Stability Index (APSI), and a Medial-lateral Stability index (MLSI). We conducted bilateral postural stability task on stability level 8 [23], that consisted of 3 trials of 20 seconds each with 10 seconds rest in between each trial.

Oculomotor function was examined with clinical bedside measures for three eye movements namely saccades, smooth pursuit and vergence. The nature of eye movements and the speed at which they occur makes them difficult to identify visually. Hence, the assessor was trained a priori. *Smooth pursuit:* The child's head was held to prevent any movement. The child was asked to follow horizontally and vertically (30 degrees from the centre) a slow moving red colored target at a rate of 0.1 to 1 Hz or 20 degrees per second. The target was held at least 12 inches from child's eyes. The response was noted as normal or abnormal along with the side of affection. A response was considered abnormal if quick saccadic, jerky eye movements were observed during mid range [24]. *Saccades:* The child's head was held to prevent any movement and the child was asked to quickly move eyes to fix his/her gaze between two stationary targets. The response and side of affection were noted. Inability to fixate on target, overshooting the target, and taking more than 2 eye

movements to reach the target indicated an abnormal response [24]. *Vergence:* The child's head was held to prevent any movement. The child was asked to focus on a target kept 2 feet away from child's face and then moved forward towards his/her nose. Symmetrical convergence with pupil constriction was considered a normal response. If the child experienced double vision at more than 6 inches (15.24cm) from his/her nose, vergence was considered abnormal [24].

Vestibular function: Given that the oculomotor system and vestibular system are interrelated, in order for the two clinical vestibular function tests to be valid, normal oculomotor function is required [25]. Thus, only children with no identified deficits in oculomotor function (smooth pursuit, saccades and vergence) went on to be tested for their vestibular function. Two components of vestibular function were tested: the Vestibulo-Ocular Reflex (VOR), and Subjective Visual Vertical (SVV). VOR was assessed through Dynamic Visual Acuity and Subjective Visual Vertical was tested using the Bucket Test.

To determine static visual acuity, the child was asked to identify Lea symbols [26] at a distance of 3 meters/ 9.84 feet. Lea symbols are four symbols randomly distributed over a chart, namely an apple, a circle, a square and a house. Lea symbols were designed to be used with young children, rather than letters traditionally used with adults. The child was instructed to identify the symbols from the bottom most line on the chart until he/she could correctly identify 3 out of 5 symbols. That line was used to determine their static visual acuity (SVA) [27].

The physiotherapist then tipped the child's head to 30 degrees (downward direction, towards the chest) and passively rotated the head for 20 oscillations at a frequency of 2 Hz in the yaw plane. The line where the child could identify 3 out of 5 symbols correctly while

the head was in motion, was recorded. Dynamic visual acuity (DVA) score was calculated as the difference between SVA and DVA lines and a decrement of three or more lines between static and dynamic acuity was considered an abnormal response [27].

The Bucket test is a clinical tool used for bedside evaluation of Subjective Visual Vertical (SVV). The test is performed in a dark room. On the inside bottom of the bucket, is a straight line (glow in dark tape) and on the outside bottom is a plumb line on a protractor. The bucket was placed close to the child's head and the assessor randomly rotated the bucket to either right or left. The child was asked to align the bucket where he/she perceived the inside line (glow in dark tape) to be vertical. Ten repetitions were averaged to obtain SVV value. Normal values for the binocular testing of SVV are 0±2.3° [28]. The DVA and Bucket Test have good psychometric properties with the pediatric population [29].

Once testing was complete, the following were collected from the Medical Records pertaining to their concussion clinic visit. Post concussion symptoms were documented as a part of routine assessment in clinic for children with mTBI. The Post-Concussion Symptom Scale (PCS), which is a 22-item scale designed to measure the severity of symptoms after concussion was used. Individuals rate the symptoms from 0 (no symptom) to 6 (severe symptom) [30]. Participant's characteristics such as history and number of concussions within a year, cause of concussion, their neck range of motion were also noted from the medical chart. Of the 22 self reported post concussion symptoms (PCS) on the PCS scale [30], we focused on two symptoms that may relate to visual, vestibular and postural stability problems. 34.8% of the children in our sample reported dizziness and 27.6% reported blurred vision.

Data Analysis:

Descriptive statistics (Mean, SD, frequency and percentages) were used to describe the sample, including demographic and injury characteristics, as well as study variables of interest.

To address our study objectives, we ran Pearson Product Moment Correlations to determine the relationship between our dependent variable (FGA) and all the independent variables (demographics, injury characteristics, symptoms, oculomotor function and vestibular function.) using SPSS version 17.0.

Because vestibular function was assessed in only those children presenting with no oculomotor deficits, we planned to examine the relationship of oculomotor function to FGA and that of vestibular function to FGA in two different regression models, (i) *FGA with oculomotor function:* Since the post-concussion symptom "blurred vision" could theoretically be a reflection of eye movement impairments, we planned to include it in a stepwise regression model along with the variables targeting oculomotor function specifically (saccades, smooth pursuits, vergence). (ii) *FGA with vestibular function* A self-reported post-concussion symptom related to vestibular function, dizziness, was to be included in a stepwise regression along with the vestibular function variables.

3.3 Results

Refer to table 3.3.1 for the descriptive statistics of the variables of interest. Children and adolescents in our sample had functional mobility deficits with a mean FGA score of 25.7 ± 3.9, which is considered below the 5th percentile for this age group [22]. Although large sample normative data for this age group are not readily available for the BBS indices (OSI, MLSI, APSI), previous work with healthy youth suggest that static balance was within normal limits[31,32] .

Among the three oculomotor control tests, performed on the whole sample of participants (n=29), vergence was found abnormal in 20.7% of the children while saccades and smooth pursuits were found to be abnormal in 13.8% and 6.9% children respectively. Of the 20 children eligible for vestibular testing (children with normal oculomotor function), DVA was reported as abnormal for 47.05% of the 17 children for whom it was available, while SVV was found to be normal in all participants.

