

**The Effect of Concussion on Head Stabilization and Body Movement Strategies in Youth
Performing a Dual-Task**

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NOTE:

This thesis is compiled in manuscript format with one manuscript. The first section of this document consists of an introduction of general information, followed by a review of literature, and a methodology section. The manuscript outlines the methods of this study and therefore Chapter 3 will strictly contain additional methodological information, not included in the manuscript. One manuscript *The Effect of Concussion on Head Stabilization and Body Movement Strategies in Youth Performing a Dual-Task* is included in Chapter Four and is intended for submission for publication. To conclude, a brief general discussion outlining manuscript findings, significance, and future recommendations is included.

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ABSTRACT

According to the Guidelines for Diagnosing and Managing Pediatric Concussion, concussion is defined as “an injury to the brain caused by a blow to the head or to another part of the body that causes the head to spin or jolt” (Zemek, Duval, Dematteo, 2014, p. 40), and is a common injury among the youth population (National Institute of Health, 1999). When moving or remaining stationary the head can be stabilized in two ways: head stabilized in space and head stabilized on trunk (Bazarian, Veazie, Mookerjee, & Lerner, 2006). When under anxiety inducing conditions during development and when learning novel tasks individuals tend to shift from a head stabilized in space strategy to a head stabilized on trunk strategy in an effort to decrease the degrees of freedom required to move the head (Assaiante, McKinley, & Amblard, 1997). However, it is unclear whether certain pathologies result in movement strategies and whether these are influenced by the difficulty of the task performed. **Objective** The present study examined the effects of concussion on head stabilization strategies in adolescents while performing three dual-tasks. **Participants** Fifty-four participants, 24 concussed with post-concussion syndrome (age, 13.5 ± 1.9 years; 15 females, 9 males) and 30 healthy typically developing adolescents (age, 14.3 ± 1.7 years; 12 females, 18 males), performed one session of three dual-task conditions. Centre of pressure along with head, trunk and pelvis kinematics were captured during task performance using a Nintendo® Wii Balance Board and Ascension 3D Guidance TrakSTAR respectively. A head anchoring index (AI) was used to identify either head stabilized in space or head stabilized on trunk movement strategies, while center of pressure was collected to further support the use of movement strategies. **Results** There were no significant differences in AI between the two groups in any of the three dual-task conditions. **Conclusion** These results could be attributed to balance recovery or lack of balance problems in the concussed population.

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thank all of the kids and their families who participated in our study, along with Turnbull School and Ashbury College for their cooperation and assistance in the data collection process. It is because of them I was able to conduct my research and complete my thesis.

LIST OF EQUATIONS:

Equation 1: Traditional Anchoring Index of Head on Trunk and Trunk on Pelvis

$$AI = \frac{\sigma(\theta_r^h) - \sigma(\theta_a^h)}{\sigma(\theta_r^h) + \sigma(\theta_a^h)}$$

AI = Anchoring Index

σ : Sigma

θ : Theta

h: Head

r: Relative

a: Absolute

Equation 2: Modified Anchoring Index of Head on Trunk and Trunk on Pelvis

$$AI = \frac{\sigma(\theta_r^t) - \sigma(\theta_a^t)}{\sigma(\theta_r^t) + \sigma(\theta_a^t)}$$

AI = Anchoring Index

σ : Sigma meaning sum or deviation

θ : Theta representing the angular point of a vector

h: Trunk

r: Relative

a: Absolute

Equation 3: Relative Equation for Head on Trunk

r = trunk – head

r: relative

Equation 4: Relative Equation for Trunk on Pelvis

r = pelvis – trunk

r: relative

Equation 5: 95% Ellipse Covering 95% of COP Trajectory

$$[\text{vec}, \text{val}] = \text{eig}(\text{cov}(\text{COP}_{A/P}, \text{COP}_{M/L}))$$

$$95\% \text{ ellipse} = \pi * \text{prod}(2.4478 * \text{sqrt}(\text{svd}(\text{val})))$$

vec: vector

val: value

eig: eigenvalue

cov: covariate
COP: Centre of Pressure
A/P: Anterior-posterior
M/L: Medio-lateral
pi: 3.14
prod: product of array of elements
sqrt: square root
svd: signalr value decomposition
val: value

Equation 6: Medio-Lateral Velocity

$$\text{M/L velocity} = \text{sum (absolute difference (COP}_{\text{M/L}})) \\ * \text{frequency/length (COP}_{\text{M/L}})$$

M/L: Medio-lateral
COP: Centre of Pressure

Equation 7: Anterior-Posterior Velocity

$$\text{A/P velocity} = \text{sum (absolute difference (COP}_{\text{A/P}})) \\ * \text{frequency/length (COP}_{\text{A/P}})$$

A/P: Anterior-posterior
COP: Centre of Pressure

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CHAPTER ONE

INTRODUCTION

According to the Guidelines for Diagnosing and Managing Pediatric Concussion, concussion is defined as “an injury to the brain caused by a blow to the head or to another part of the body that causes the head to spin or jolt” (Zemek, Duval, Dematteo, 2014, p. 40). In North America, concussions make up 75% of the spectrum of traumatic brain injuries (TBI) and continue to be a rampant concern among youth due to the potential long-term consequences on neurodevelopment, as well as the risk to overall health and well-being (Bazarian, Veazie, Mookerjee, & Lerner, 2006; National Institute of Health, 1999; Patel & Reddy, 2010). Commonly concussion is characterized by a series of various symptoms including dizziness and visual instability, linking the role of the vestibular system in concussion and concussion rehabilitation (Mucha et al., 2014).