Correlations: Correlations between FGA and oculomotor function variables, vestibular function (DVA), Post-Concussion Symptoms and as well as stability indices (OSI, MLSI, APSI) are presented in table 3.3.2. Static balance (OSI, MLSI, APSI) was moderately related to functional mobility (FGA). There was no significant correlation found between saccades or smooth pursuits and functional mobility but vergence was negatively related to functional mobility (FGA) (r= -0.4, p=0.02). Interestingly, smooth pursuit and saccades were related to each other but not to vergence. Children from the total sample reporting greater dizziness on the Post-Concussion Symptom Scale presented with decreased functional mobility scores on the FGA (r= -0.47, p=0.01). However, self-reported blurred vision problems were not correlated to the FGA (r= -0.13, p= 0.48).

In the sample eligible for vestibular function testing, there was no significant relationship between DVA(r=0.03, p=0.88) or dizziness (r=-0.30, p=0.19) to FGA.

Independent regression models:

Oculomotor regression model: Oculomotor variables (saccades, smooth pursuits ,vergence) and blurred vision were entered in a forward stepwise multiple regression with FGA as a dependent variable. Tests for multi co-linearity indicated that a very low level of variance inflation factor for vergence and blurred vision (VIF=1.12) was present. However, saccades and smooth pursuit showed higher VIF (2.02), therefore were not included in the model. Predictor variable, *ß* coefficients and *p* value are mentioned for the Oculomotor regression model in table 3.2.3. Only vergence (p= 0.01) was significantly related to functional mobility. Overall, the oculomotor model accounted for 22% variance with the functional mobility. Because DVA or dizziness showed no significant relationship to FGA, we did not construct a separate regression model for vestibular function.

3.4 Discussion

As expected children and adolescents in our sample presented with functional mobility deficits but no significant problems with static balance. In an effort to explore the nature of these balance difficulties, the objective of our study was to characterize oculomotor and vestibular function in the sub-acute period following concussion in children, as well as explore their relationship to functional mobility.

Abnormal saccades and smooth pursuits were present in 13.6% and 6.9% children respectively. Over 20% of children in our sample presented with abnormal vergence. This proportion exceeds that reported in the general population [33]. This finding is supported by earlier work in the adult population, in which subjects with mTBI (n=21) were examined using infrared videography and were found to exhibit impaired vergence (p<0.05) in comparison to matched controls. Of the three eye movements, it is also vergence that was significantly related to the functional mobility. Vergence involves simultaneous movements of both eyes in opposite directions to maintain a clear binocular vision. Thus, a deficit in vergence may lead to depth perception deficits which may contribute to difficulties during functional mobility [35]. Persons with vergence dysfunction will likely also have difficulties with reading, writing and ambulating through complex environments [36]. The neuromotor control of vergence is not clearly understood [37]. The neural pathways responsible for vergence are located in the mesencephalic reticular formation near the oculomotor nerve in the brainstem. The additional pre-motor components include the medial longitudinal fasciculus, cerebellum and frontal eye fields [38]. Exhibiting adequate vergence thus requires elicitation of various motor and pre motor neuronal pathways. Those axonal pathways that are prone to adverse effect related to diffuse axonal brain injury such as that present in mTBI [39].

Saccades and smooth pursuits were normal in large proportion of population in this study. Previous studies have shown mixed response to saccades and smooth pursuits impairments following a traumatic brain injury. Heitger et al [40], examined eye movements with help of IRIS infra red tracker, in mild closed head injury subjects (n=30, 10 days post injury, aged 15-37 years) and matched them with controls. The author found no abnormality in smooth pursuits (p=0.61), however saccades were significantly impaired (p=0.07). In another study performed by the same group [41], where individuals with post concussion syndrome (PCS) (n=36) were compared to matched controls with mild closed head injury and good recovery (n=36), the PCS group performed worse on saccades (p=0.02) and smooth pursuits (p=0.07) indicating poor oculomotor control. In a study by Braun Peter [42], performed on concussed collegiate athletes (n=140) with the help of King Devik Test, found no significant abnormality (p=0.35) in eye movement control. Kraus et al [43], examined oculomotor function in mild (n=17), moderate and severe TBI subjects (n=19) and found that saccades were significantly impaired (p=0.001) particularly in mTBI group.

We tested vestibular function in the current study with focus on the Vestibulo-Ocular reflex (VOR) and Subjective Visual Vertical. 47.05% of the children eligible for vestibular testing presented with a VOR impairment. This finding may be explained by the fact that following acute loss of vestibular function, the Central Nervous System (CNS) gradually adapts by increasing reliance upon other available sensory information. This compensation is likely to be complete when the vestibular loss occurs slowly, as seen with aging. If, on the other hand, the vestibular loss occurs quickly; as in the case of a trauma, the compensation remains incomplete [44] leading to observable VOR impairments. The specific mechanism responsible for the vestibular impairment observed in the mTBI children remains unclear. An insult to the vestibular system sustained during trauma could be either

peripheral or central. In peripheral vestibular injury, structures of the inner ear itself are damaged while in injury to the central vestibular system, it is the vestibular pathways responsible to integrate the input with the cerebellum and midbrain to execute movements that are affected [45]. It was also noted in our study, that the observed VOR impairments were not related to the functional mobility. One of the reasons could be, that functional mobility tasks did not demand the integration of VOR specifically. For instance, the tasks included horizontal and vertical head turns, but it did not ask specifically to focus on a target while doing the head turns, which is when actually the VOR is required. Further studies will be necessary to investigate the mechanisms responsible for our observed impairments.

Interestingly, dizziness was not significantly related to the functional mobility in the group of children eligible for vestibular testing (n=20). This could be because the FGA did not involve tasks that could be affected due to presence of dizziness. It is also possible that the dizziness in our population was not severe enough to impact upon the daily functional mobility.

Strength and weakness:

The strength of the study lies in the fact that it is one of the first studies using bedside clinically available testing of oculomotor and vestibular function following concussion specifically in pediatric population. The rationale behind this study was to include basic clinical tests that could be incorporated in rehabilitation settings and would not demand high levels of expensive technology. It is also the first study to examine subjective visual vertical using the bucket test in children post-mTBI. However, the study also has limitations. The participants were recruited from a single centre, and although it provides care to a diverse population, generalization of our results can be difficult. There was no

control group with which to compare our sample of injured children and our sample size was small which limited the use of more powerful statistical analysis.