The vestibular system is comprised of two functioning components: the vestibulo-ocular and vestibulo-spinal systems. Although these two sub-systems together make up the vestibular system they do not share the same neuronal circuitry and; therefore, one can be impaired without affecting the other (Mucha et al., 2014). The vestibulo-ocular system maintains visual stability while the head moves, and the vestibulo-spinal system controls posture (Cullen, 2012). Due to the potential vestibulo-ocular impairments that could be sustained when concussed, the ability to move the head independently of the trunk and hold images stable may be impaired (Mucha et al., 2014; Assaiante, 1998).

When suffering from a concussion it can be more difficult to perform two tasks simultaneously with the effect of either a slowed response time or diminished performance in one or both of the tasks (Lee, Sullivan & Schneider, 2012). A dual-task is considered any two motor, two cognitive, or one motor and one cognitive task(s) performed simultaneously, where there is a primary and a secondary task (Kleiner, Wong, Dubé, Wnuk, Hunter, & Graham, 2018; McCulloch, 2007). Literature suggests that the balance measures collected from performing a dual-task may detect a larger range of functional deficits highlighting cognition, balance, and the interaction of the two that examining balance alone does not identify (Dorman et al., 2013).

When examining movement strategies Head Stabilized in Space (HSS) and Head Stabilized on Trunk (HST) are the two terms used to distinguish between movements. HSS is used to describe when the head moves independently of the trunk and HST or 'en bloc' describes when the head is strapped down to the trunk moving as one stiff unit (Assaiante & Amblard, 1992; Sveistrup, Schneiberg, McKinley, McFadyen, & Levin, 2008). These classifications are used to distinguish between independent head movement and stiff movements of the head on trunk that may be employed based on circumstance, developmental characteristics, or vestibular impairments (Assaiante, 1994; Assaiante & Amblard, 1993; Assaiante, Mallau, Viel, Jover, & Schmitz, 2005). The anchoring index (AI) paradigm is used to examine movement strategies providing a value of between +1 and -1, where a positive value indicates the use of an HSS movement strategy and a negative value indicates the use of an HST movement strategy (Amblard & Assaiante, 1992). When a value sits around zero there is no preference for either an HST or HSS movement strategy (Assaiante & Amblard, 1992).

The AI paradigm has been used to characterize movement strategies during a dynamic task (running, walking, jumping, etc.), where the head remains either stable in space despite any perturbations that the trunk encounters or reacts to perturbations with the trunk as one stiff unit (Assaiante, McKinley & Amblard, 1997). For the present study three tasks were used: dual-task cognitive (DTcognitive), dual-task visual (DTvisual), and dual-task combined (DTcombined). In each of the three tasks, the participants stood quietly and were asked to complete a version of the Stroop Colour-word test. The Stroop Colour-word test is a task that has the names of colours written in either the congruent or an incongruent colour (Sarason, Pierce, & Sarason, 2009). In the DTcognitive condition, the Stroop task consisted of an incongruent Stroop Colour-word test on a tablet, displaying one word at a time. In the DTvisual condition, the Stroop task consisted of an incongruent Stroop Colour-word test on a board with 20 rows of 5 words. Finally, in the DTcombined condition, the Stroop task consisted of an incongruent Stroop Colour-word test on a board with 20 rows of five words.

DTcognitive did not require participants to move their head, trunk or pelvis to complete the Stroop Colour -word test. DTvisual and DTcombined, however, did require participants to move their head to complete the Stroop task. Although the head was required to move for these two tasks, the feet remained stationary as the participant was instructed to stay still while standing on a Nintendo® Wii Balance Board (WBB). The traditional computation of AI assumes

that the head is not constrained to a particular task, but that it is rotating or stabilized on the trunk. For the present study the tasks, however, constrained the head to complete the Stroop tasks. This required the trunk to be the segment to be stabilized in space, because the head is the dynamic component. Therefore, the traditional equation was modified to account for trunk movement relative to the head to accurately assesses the movement strategy employed by the participants in a stationary task.

The purpose of the present study was to use three cognitive-standing balance dual-tasks to document head-trunk and trunk-pelvis movement strategies that could be evident in concussed patients that are different than typically developing youth.

QUESTION

Do children and adolescents with a concussion and healthy children and adolescents aged 11 to 17 years use different head-trunk or trunk-pelvis movement strategies while standing and performing a dual-task?

PURPOSE OF THE STUDY

The purpose of the present study was to use a cognitive-standing balance dual-task to document the head-trunk and trunk-pelvis movement strategies that could be evident in concussed patients that are different than typically developing youth.

LIMITATIONS

Limitations of this study included the attachment of sensors to participants, specifically the trunk sensor. Material of the clothing that the participant wore occasionally caused the tensor bands, holding the sensors, to slip throughout the session. It was also difficult to ensure the trunk sensor remained in place depending on the participants' body type. Another limitation included a lack of balance problems in the concussed participant population. Participants were recruited into the study between one and three months post-concussion and it is possible that the balance impairments participants possibly experienced after their concussion would have resolved by this point.

DELIMITATIONS

We purposefully did not control for the occurrence of previous concussions in the Concussed group. To control for this variable would have impacted the number of participants qualified to participate in the study to a degree that would result in a limiting sample size. An initial question was to characterize changes in AI over a recovery time period of 5 months; however, we purposefully eliminated the repeated testing sessions from the protocol. Recruitment proved to be more difficult than originally expected, and due to scheduling complications and patient inability to return for multiple sessions, the second and third sessions were eliminated.