3.5 Conclusion

In summary, children presented with clinical oculomotor and vestibular deficits in the sub-acute stage following mTBI. Children also exhibited functional mobility deficits. Except for vergence, neither oculomotor nor vestibular deficits were significantly related to functional mobility following mTBI in children. Static balance was normal in our population. Despite the fact that they were not related to functional mobility, such impairments may be responsible for a number of self-reported post-concussion symptoms and could be the object of specific targeted intervention. We therefore recommend the inclusion of basic clinical tests for oculomotor and vestibular function to screen children and adolescents post-mTBI. Since the problems do not come from oculomotor or vestibular function specifically, it has to come from other factors which further needs to be investigated.

Tables

Table 3.2.1 Participant's characteristics:

Characteristics	**Mean (SD) or %**
Age	14.49 (±1.36)
Gender	
Boys	22(75.9%)
Girls	7(24.1%)
Post injury days	6.27(±2.95)
Cause of injury	
Contact Sports	22 (75.8%)
Others	7 (24.1%)
Number of previous concussions	
0	21 (72.4%)
1	4 (13.7%)
2	4 (13.7%)
Post-Concussion Symptom Scale Total	21.68 (±21.95)
Dizziness	1.03 (± 1.34)
Blurred Vision	0.65 (± 1.00)

Table 3.3.1 Descriptive statistics for the total sample of children: (n=29)

Variables	**Mean (SD) or %**
Saccades	
Normal	25 (86.2%)
Abnormal	4 (13.8%)
Smooth pursuits	
Normal	27 (93.1%)
Abnormal	2 (6.9%)
Vergence	
Normal	23 (79.3%)
Abnormal	6 (20.7%)
Dynamic Visual Acuity *(n=17)*	
Normal (<3 lines difference)	9 (52.94%)
Abnormal (>3 lines difference)	8 (47.05%)
Bucket Test *(n=17)*	
Normal (<±2.3˚)	0.41˚(±0.08)
Abnormal (>±2.3˚)	-
Functional Gait Assessment	25.68 (±3.91)
Biodex Balance System	
OSI	0.74 (±0.39)
APSI	0.59 (±0.36)
MLSI	0.32 (±0.16)

Table 3.3.2 Pearson correlation coefficient with functional mobility (FGA)

Variables	**Correlation coefficient *r***	***p* value**
Correlation for total sample of children ***n=29***		
Overall Stability Index	**-0.600**	**0.001****
Anterior Posterior Stability Index	**-0.523**	**0.001****
Medial-lateral Stability Index	-0.312	0.10
Vergence	**-0.423**	**0.02***
Saccades	0.032	0.86
Smooth pursuits	0.022	0.91
Dizziness	**-0.471**	**0.01***
Blurred Vision	-0.136	0.48
Correlations for children eligible for vestibular testing ***n=20***		
Overall Stability Index	**-0.60**	**0.005****
Anterior Posterior Stability Index	**-0.50**	**0.007****
Medial-lateral Stability Index	-0.21	0.35
Dynamic Visual Acuity	0.03	0.88
Dizziness	-0.30	0.19
Blurred Vision	-0.37	0.10

** : Correlation is significant at 0.01 level (2-tailed).

* : Correlation is significant at 0.05 level (2-tailed).

Table 3.3.3: Multiple linear regression predicting the relationship between clinical oculomotor function to functional mobility (FGA).

Regression Model	Predictor Variable	R	R^2	Un standardized ß coefficients	Standard Error	Standardized ß coefficients	t	*p* value
Oculomotor Function	Constant	-	-	27.13	0.90	-	30.10	0.00*
	Vergence	0.47	0.22	-4.35	1.66	-0.45	-2.61	0.01*
	Blurred vision			-0.82	0.68	-0.21	-1.21	0.23

Constant = FGA score.
* ***p*** value <0.05

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CHAPTER 4

Summary and Conclusion

It is now widely recognized that balance deficits are hallmark sign of mTBI[46,49,95] even in the pediatric population. We initiated our study with the desire to contribute to the body of knowledge regarding the nature of these impairments, which despite the efforts of many over the last few years, remains largely unclear. We chose to focus our attention on 2 specific sensory systems, visual and vestibular, known to contribute to the maintenance of balance. The objectives of our study were therefore to determine the presence of clinical oculomotor and vestibular function deficits in the sub acute stage following mTBI in children and adolescents as well as to explore whether such deficits could be related to functional mobility and balance in our population.

Our results, lead us to conclude that children and adolescents do indeed present with clinical oculomotor and vestibular impairments following mTBI. However, we also revealed that, amongst the examined oculomotor and vestibular impairments, it was only vergence that was related to functional mobility. At this point, we can therefore only say that the observed impairments could be one of the contributing factors to the functional mobility difficulties but not the whole story. Further research will therefore be necessary in order to improve our understanding of the nature of functional mobility or balance deficits after mTBI.

We need to stress however, that while the oculomotor or vestibular impairments are not related to functional mobility, it remains important to evaluate these problems, as they are

not always 'clinically obvious' particularly in this population [92]. Despite the fact that the impairments were not related to functional mobility, they may be responsible for a number of self-reported post-concussion symptoms and could be the object of specific targeted intervention. We therefore recommend the inclusion of basic clinical tests for oculomotor and vestibular function to screen children and adolescents post-mTBI.

By far this is the first study exploring the clinical oculomotor and vestibular deficits in children following mTBI and relating the deficits to the functional mobility. Since the impairments are not coming from either the oculomotor or vestibular system, it has to come from some other factors. We recommend future research in order to further investigate the mechanisms responsible for balance deficits observed post mTBI.

APPENDIX

A. Post-Concussion Symptom Scale (PCS)

B. Functional Gait Assessment (FGA)

C. D. Informed Consent Form (English)

D. Informed Consent Form (French)

E. Assent Form (English)

F. Assent Form (French)

G. Data collection Manual

H. Compensation Form

I. Medical chart Information Form

J. Ethics and Confidentiality

K. Sample Size

Concussion Grading Scale

The Post concussion Symptom Scale is essentially a "state" measure of perceived symptoms associated with concussion. That is, the athlete is asked to report his or her "current" experience of the symptoms. This allows tracking of symptoms over very short intervals, such as consecutive days or every few days.