CHAPTER TWO

REVIEW OF LITERATURE

General Overview

There are many balance and movement strategies employed by adults, adolescents, and children. Of these balance and movement strategies there are two classifications that encompass movements made to maintain balance. Head Stabilized on the Trunk (HST)/'en bloc' is when the head and trunk move as one rigid segment and Head Stabilized in Space (HSS) is when the head moves independently of the trunk (Assaiante, 1998). The HST movement strategy can be present in an attempt to decrease the degrees of freedom required to move the head independently. This can occur when young adults and the elderly are in anxiety inducing situations such as when a threatening state of falling is present. For example, standing on the edge of an elevated surface or cliff (Adkin, Frank, Carpenter, & Pevsar, 2000; Carpenter, Frank, Slicher, & Pevsar, 2001). HST has also been reported to be present under challenging equilibrium conditions, like walking along a narrow line or beam in both adults and children (Assaiante & Amblard, 1992).

In the first strategy, HST/'en bloc' is when the head is stabilized on the trunk through the activation of the neck muscles (Assaiante & Amblard, 1995). The HST/'en bloc' stabilization strategy results in a decrease in degrees of freedom allowing easier simultaneous control of movements. In the second strategy HSS, also known as stable platform strategy, the head is stabilized in space with the neck muscles relaxed, allowing movement of the body that is not transferred to the head (Assaiante & Amblard, 1995). In the HSS strategy control must be maintained over the orientation of the head and trunk, relying on the visual and vestibular systems more heavily (Lund, 1983).

Rocheffort et al. (2017) examined balance during a dual-task in typical adolescents and adolescents one-month post concussive impact. The dual-task consisted of standing with the feet comfortably apart and reading words from a chart far enough from the participants that they would turn their head in conjunction with their eyes to complete the task. Although no data were reported, they noted that the healthy controls appeared to move their head independently from their trunk when performing the dual-task. They also observed that in contrast to healthy participants, participants with concussion had a tendency to move their head and trunk as a single segment in order to perform the task. This HST movement strategy was also evident in the centre

of pressure (COP) data collected when participants with concussion became rigid and moved their head and trunk as one unit, causing the COP displacement to increase (Rocheffort et al., 2017). While it is normal for the head to be stabilized in space, the presence of an HST/‘en bloc’ movement strategy could be due to a vestibular impairment or deficit (Assaiante, 1998).

Vestibular System

The vestibular system together with visual and somatosensory inputs is responsible for maintaining balance, as well as maintaining eye fixation during body and head movements (Guskiewitz, 2003). Concussion has the capability to cause vestibular impairments including visual instability, dizziness, and trouble reading (Mucha et al., 2014).

Vestibular impairments. Mergner, Nasios, and Anastasopoulos (1998) used horizontal head and trunk rotations to assess the effects of neck and vestibular proprioceptive stimulation on memory dependent saccades. Six healthy participants completed four rotational stimulus conditions: (1) whole body rotation, (2) neck rotation; head rotation and counter rotation of the trunk, (3) neck and trunk rotation; rotation of head on a stable trunk, and (4) trunk and neck rotation; double amplitude trunk rotation with superposition of head counter rotation. All rotations were done towards the right and left side, at an amplitude of 16 degrees, and at three frequencies. Participants completed the series of conditions four times over multiple days. The authors reported that neck proprioception improved precision when vestibular feedback was used to redirect gaze to a remembered target.

The above is an indication that rotation of the head is important when redirecting gaze to a remembered target and supports why healthy individuals are more inclined to use this method when redirecting their gaze. Impairments of eye-head coordination are common post concussive injury and could be the result of a disturbance of the vestibulo-ocular reflex or the result of impairments of head and eye movement (Alsalaheen, Whitney, Mucha, Morris, Furman, & Sparto, 2013). Alsalaheen et al. (2013) implemented exercises comparable to those developed for unilateral vestibular hypo-function and applied them to concussed individuals complaining of dizziness and imbalance. Although the purpose of their study was to identify exercise prescription patterns for the treatment of vestibular rehabilitation, they reported that eye-head coordination exercises were the most commonly prescribed. They also reported that the eye-head coordination exercises were directed to improve the vestibular-ocular reflex and therefore improve gaze stabilization throughout head movement. By improving gaze stabilization, visual

instability would be decreased therefore positively affecting the movement strategy of the head, torso, and lower extremities (Alsalaheen et al., 2013).

Vestibular ocular reflex (VOR). The vestibulo-ocular reflex (VOR) is used to hold images stable during rotation of the head in order to maintain clear vision. Therefore, rotation of the head in one direction elicits eye movement contrary to the head, creating a stable gaze (Crossman, 1989). Input for the VOR comes from receptors that measure head linear acceleration, head angular velocity, and head orientation: this system acts through its three components according to Szentagothai (1950). These three components consist of “the peripheral sensory apparatus (the labyrinth), a central processing mechanism, and the motor output (the eye muscles)” (Szentagothai, 1950). The VOR has two components: angular VOR and linear VOR. The angular VOR uses information from the horizontal semicircular canal in order to detect rotation, and the linear VOR uses information from the saccule and utricle otolith organs to capture translation (Fetter, 2007).

Within the central nervous system, the above signals in combination with additional sensory information are used to approximate head orientation. The central vestibular system output is directed to the ocular muscles and the spinal cord to allow the VOR and the vestibulo-spinal reflex (VSR) to provide compensatory movements in order to sustain postural and head stability (Fetter, 2007). This information is also directed to the cortical structures where it is integrated with proprioceptive, auditory, tactile, and visual input to provide spatial orientation and perception of motion. Thus, the central nervous system monitors VOR and VSR to adapt and readjust to new conditions (Grusser, Pause & Schreier, 1990; Lisberger, Miles & Zee, 1984). Mucha et al. (2014) examined the assessment of vestibular and ocular motor impairments to establish a screening tool to assess vestibular symptoms. They identified that balance alone may not be a fully encompassing vestibular assessment of post concussive injury. For example, clinical measures such as the balance error scoring system (BESS) and sensory organization test (SOT) focus on the assessment of the vestibulo-spinal functions. Rochefort et al. (2017) examined balance performance in concussed youth at one-month post injury with a control group of the same ages. It is important to note that all concussed and healthy participants scored normal when performing the BESS but demonstrated balance impairments in their COP data. They were able to subjectively observe that a subset of the concussed participants had a tendency to stabilize their heads over their trunks while shifting their body from side to side to perform the

dual-task. This strategy is known as the HST /‘en bloc’ stabilization strategy. However, the healthy controls moved their heads freely from their trunks, the HSS stabilization strategy.