Directions: After reading each symptom, please circle the number that best describes the way the athlete has been feeling today. A rating of 0 means they have not experienced this symptom today. A rating of 6 means they have experienced severe problems with this symptom today.

Date tested							
Date of Last known concussion(s)							
SYMPTOM	**None**	**Mild**		**Moderate**		**Severe**	
Headache	0	1	2	3	4	5	6
Nausea	0	1	2	3	4	5	6
Vomiting	0	1	2	3	4	5	6
Balance Problems	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Fatigue	0	1	2	3	4	5	6
Trouble Falling Asleep	0	1	2	3	4	5	6
Sleeping More Than Usual	0	1	2	3	4	5	6
Sleeping Less Than Usual	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Sensitivity to Light	0	1	2	3	4	5	6
Sensitivity to Noise	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervousness	0	1	2	3	4	5	6
Feeling More Emotional	0	1	2	3	4	5	6
Numbness or Tingling	0	1	2	3	4	5	6
Feeling Slowed Down	0	1	2	3	4	5	6
Feeling Mentally "Foggy"	0	1	2	3	4	5	6
Difficulty Concentrating	0	1	2	3	4	5	6
Difficulty Remembering	0	1	2	3	4	5	6
Visual Problems (double vision, blurring, etc)	0	1	2	3	4	5	6
TOTAL SYMPTOM SCORE:							
GRAND TOTAL OF ALL SYMPTOMS:							

Functional Gait Assessment

Requirements: A marked 6-m (20-ft) walkway that is marked with a 30.48-cm (12-in) width.

_____1. GAIT LEVEL SURFACE

Instructions: *Walk at your normal speed from here to the next mark (6 m[20 ft]).*

Grading: Mark the highest category that applies.

(3) Normal—Walks 6 m (20 ft) in less than 5.5 seconds, no assistive devices, good speed, no evidence for imbalance, normal gait pattern, deviates no more than 15.24 cm (6 in) outside of the 30.48-cm (12-in) walkway width.

(2) Mild impairment—Walks 6 m (20 ft) in less than 7 seconds but greater than 5.5 seconds, uses assistive device, slower speed, mild gait deviations, or deviates 15.24–25.4 cm (6–10 in) outside of the 30.48-cm (12-in) walkway width.

(1) Moderate impairment—Walks 6 m (20 ft), slow speed, abnormal gait pattern, evidence for imbalance, or deviates 25.4–38.1 cm (10–15 in) outside of the 30.48-cm (12-in) walkway width. Requires more than 7 seconds to ambulate 6 m (20 ft).

(0) Severe impairment—Cannot walk 6 m (20 ft) without assistance, severe gait deviations or imbalance, deviates greater than 38.1 cm (15 in) outside of the 30.48-cm (12-in) walkway width or reaches and touches the wall.

_____2. CHANGE IN GAIT SPEED

Instructions: *Begin walking at your normal pace (for 1.5 m [5 ft]). When I tell you "go," walk as fast as you can (for 1.5 m [5 ft]). When I tell you "slow," walk as slowly as you can (for 1.5 m [5 ft]).*

Grading: Mark the highest category that applies.

(3) Normal—Able to smoothly change walking speed without loss of balance or gait deviation. Shows a significant difference in walking speeds between normal, fast, and slow speeds. Deviates no more than 15.24 cm (6 in) outside of the 30.48-cm (12-in) walkway width.

(2) Mild impairment—Is able to change speed but demonstrates mild gait deviations, deviates 15.24–25.4 cm (6–10 in) outside of the 30.48-cm (12-in) walkway width, or no gait deviations but unable to achieve a significant change in velocity, or uses an assistive device.

(1) Moderate impairment—Makes only minor adjustments to walking speed, or accomplishes a change in speed with significant gait deviations, deviates 25.4–38.1 cm (10–15 in) outside the 30.48-cm (12-in) walkway width, or changes speed but loses balance but is able to recover and continue walking.

(0) Severe impairment—Cannot change speeds, deviates greater than 38.1 cm (15 in) outside 30.48-cm (12-in) walkway width, or loses balance and has to reach for wall or be caught.

_____3. GAIT WITH HORIZONTAL HEAD TURNS

Instructions: *Walk from here to the next mark 6 m (20 ft) away. Begin walking at your normal pace. Keep walking straight; after 3 steps, turn your head to the right and keep walking straight while looking to the right. After 3 more steps, turn your head to the left and keep walking straight while looking left. Continue alternating looking right and left*

every 3 steps until you have completed 2 repetitions in each direction.
Grading: Mark the highest category that applies.

(3) Normal—Performs head turns smoothly with no change in gait. Deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width.

(2) Mild impairment—Performs head turns smoothly with slight change in gait velocity (eg, minor disruption to smooth gait path), deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width, or uses an assistive device.

(1) Moderate impairment—Performs head turns with moderate change in gait velocity, slows down, deviates 25.4–38.1 cm (10– 15 in) outside 30.48-cm (12-in) walkway width but recovers, can continue to walk.

(0) Severe impairment—Performs task with severe disruption of gait (eg, staggers 38.1 cm [15 in] outside 30.48-cm (12-in) walkway width, loses balance, stops, or reaches for wall).

_____4. GAIT WITH VERTICAL HEAD TURNS

Instructions: *Walk from here to the next mark (6 m [20 ft]). Begin walking at your normal pace. Keep walking straight; after 3 steps, tip your head up and keep walking straight while looking up. After 3 more steps, tip your head down, keep walking straight while looking down. Continue alternating looking up and down every 3 steps until you have completed 2 repetitions in each direction.*
Grading: Mark the highest category that applies.

(3) Normal—Performs head turns with no change in gait. Deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width.

(2) Mild impairment—Performs task with slight change in gait velocity (eg, minor disruption to smooth gait path), deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width or uses assistive device.

(1) Moderate impairment—Performs task with moderate change in gait velocity, slows down, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width but recovers, can continue to walk.

(0) Severe impairment—Performs task with severe disruption of gait (eg, staggers 38.1 cm [15 in] outside 30.48-cm (12-in) walkway width, loses balance, stops, reaches for wall).

_____5. GAIT AND PIVOT TURN

Instructions: *Begin with walking at your normal pace. When I tell you, "turn and stop," turn as quickly as you can to face the opposite direction and stop.*
Grading: Mark the highest category that applies.

(3) Normal—Pivot turns safely within 3 seconds and stops quickly with no loss of balance.

(2) Mild impairment—Pivot turns safely in _3 seconds and stops with no loss of balance, or pivot turns safely within 3 seconds and stops with mild imbalance, requires small steps to catch balance.

(1) Moderate impairment—Turns slowly, requires verbal cueing,

or requires several small steps to catch balance following turn and stop.

(0) Severe impairment—Cannot turn safely, requires assistance to turn and stop.

_____6. STEP OVER OBSTACLE

Instructions: *Begin walking at your normal speed. When you come to the shoe box, step over it, not around it, and keep walking.*
Grading: Mark the highest category that applies.

(3) Normal—Is able to step over 2 stacked shoe boxes taped together (22.86 cm [9 in] total height) without changing gait speed; no evidence of imbalance.

(2) Mild impairment—Is able to step over one shoe box (11.43 cm [4.5 in] total height) without changing gait speed; no evidence of imbalance.

(0) Moderate impairment—Is able to step over one shoe box (11.43 cm [4.5 in] total height) but must slow down and adjust steps to clear box safely. May require verbal cueing.

(0) Severe impairment—Cannot perform without assistance.

_____7. GAIT WITH NARROW BASE OF SUPPORT

Instructions: *Walk on the floor with arms folded across the chest, feet aligned heel to toe in tandem for a distance of 3.6 m [12 ft]. The number of steps taken in a straight line are counted for a maximum of 10 steps.*
Grading: Mark the highest category that applies.

(3) Normal—Is able to ambulate for 10 steps heel to toe with no staggering.

(2) Mild impairment—Ambulates 7–9 steps.

(1) Moderate impairment—Ambulates 4–7 steps.

(0) Severe impairment—Ambulates less than 4 steps heel to toe or cannot perform without assistance.

_____8. GAIT WITH EYES CLOSED

Instructions: *Walk at your normal speed from here to the next mark (6 m [20 ft]) with your eyes closed.*
Grading: Mark the highest category that applies.

(3) Normal—Walks 6 m (20 ft), no assistive devices, good speed, no evidence of imbalance, normal gait pattern, deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width. Ambulates 6 m (20 ft) in less than 7 seconds.

(2) Mild impairment—Walks 6 m (20 ft), uses assistive device, slower speed, mild gait deviations, deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width. Ambulates 6 m (20 ft) in less than 9 seconds but greater than 7 seconds.

(1) Moderate impairment—Walks 6 m (20 ft), slow speed, abnormal gait pattern, evidence for imbalance, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width. Requires more than 9 seconds to ambulate 6 m (20 ft).

(0) Severe impairment—Cannot walk 6 m (20 ft) without assistance, severe gait deviations or imbalance, deviates greater than 38.1 cm (15 in) outside 30.48-cm (12-in) walkway width or will not attempt task.

_____9. AMBULATING BACKWARDS

Instructions: *Walk backwards until I tell you to stop.*
Grading: Mark the highest category that applies.

(3) Normal—Walks 6 m (20 ft), no assistive devices, good speed, no

more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width.

(2) Mild impairment—Walks 6 m (20 ft), uses assistive device, slower speed, mild gait deviations, deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width.

(1) Moderate impairment—Walks 6 m (20 ft), slow speed, abnormal gait pattern, evidence for imbalance, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width.

(0) Severe impairment—Cannot walk 6 m (20 ft) without assistance, severe gait deviations or imbalance, deviates greater than 38.1 cm (15 in) outside 30.48-cm (12-in) walkway width or will not attempt task.

_____10. STEPS

Instructions: *Walk up these stairs as you would at home (ie, using the rail if necessary). At the top turn around and walk down.*

Grading: Mark the highest category that applies.

(3) Normal—Alternating feet, no rail.

(2) Mild impairment—Alternating feet, must use rail.

(1) Moderate impairment—Two feet to a stair; must use rail.

(0) Severe impairment—Cannot do safely.

TOTAL SCORE: _____ MAXIMUM SCORE 30

Hôpital de Montréal pour enfants
Centre universitaire de santé McGill

Montreal Children's Hospital
McGill University Health Centre

INFORMED CONSENT

Relationship between oculomotor deficits, vestibular deficits and balance in children following mild traumatic brain injury.

Principal Investigator: Dr Isabelle Gagnon, PhD
Researcher, Trauma and General Pediatrics,
Montreal Children's Hospital, McGill University Health Centre
Assistant Professor, School of Physical and Occupational Therapy.
Mc Gill University.

Sponsor/Funded By: Dr. Isabelle Gagnon's internal funds.

'You' refers to you or your child.

Purpose and General Information:

The purpose of this study is to examine eye movements and inner ear function in children and adolescents who have had a mild traumatic brain injury or concussion and to see whether findings of the examination relate to balance.

A total of 40 children with mild traumatic brain injury are expected to participate in this study. Your participation will involve you to be tested at concussion clinic of Montreal Children's Hospital. You will be tested on the same day as your appointment and will require about 60 minutes of extra time.

Study procedures:

The Study will be conducted in a quiet room at the Montreal Children's Hospital by a research assistant. First we will assess balance by asking you to walk on a level surface with head turns, step over and around obstacles as well as by asking you to stand upright on a movable surface with your eyes open and eyes closed.

Breaks will be given at different times during the testing.

Following the balance tests, a trained physiotherapist will examine your eye movements and inner ear function. For eye movements, you are required to follow simple commands such as follow and focus on target placed at different directions. Inner ear function will be examined with help of several tests which involve for example identification of symbols on a chart while your head is moving. In order to obtain required information for the study, the principal investigator will have access to your hospital records.

Possible Risks and Discomfort:

Your participation will not place you at any risk of injury. You may be disappointed if you cannot perform task to your optimum level.