It has been shown that quiet stance characteristics measured using force plates and accelerometers are more accurate than clinical measures such as the BESS and SOT, but centre of pressure does not reflect vestibulo-ocular control or the dynamic aspect of the vestibular system (Mucha et al., 2014; Rochefort et al., 2017). For the purpose of this study by incorporating a dual-task that allowed the participants to move freely while being tested allowed for the investigation of different head-trunk and trunk-pelvis movements evident in concussed adolescents compared to healthy typically developing adolescents.

Dual-Task

Performing two functional tasks at once is a common component of everyday life for adolescents and adults and is known as dual-tasking. When assessing dual-task abilities the two tasks performed simultaneously for the dual-task paradigm can be: two motor, two cognitive, or one motor and one cognitive task(s) (Saxena, Cinar, Majnemer, & Gagnon, 2017). The literature is inconclusive on whether there is a change in ability to perform dual-tasks across different age groups (Saxena et al., 2017), but for the present study an older adolescent group, between the ages of 11 and 17 were used. What is evident in the literature, is that the ability to control interference is directly related to the capability of working memory (Spronk & Jonkman, 2012). Interference is the change in performance of one or both tasks, either motor, cognitive, or both, when performing a dual-task. This interference can be due to allocation of resources and attention and is measured by dual-task cost, the difference between performing the single task and the dual-task (Saxena et al., 2017).

The assessment of dual-tasking in concussion rehabilitation could result in identification of symptoms because it is the closest measure to replicate daily activities and tasks (Fabri, Wilson, Holland, Hickling, Murphy, Fait, & Reed, 2017; Teel, Register-Mihalik, Blackburn, & Guskiewicz, 2013). Testing cognition and balance simultaneously is an accepted method to assess individuals using the dual-task paradigm (Snijders, Verstappen, Munneke, & Bloem, 2007). When performing the two tasks simultaneously the addition of the secondary task can exceed cognitive capacity resulting in postural instability and the decline of overall performance of the two individual tasks (Kleiner et al., 2018). Due to the variability of concussion and

concussive symptoms there is no one clinical measure or assessment to conclusively diagnosis a concussion; therefore, the diagnosis and treatment of concussion falls on multidisciplinary assessments from published guidelines (Harmon et al., 2013; McCrory et al., 2012; Marshall et al., 2015; Quality Standards Subcommittee of the American Academy of Neurology, 1997). Dual-task assessment is an important component in the rehabilitation of concussion, with much value due to its replication of many everyday activities (Kleiner et al., 2018). As COP measures are considered the gold standard in evaluating static balance, by having participants perform a dual-task while standing on a force plate provided measurement of postural instability or balance change; thus, effectively measuring the balance performance of the dual-task (Clark et al., 2010).

Stroop colour-word test. The Stroop Colour-word test is an assessment used to evaluate executive function, through the measure of verbal response time and response inhibition (Homack & Riccio, 2003). The test is comprised of three components: the word task, the colour task, and the colour-word task. The word task requires the participant to read the names of colours, where the words are printed in a congruent colour. The colour test requires participants to name the colour of a bar. Finally, the colour-word test requires the participant to state the colour of the ink, not the word itself, which is displayed in an incongruent colour. The first two tasks measure verbal processing speed and the third task is a measurement of inhibition (Sarason, Pierce, & Sarason, 2009).

Executive function is referred to as “those abilities that enable an individual to engage successfully in autonomous, purposive, self-serving behavior” (Moering, Schinka, & Mortimer, 2003). Motor and cognitive performance are two areas that have been reported as affected by concussion, along with executive function (Howell, Osternig, & Chou, 2013). The Stroop Colour-word test is a reliable measure of executive function (Lezak, 2004), and has been suggested as an appropriate cognitive measure for dual-tasks of a cognitive and balance nature, specifically concerning concussion (Howell, Osternig, & Chou, 2013). When performing a cognitive and motor dual-task it has been reported that both the primary and secondary tasks can be affected, causing it to be quite difficult to complete the Stroop Colour-word test (Woollacott & Shumway-Cook, 2002). Slow response times have been attributed to failure of response inhibition, selective attention failure, or conflict of responses; while ultimately attesting to the difficulty of concentrating or ignoring distractions (Lezak, 2004).

Although there are many variations of the Stroop Colour-word test (Homack & Riccio, 2003), the paradigm remains the same. Executive function is based on the comparison of an individual's performance in the congruent versus the incongruent task. Therefore, the results of a basic task are compared with that of an analogous task where a typical response is altered to require a more complex response (Moering, Schinka, & Graves, 2003). Scoring the Stroop Colour-word test consists of the time taken to complete each of the components, or the amount of words and colour bars identified in a set period of time. The increase in time to perform the analogous incongruent task in comparison to the basic task is known as "the Stroop interference effect" (Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2006).

Multiple studies provide normative data for the Stroop Colour-word test. Barbarotto, Laiacona, Frosio, Vecchio, Farinato, and Capitani (1998) conducted a study that focused on visual reaction time when performing the Stroop Colour-word test in the sitting position. Two hundred and nine healthy participants, ages 18-81 years, provided normative data for two Stroop tests: the Computer-assisted Stroop Test and the Card Stroop Test. Another study conducted by Comalli, Wapner, and Werner (1962) recorded the amount of time needed to complete a 100 word Stroop Colour-word test with 235 participants aged from 7 to 80 years.

Bohnen, Twijnstra, and Jolles (1992) examined the performance of individuals presenting with post concussive syndrome (PCS) 3-months post injury and individuals who had displayed symptoms of PCS but had recovered from their mild traumatic brain injury (mTBI) within 3-months. They used a commercial version of the Stroop Colour-word test that consisted of the three components described above. They found that participants with continuing PCS after 3-months scored lower in Stroop test performance in sitting, than those who had recovered. This suggests that a persistence of cognitive impairments could be one possible factor leading to a persistence of PCS after a brain injury (Bohnen, Twijnstra, & Jolles, 1992). Rochefort et al. (2017) utilized the incongruent Stroop Colour-word test as their dual-task condition to challenge balance in adolescents one-month post-concussion. They found more sway in the medio-lateral directions associated with the dual-task showing increased sway in the direction of the reading required to perform the task, and increased antero-posterior sway associated with the eyes open and eyes closed conditions. This pattern was found in a greater magnitude in the concussed participants (Rochefort et al., 2017). They also found that both the concussed and control groups made a similar number of errors on the incongruent Stroop Colour-word test indicating that the

difference in balance performance between the two groups is due to balance impairment and not prioritization of the cognitive task (Rocheffort et al., 2017).

Assessment Tools

Electromagnetic tracking system. Electromagnetic tracking systems use a 3D measurement system to measure sensor position (Tao, Liu, Zheng, & Feng, 2012). Based on research by Milne, Chess, Johnson, and King in 1996 the optimal distance of the transmitter to the sensors is between 22.5 to 64.0 cm. Along with this they found that mild steel caused the most interference when placed close and adjacent to the receiver (Milne et al., 1996). Their research focused on the accuracy, optimal operating range, and interference with electromagnetic tracking systems. They also established that the ‘Flock of Birds’ device produced less than 2% positional and rotational error, which is comparable to other literature on electromagnetic tracking systems accuracy (An, Jacobsen, Gerlund, & Chao, 1988; Bull, Berkshire, & Amis, 1998; Milne et al., 1996). Sensor data are then used to compute segment position in space.

Wii balance board (WBB). Force plates are considered the golden standard for measuring static balance, due to their accuracy and objectivity (Clark et al., 2010). Although, due to their lack of portability and expensive nature they are considered less than ideal for clinicians and research that takes place outside of a laboratory (Doherty et al., 2017). This highlights a demand for a portable and affordable option for researchers and clinicians. The Nintendo® Wii Balance Board (WBB) contains four transducers used to measure force distribution and resultant movements in COP, similarly to force plates used in laboratories and COP values acquired from the WBB resemble those of laboratory grade force plates (Clark et al., 2010; Huurnink, Fransz, Kingma, & van Dieën, 2013).

Clark et al. (2010) examined the validity of the WBB in conducting postural control measurements, in comparison to traditional laboratory grade force plates. They reported consistent results from the WBB in comparison to force plates even with the presence of larger mean displacements from the WBB. The authors accounted this to “device specific factors” (Clark et al., 2010). Park and Lee (2014) measured reliability and validity of the WBB for balance tests, specifically examining COP path length and COP velocity. The authors reported that COP path length and COP velocity obtained from the WBB were excellent in inter-rater reliability and intra-rater reliability, they also reported consistently excellent concurrent validity

(Park & Lee, 2014). This suggests that the WBB is a practical option as a portable way to assess COP for clinicians or researchers.

Saccadic Eye Movement

Previous research focuses on balance control and/or eye movements but does not specifically look at the movement of the head, trunk, or pelvis when performing a dual-task. Cifu, Wares, Hoke, Wetzel, Gitchel, and Carne (2015) examined eye movements in healthy individuals and individuals displaying PCS. For their assessment, they used a head mounted eye tracker with a chin rest while participants were sitting and were therefore unable to assess any head, trunk or pelvis movements that occurred while performing the target stimulus task. They were able to identify significant differences in saccades and smooth pursuit eye movements (SPEM) between the control group and the PCS group. Specifically, the PCS group had a difficult time tracking the stepwise moving targets resulting in less accuracy. Interestingly, there were no identifiable differences between groups in computation of the position variance, root mean square of eye velocity, and mean and absolute mean velocity of eyes during fixation (Cifu et al., 2015). Furthermore, Heitger, Anderson, and Jones (2002) examined saccadic eye movements in mild and moderate cases of mTBI and used a similar assessment tool using a bite bar that restricted any head, trunk, or pelvis movement in participants completing a different target stimulus task. These authors identified response errors as well as significantly reduced spatial accuracy in participants' final eye position.

Thiagarajan and Ciuffreda (2014) examined the effects of oculomotor training (OMT) on versional eye tracking in mTBI. They used the Arrington Viewpoint Eye Tracker® system to assess vertical and horizontal versional eye movements. This particular instrument requires the participant to place their head on a chin mount while seated. The Arrington ViewPoint Tracker® recording system is mounted on a table with a screen 40 cm away from the participants' midline of the head. This study was successful in identifying that OMT can increase visual attention, reduce near-vision associated symptoms, and improve general reading ability, but did not assess any movement beyond the eyes (Thiagarajan & Ciuffreda, 2014).