Possible Benefits:

You may or may not benefit from the study. Data from this project are intended to provide insight into the proper assessment of the concussion therefore you will contribute to new knowledge which may benefit other children in the future.

Compensation:

There will be no compensation for participating in this study. However, out of pocket expenses such as parking, transportation and babysitting will be covered with up to $25.00/ per study visit.

Voluntary Participation:

With no obligation, participation in this study is voluntary. You are free to withdraw at any point of time. Your decision to refuse to participate or withdrawal will not affect the services provided to you at this hospital. If you choose to discontinue, please contact Dr. Isabelle Gagnon, Principal Investigator at 514-412-4400 x22001 or Vishwa Buch, research assistant at 514-806-9128.

During the course of the study you will be informed of any new findings which may affect your willingness to continue participation in this study.

Confidentiality:

All information obtained during the study will be kept confidential as required or permitted by law and will be kept for 5 years. Your personal identity will remain confidential, as you will only be identified by a subject identification number.

Your name and other personal identifying information will be replaced by a study code and will not be used in any reports, presentations or publications. If the results of this study are published, you will not be identified in any way. Your personal information will be kept strictly confidential except as required or permitted by law. Representatives from Health Canada, the sponsor, and the McGill University Health Centre Research Institute Quality Assurance, may have access to your records as it pertains to this study. The research team will have access to your hospital records.

Contact Person:

Should you have any questions or desire further information, please contact :

Dr. Isabelle Gagnon- (514) 412-4407 x22001

For additional information regarding your (child's) rights as a research subject, you may contact the hospital's Patient Representative (ombudsman), Patricia Boyer (514) 412-4400 ext. 22223, who is independent of the investigator, and works to protect patients' rights.

Consent

I have read this information and consent form and have had the opportunity to ask questions which have been answered to my satisfaction before signing my name. I acknowledge that I will receive a copy of the Information and Consent Form for future reference. I agree to (have my child) participate in the research study.

Participant's name: _____

Parent or legal guardian's printed name: _____

Parent or legal guardian's signature: _____

Relationship to child: _____

Date: (dd/month/yy): _____

Name of the person who obtained consent: _____

Signature of the person who obtained consent : _____

Date: (dd/month/yy): _____

Hôpital de Montréal pour enfants
Centre universitaire de santé McGill

Montreal Children's Hospital
McGill University Health Centre

CONSENTEMENT

Relation entre les déficits oculomoteurs, les déficits vestibulaires et l'équilibre chez les enfants après un traumatisme craniocérébral léger

Chercheur principal : Isabelle Gagnon
Chercheure traumatologie et développement de l'enfant
Hôpital de Montréal pour enfants Professeure adjointe
École de physiothérapie et d'ergothérapie
Université McGill

Financement : L'étude est financée par les fonds internes du Dr Isabelle Gagnon.

«Vous» fait référence à vous ou à votre enfant.

Objectif et renseignements généraux:

Le but de cette étude est d'examiner le mouvement des yeux ainsi que la fonction de l'oreille interne chez les enfants et les adolescents qui ont eu un traumatisme craniocérébral léger ou une commotion cérébrale. Nous évaluerons ensuite si les résultats de l'examen sont en lien avec l'équilibre.
Un total de 40 enfants avec traumatisme craniocérébral léger seront recrutés pour participer à cette étude. La participation de votre enfant consistera à une séance d'évaluation à la clinique de commotion cérébrale de l'hôpital de Montréal pour enfants. Votre enfant sera testé la même journée que son rendez-vous en clinique et la séance supplémentaire aura une durée d'environ 60 minutes.

Les procédures d'étude :

L'étude sera menée par un assistant de recherche dans une pièce tranquille à l'hôpital de Montréal pour enfants. Nous allons d'abord évaluer l'équilibre de votre enfant en lui demandant par exemple de marcher tout en tournant sa tête, ainsi que d'enjamber et de contourner des obstacles. De plus, nous allons demander à votre enfant de se tenir debout sur une surface instable avec ses yeux ouverts ou fermés.

Des pauses seront données à des moments stratégiques durant les essais.

Après les tests d'équilibre, un physiothérapeute qualifié examinera le mouvement des yeux et les fonctions de l'oreille interne de votre enfant. Pour les mouvements oculaires, votre enfant devra suivre des commandes simples telles que suivre et se concentrer sur une cible placée dans des directions différentes. Les fonctions de l'oreille interne seront examinées avec l'aide de quelques tests qui impliquent des mouvements de la tête.

Pour obtenir des informations requises pour l'étude, la chercheure principale aura accès au dossier hospitalier de votre enfant.

Risques et inconvénients

Il n'y a pas risque de blessures pour votre enfant lors de cette étude. Votre enfant pourrait être déçu s'il ou elle ne peut pas effectuer la tâche à son niveau optimal.

Avantages possibles:

Il n'y a pas de bénéfice direct lié à votre participation à cette étude. Les informations que nous recevrons de cette étude pourront, ultérieurement, améliorer les soins donnés aux enfants avec les blessures à la tête.

Compensation :

Il n'y aura pas de compensation pour participer à cette étude. Cependant, des frais additionnels comme le stationnement, le transport en commun et la garde d'enfants seront couverts (jusqu'à 25.00 $ par visite).

Liberté de participation

Votre participation à cette étude est volontaire et vous ne devriez pas sentir d'obligation à participer. En tout temps et peu importe la raison, vous pouvez vous retirer de l'étude. Le refus de participer n'affectera pas la qualité des soins prodigués à votre enfant. Si vous choisissez de mettre fin à votre participation, s'il vous plaît communiquer avec Dr Isabelle Gagnon , chercheure principale au 514-412-4400 x22001 ou Vishwa Buch , assistante de recherche au 514-806-9128.

Au cours de l'étude, vous serez informé de toute nouvelle découverte qui pourrait affecter votre volonté de continuer à participer à cette étude.

Confidentialité:

Tous les renseignements obtenus lors de cette étude seront tenus confidentiels comme requis ou permis par la loi et seront conservés pendant 5 ans. L'identité personnelle de votre enfant restera confidentielle puisqu'il sera identifié par un numéro d'identification de sujet.