These studies were all conducted to evaluate eye movements and saccadic impairments in healthy individuals and individuals with concussion. They were able to successfully identify impairments, but because of methodological constraints focused their variables to eye

movements and restricted all other body movements (Cifu et al., 2014; Heitger et al., 2002; Thiagarajan & Ciuffrda, 2014). The results found on saccadic eye movement impairments and SPEM could explain a possible use of the head, trunk, and pelvis in performing a dual-task, requiring reading from a distance with no body movement restrictions (Cifu et al., 2014). This is not an ecologically valid approach to understanding concussion and the vestibulo-ocular or vestibulo-spinal impairments concussion can cause. It is important to test participants under freely moving conditions to measure the vestibulo-ocular and vestibulo-spinal concussive symptoms, along with their saccadic eye movements (Rocheffort et al., 2017).

Anchoring Index (AI)

The AI is the relationship of the stabilization of one body segment in relation to another and external axis (Sveistrup et al., 2008). Traditionally, AI is calculated using the formula $AI = \frac{\sigma(\theta_r^h) - \sigma(\theta_a^h)}{\sigma(\theta_r^h) + \sigma(\theta_a^h)}$, where $\sigma(\theta_r^h)$ represents the standard deviation of the angular distribution of the head movements in relation to the trunk, while $\sigma(\theta_a^h)$ represents the standard deviation of the absolute angular distribution of the head movements in space, keeping in mind external axes (Sveistrup et al., 2008). The traditional AI is based on the concept of locomotion and the rhythmic sequences that oscillate through the trunk and head, in that order (Grossman, Leigh, Abel, Lanska, & Thurston, 1988). The head is the control center for the vestibular and visual systems, which are pertinent in detecting loss of balance (Assaiante & Amblard, 1993). It is understood that the head is stabilized in space while walking, through the adaptation of perturbations through the trunk to keep the head stable and support better vestibular processing and clear vision (Assaiante & Amblard, 1993).

The AI paradigm was traditionally designed for use when the task elicits a stable head and a moving trunk. When the trunk is moving it adapts to perturbations and the head remains stable in space or strapped to the trunk as one unit (Assaiante & Amblard, 1993). For the present study, the task required participants to move the head as they read words on a board. Since the dual task paradigm required the participant to rotate the head, the corresponding equation for AI was modified to account for a moving head and a, potentially, stable trunk. Thus, $AI = \frac{\sigma(\theta_r^t) - \sigma(\theta_a^t)}{\sigma(\theta_r^t) + \sigma(\theta_a^t)}$, where $\sigma(\theta_r^t)$ represents the standard deviation of the angular distribution of the trunks movements in relation to the head, and $\sigma(\theta_a^t)$ represents the standard deviation of the

absolute angular distribution of the trunks movements in space, keeping in mind external axes. In altering the paradigm and modifying the formula, it was important to validate the accuracy of the results. To validate the accuracy, we compared the original anchoring index results of isolated: head rotation, neck lateral flexion, neck bending, trunk rotation, trunk lateral flexion, trunk bending, and head and trunk simultaneous rotation, head and trunk simultaneous lateral flexion, and head and trunk simultaneous bending. We then compared the anchoring index of both the traditional and modified formula to the corresponding graphs to ensure the movement strategy executed matched the graph and the AI output. Thus, accurately assessing the movement strategy employed by the participant in a stationary task (refer to Appendix G). This comparison is also further explained in chapter 3.

Summary

Although information is available on saccadic eye movement impairments and balance deficits post concussive injury, the literature is limited regarding measures of head and trunk movements while performing a dual-task in individuals with concussion. Vestibular impairments are prevalent post concussive injury affecting the VOR and causing symptoms of dizziness, balance impairments, and visual instability (Mucha et al., 2014).

The aim of the present study was to determine whether 11-17-year-old children and adolescents with concussion use different head-trunk and trunk-pelvis movement strategies while performing a standing dual-task than healthy children and adolescents between the same ages. The study investigated the AI of the head on trunk along with the AI of the trunk on pelvis in both the yaw and roll planes (refer to Appendix B). Lastly, the 95% ellipse of the COP data from both the Concussed and Control groups were used to determine balance problems during each of the three dual-tasks (DTcognitive, DTvisual, and DTcombined).

Objectives The present study examined concussed and healthy typically developing adolescents' movement strategies while performing a dual-task. Movement strategies were analyzed using the following dependent variables:

- Anchoring index of the head on trunk in yaw
- Anchoring index of the head on trunk in roll
- Anchoring Index of the trunk on pelvis in yaw
- Anchoring Index of the trunk on pelvis in roll

- Centre of pressure medio-lateral velocity
- Centre of pressure anterior-posterior velocity
- 95% ellipse of the centre of pressure

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CHAPTER THREE

METHODOLOGY

GENERAL INFORMATION

Information pertaining to the participants, instrumentation, data analysis, statistical analysis, and experimental protocol are reported in the following manuscript in detail (Chapter 4). The explanation for the modified AI as well as a retrospective power analysis are provided in detail in this chapter.

Anchoring Index

As reported previously, the traditional AI paradigm was designed to examine movement strategies in tasks where a stable head in space is beneficial and the trunk is moving. Examples of moving tasks include: walking, running, hopping, and reaching (Sveistrup et al., 2008). For the present study, participants were required to rotate the head in order to complete two of the three (DTvisual and DTcombined) dual-task conditions effectively. This head constraint was implemented purposefully by the authors in an attempt to increase the motor demand of the dual-task.

Due to the nature of this task, the traditional AI equation was not able to accurately identify when the participant moved their head independently of their trunk, the HSS movement strategy. The traditional AI equation was however still able to identify successfully when the participant moved their head and trunk as one unit, the HST/‘en bloc’ movement strategy. The traditional AI equation was able to identify the HST/‘en bloc’ movement strategy because whether the trunk is moving or remains stationary, the head and trunk move as one unit together.

For the purpose of this study, the traditional AI equation was thus modified in order to compare the moving head to a stationary stable trunk: modified AI = $\frac{\sigma(\theta_r^t) - \sigma(\theta_a^t)}{\sigma(\theta_r^t) + \sigma(\theta_a^t)}$, where $\sigma(\theta_r^t)$ represents the standard deviation of the angular distribution of the trunk movements in relation to the head, and $\sigma(\theta_a^t)$ represents the standard deviation of the absolute angular distribution of the trunk movements in space, keeping in mind external axes. To validate the accuracy, we compared the traditional AI results of large isolated movements: head rotation, neck lateral flexion, neck bending, trunk rotation, trunk lateral flexion, trunk bending, and head and trunk

simultaneous rotation, head and trunk simultaneous lateral flexion, and head and trunk simultaneous bending. We then compared the traditional AI and the modified AI results to the corresponding graphs to ensure the movement strategy executed matched the graph and the modified AI output. Thus, accurately assessing the movement strategy employed by the participant in a stationary task (refer to Appendix D, E, F, G).

For the purpose of the present study the authors also changed the movement strategy names to accurately account for the modified AI. The equivalent to HST will be referred to as Trunk Stabilized to Head (TSH) indicating that the trunk rotated with the head as a single segment in order to complete the task. The equivalent to HSS will be referred to as Trunk Stabilized in Space (TSS) indicating that the head rotated as a separate segment on a stable trunk in order to complete the task. This decision was made to account for the modified AI equation defining a stable trunk and a moving head, instead of the traditional AI which accounted for a moving trunk and a stable head.

Figure 1. Yaw and Roll Plane - Trunk Stabilized in Space

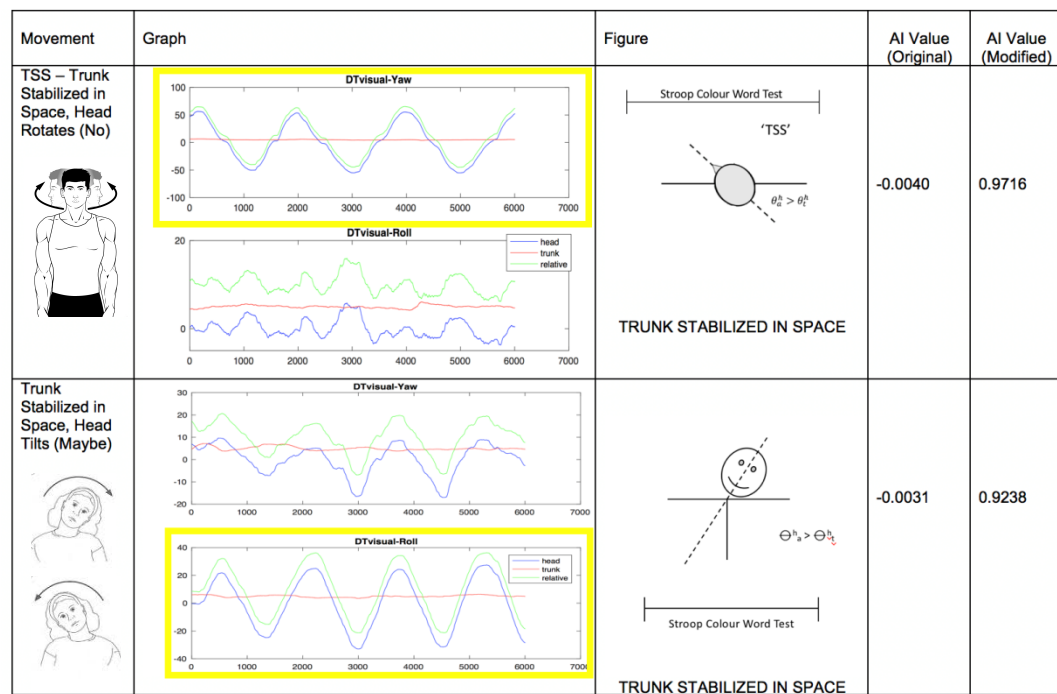


Figure 1. TSS is demonstrated in the yaw and roll planes comparing the traditional AI results to the modified AI results. The movements are represented by the figures for head rotation and head tilting. The highlighted graphs represent the head movement, body movement, and relative movement in relation to the corresponding movement figure. The figures are a visual aid displaying the movement strategy in the appropriate planes. Finally, the original AI value and the modified AI value are displayed to demonstrate the inaccuracy of the original equation for a stationary task and the validity of the modified equation.