Le nom et d'autres informations d'identification personnelle de votre enfant seront remplacés par un code d'étude et ne seront pas utilisés dans des rapports, des présentations ou des publications. Si les résultats de cette étude sont publiés, vous ne serez pas identifié d'aucune façon. Vos informations personnelles resteront strictement confidentielles, sauf tel que requis ou permis par la loi. Des représentants de Santé Canada, le promoteur et le Centre universitaire de santé McGill institut de recherche (CUSM IR) pourraient avoir accès à vos dossiers en lien à cette étude. L'équipe de recherche aura accès à vos dossiers hospitaliers.

Personne à contacter:

Si vous avez des questions ou désirez de plus amples informations, s'il vous plaît contacter : Dr Isabelle Gagnon- (514) 412-4407 x22001.

Si vous avez des questions concernant vos droits comme participant à cette étude, vous pouvez communiquer avec la représentante des patients (ombudsman) de l'hôpital de Montréal pour enfants, Patricia Boyer au (514) 412-4400 poste 22223. Elle est indépendante des chercheurs et travaille afin de protéger les droits des patients.

Consentement :

J'ai lu le formulaire de consentement et eu l'opportunité de poser des questions auxquelles on a répondu à ma satisfaction avant de signer mon nom. Je reconnais que je recevrai une copie du formulaire de consentement comme référence. J'accepte que mon enfant participe à ce projet de recherche.

Nom du participant :_____

Nom de la personne/tuteur légal :_____

Date de consentement (dd/mois/aaaa):_____

Nom de la personne qui a obtenu le consentement :_____

Signature :_____

Date de consentement (dd/mois/aaaa) :_____

Hôpital de Montréal pour enfants
Centre universitaire de santé McGill

Montreal Children's Hospital
McGill University Health Centre

ASSENT FORM

Relationship between oculomotor deficits, vestibular deficits and balance in children following mild traumatic brain injury.

Principal Investigator: Dr Isabelle Gagnon, PhD
Researcher, Trauma and General Pediatrics,
Montreal Children's Hospital, Mc Gill University Health Centre
Assistant Professor, School of Physical and Occupational Therapy.
Mc Gill University.

Sponsor/Funded By: Dr. Isabelle Gagnon's internal funds.

You are invited to participate in a research study.

What is this study about?

In this study we will examine eye movements and ear, in children and adolescents who have had a mild traumatic brain injury or concussion .This will help us understand if findings of the examination relate to balance performance.

Your participation will involve you to be tested at concussion clinic of Montreal Children's Hospital.
You will be tested on same day as your appointment and will require about 60 minutes of extra time.

What will I have to do?

Study will be conducted in a quiet room at the Montreal Children's Hospital by a research assistant.

First we will assess balance with the help of a physiotherapy test and a machine. For example, the physiotherapy test examines if you are able to walk with head turns, step over and around obstacles placed in your way. While on machine you will be asked to stand upright on a moving surface with eyes open and eyes closed.

Breaks will be given at different times during the testing.

Following the balance tests, a physiotherapist will examine your eye movements and inner ear. For eye movements, you are required to follow simple commands such as follow an object placed at different directions (up, down, left and right). Your inner ear will be examined with several tests which involve identification of certain drawings on a chart while moving your head for example.

In order to obtain required information for the study, the principal investigator will have access to your hospital records.

What Are the Possible Risks and Discomforts?

Your participation will not place you at any risk of injury. You also may be disappointed if you cannot perform the tests perfectly.

What Are the Possible Benefits?

You will not benefit from the study. Data from this project will help provide information into the proper assessment of the concussion therefore you will contribute to new medical knowledge which may benefit other children in the future.

Will I Get Paid?

You will not be paid for your participation.

What Are My Options?

Participation in this study is voluntary. You should not feel any obligation. You may agree now and you are free to withdraw at any point of time, no one will be mad at you. Your decision to refuse to participate or if you discontinue will not affect your care by your doctor. If you choose to discontinue, please contact Dr. Isabelle Gagnon, Principal Investigator at 514-412-4400 x22001 or Vishwa Buch, research assistant at 514-806-9128.

During the course of the study you will be informed of any new findings which may affect your willingness to continue participation in this study.

Who Will Know What I Did?

All information obtained during the study will be kept confidential as required or permitted by law and will be kept for 5 years. Your personal identity will remain confidential, as you will only be identified by a subject identification number.

Your name and other personal identifying information will not be used in any reports, presentations or publications.

If the results of this study are published, you will not be identified in any way. Your personal information will be kept strictly confidential except as required or permitted by law. Representatives from Health Canada, the sponsor, and the McGill University Health Centre Research Institute Quality Assurance, may have access to your records as it pertains to this study. The research team will have access to your hospital records.

Who Can I Contact if I Have Questions?

Should you have any questions or desire further information, please contact :

Dr. Isabelle Gagnon- (514) 412-4407 x22001

Vishwa Buch – (514)-806-9128.

Assent:

I have read this information and have had the opportunity to ask questions which have been answered to my satisfaction before signing my name. I agree to participate in the research study.

_____

Participant's name:

_____

Participant's signature:

_____

Date: (dd/month/yy)

_____

Name of the person who explained the assent

_____

Signature of the person who explained the assent

_____

Date: (dd/month/yy)

Hôpital de Montréal pour enfants
Centre universitaire de santé McGill

Montreal Children's Hospital
McGill University Health Centre

FORMULAIRE D'ASSENTIMENT

Relation entre les déficits oculomoteurs, les déficits vestibulaires et l'équilibre chez les enfants après un traumatisme craniocérébral léger

Chercheur principal: Dr Isabelle Gagnon, Ph.D.
Chercheur, Trauma et pédiatrie générale,
Hôpital de Montréal pour enfants, Centre universitaire de santé Mc Gill Professeure adjointe, École de physiothérapie et d'ergothérapie, Université McGill

Financement : L'étude est financée par les fonds internes du Dr Isabelle Gagnon.

Tu es invité à participer à une étude de recherche.

Quelle est cette étude?

Dans cette étude, nous allons examiner le mouvement des yeux et l'équilibre chez les enfants et les adolescents qui ont eu un traumatisme craniocérébral léger ou une commotion cérébrale.

Ta participation consistera à être testé à la clinique de commotion cérébrale de l'hôpital de Montréal pour enfants. Tu seras testé la même journée que ton rendez-vous et cela prendra environ 60 minutes de temps supplémentaire.

Que dois-je faire?

L'étude sera menée par un assistant de recherche dans une pièce tranquille à l'hôpital de Montréal pour enfants.

Nous allons d'abord évaluer l'équilibre à l'aide d'un test de physiothérapie et d'une machine. Par exemple, le test de physiothérapie examine si tu es capable de marcher tout en tournant la tête, ainsi que passer par dessus et contourner des obstacles placés sur ton chemin. Lors des tests avec la machine, tu seras invité à te tenir debout sur une surface instable avec les yeux soit ouverts ou fermés.

Des pauses seront données à divers moments durant les essais.

Après les tests d'équilibre, un physiothérapeute examinera tes mouvements des yeux et comment tu te sent quand ta tête est bougée. Pour le mouvement des yeux, on te demandera de suivre des commandes simples telles que suivre un objet placé à différentes endroits (haut, bas, gauche et droite).

Tes mouvements de tête seront examinés avec plusieurs tests qui impliquent de tourner la tête pendant que tu regardes des dessins sur un mur par exemple.

Pour obtenir les informations requises pour l'étude, la chercheure principale aura accès à ton dossier médical.

Quels sont les risques et les malaises possibles?

Ta participation ne te mettra pas à risque de blessure, mais tu peux être déçu si te ne peux pas effectuer parfaitement les tests.

Quels sont les avantages possibles?

Tu n'auras pas de bénéfices à participant, mais tu contribueras à créer de nouvelles connaissances au profit d'autres enfants à l'avenir.

Serai-je payé?

Tu ne seras pas payé pour ta participation.

Quelles sont mes choix ?

Tu n'as aucune obligation car ta participation est volontaire. Tu peux accepter maintenant et retirer ta participation de cette étude à tout moment. Personne ne se fâchera contre toi. Ton refus ou ton retrait de cette étude n'affectera pas les soins reçus de ton médecin. Si vous désirez mettre fin à l'étude, s'il te plaît communiquer avec Dr Isabelle Gagnon , chercheure principale au 514-412-4400 x22001 ou Vishwa Buch , assistante de recherche au 514-806-9128 .

Pendant la durée de l'étude tu seras informé de toute nouvelle conclusion qui pourrait affecter ta volonté de continuer ta participation à l'étude.

Ton nom ainsi que tes autres données personnelles ne seront utilisés dans aucun rapport, présentation ou publication.

Si les résultats de cette étude sont publiés, tu ne seras pas identifié. Tes informations personnelles resteront totalement confidentielles sauf lorsque requis par la loi. Les représentants de Santé Canada, l'Institut de recherche de l'Hôpital de Montréal pour enfants, les représentants du comité d'étique de la recherche et du Programme de l'assurance de qualité du centre universitaire de santé de McGill, pourront avoir accès à tes dossiers à des fins de vérification des procédures de l'étude. L'équipe de recherche aura accès à ton dossier de l'hôpital.

Qui puis-je contacter si j'ai des questions?

Isabelle Gagnon, chercheure principale au : (514) 412-4400 poste# 22001

ou Vishwa Buch - (514) -806 à 9128.

Assentiment:

J'ai lu cette information et j'ai eu l'opportunité de poser mes questions et j'ai obtenu des réponses satisfaisantes avant de signer mon nom. Je suis d'accord pour participer à ce projet de recherche.

_____

Nom du participant:

_____

Signature du participant

_____

Date: (JJ/ MM/AA)

_____

Nom de la personne qui explique l'assentiment:

_____

Signature de la personne qui explique l'assentiment

_____

Date: (JJ/ MM/AA)

DATA COLLECTION MANUAL

Date of Evaluation:

Patient ID:	
Age:	
Gender:	
Date of injury:	

Balance Assessment:

FGA Score:		
BBS Score:		

Tandem gait (as per SCAT 3):

Pass or Fail	
If pass, note the best time here	seconds

Oculomotor function:

Eye movements	Normal	Abnormal	Remarks (Side)
Smooth Pursuit			
Saccades			
Vergence			

SVA line:	DVA line:	Difference:

Bucket test		Best of Trials
Trial 1		
Trial 2		
Trial 3		
Trial 4		
Trial 5		
Trial 6		
Trial 7		
Trial 8		
Trail 9		
Trail 10		
Average:		

COMPENSATION FORM

Hôpital de Montréal pour enfants
Centre universitaire de santé McGill

Montreal Children's Hospital
McGill University Health Centre

RELATIONSHIP BETWEEN OCULOMOTOR DEFICITS, VESTIBULAR DEFICITS, AND BALANCE IN CHILDREN FOLLOWING A MILD TRAUMATIC BRAIN INJURY.

Date: _____

_____ (please print patient's name) has participated in this study.

☐ has received a $20.00 compensation for his/her participation

Recipient's name: _____

Signature: _____

Date: _____

Witness' signature: _____

Date: _____

Research # : 13-210 PED

Patient's file # : _____

MEDICAL CHART INFORMATION FORM

Participants' characteristics	Details
Date of Incident	
Date of Discharge	
GCS Score	
Cause	
Protection`	
No. of concussions	
Duration of symptoms (If balance, persisted?)	
Attention Deficit Hyperactivity Disorder (ADHD)	
Force/Strength	
Balance Assessment on Next visit : BOT 2 Date: FGA	

Remarks:

Ethics And Confidentiality:

Ethical approval was obtained by the Research Ethics Board (REB) committee at the Montreal Children's Hospital. Each participant was recognized by Identification number (ID) number. Participation in study was completely voluntary. Data was stored in file in a locked cabinet in the department. Participant were provided with a travelling and/or parking compensation. All information in this study will remain confidential.

Sample Size Calculation:

We postulated a moderate effect size of 0.5, with power as 80% and 0.05 significance level. With 5 predictor-variables; we estimated a sample size of 30 children for the multiple liner regression and correlation analysis [141].

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