Figure 2. Yaw and Roll Plane - Trunk Stabilized in to Head

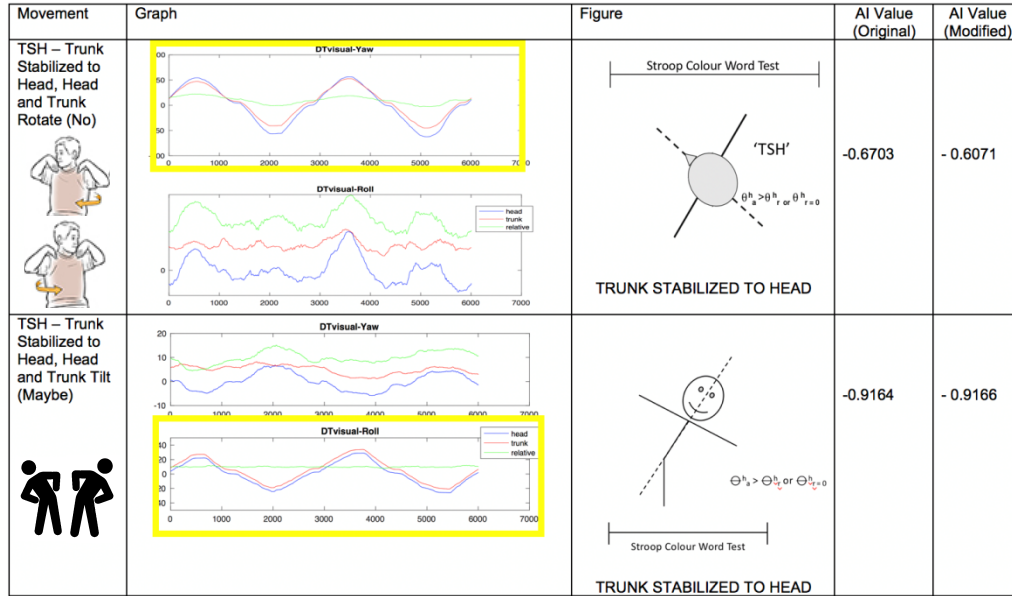


Figure 2. TSH is demonstrated in the yaw and roll planes comparing the traditional AI results to the modified AI results. The movements are represented by the figures for head and trunk rotation and head and trunk tilting. The figures are a visual aid displaying the movement strategy in the appropriate planes. The highlighted graphs represent the head movement, body movement, and relative movement in relation to the corresponding movement figures. The figures are a visual aid displaying the movement strategy in the appropriate planes. Finally, the original AI value and the modified AI value are displayed to demonstrate the inaccuracy of the original equation for a stationary task and the validity of the modified equation.

Power Analysis

A power analysis was completed in preparation for the study to determine a sufficient number of participants for each group. The averages for standard deviations (SD) for the medio-lateral velocity measured during dual-task in both Concussed and Control groups were taken from the previous study by Rochefort et al. (2017) and revealed that 30 participants per group would allow the detection of medium effects. Therefore, this sample size was deemed adequate in identifying medium effects between the Control and Concussed groups.

Additionally, a retrospective power analysis was completed using the modified AI data from both Concussed and Control groups for the dual-task condition DTcombined in the yaw

plane determining that a need for 187 participants would be required to identify medium effects between the Control and Concussed groups. The sample size was calculated using a 95% confidence interval and 0.84 to account for a medium effect size (refer to Appendix M). Due to the lack of balance impairments evident in the Concussed sample recruited for this study differences may have been less evident between the two groups, in comparison to if the Concussed sample were more balance deficient.

CHAPTER FOUR

THE EFFECT OF CONCUSSION ON HEAD STABILIZATION BODY MOVEMENT STRATEGIES IN YOUTH PERFORMING A DUAL-TASK

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Keyword: concussion, post-concussion syndrome, anchoring index, centre of pressure

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Conflict of Interest

No author has any financial or personal conflict of interest that could inappropriately impact their work.

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Abstract

According to the Guidelines for Diagnosing and Managing Pediatric Concussion, concussion is defined as “an injury to the brain caused by a blow to the head or to another part of the body that causes the head to spin or jolt” (Zemek, Duval, Dematteo, 2014, p. 40), and is a common injury among the youth population (National Institute of Health, 1999). When moving or remaining stationary the head can be stabilized in two ways: head stabilized in space and head stabilized on trunk (Bazarian, Veazie, Mookerjee, & Lerner, 2006). When under anxiety inducing conditions during development and when learning novel tasks individuals tend to shift from a head stabilized in space strategy to a head stabilized on trunk strategy in an effort to decrease the degrees of freedom required to move the head (Assaiante, McKinley, & Amblard, 1997). However, it is unclear whether certain pathologies result in movement strategies and whether these are influenced by the difficulty of the task performed. **Objective** The present study examined the effects of concussion on head stabilization strategies in adolescents while performing three dual-tasks. **Participants** Fifty-four participants, 24 concussed with post-concussion syndrome (age, 13.5 ± 1.9 years; 15 females, 9 males) and 30 healthy typically developing adolescents (age, 14.3 ± 1.7 years; 12 females, 18 males), performed one session of three dual-task conditions. Centre of pressure along with head, trunk and pelvis kinematics were captured during task performance using a Nintendo® Wii Balance Board and Ascension 3D Guidance TrakSTAR. A head anchoring index (AI) was used to identify either head stabilized in space or head stabilized on trunk movement strategies, while centre of pressure was collected to further support the use of movement strategies. **Results** There were no significant differences in AI between the two groups in any of the three dual-task conditions, but there was a significant main effect of condition for head-trunk AI. When looking at the at the main effect of condition for the head-trunk AI it can be seen that the positive AI values in the DTvisual condition were more positive than the DTcombined condition. This may be because the head was less constrained and more dissociated, and it was hypothesized that this may be why there is more displacement. **Conclusion** These results could be attributed to balance recovery or lack of balance problems in the concussed population.

1. Introduction

According to the Guidelines for Diagnosing and Managing Pediatric Concussion, concussion is defined as “an injury to the brain caused by a blow to the head or to another part of the body that causes the head to spin or jolt” (Zemek, Duval, Dematteo, 2014, p. 40). In North America, concussions make up 75% of the spectrum of traumatic brain injuries and continue to be a rampant concern among youth due to the potential long-term consequences on neurodevelopment, as well as the risk to overall health and well-being (Bazarian, Veazie, Mookerjee & Lerner, 2006; Patel & Reddy 2010). Concussion is characterized by various symptoms including dizziness and visual instability, linking the role of the vestibular system in concussion and concussion rehabilitation (Mucha et al., 2014).

The vestibular system is comprised of two functioning components: the vestibulo-ocular and vestibulo-spinal systems. Although these two sub-systems together make up the vestibular system they do not share the same neuronal circuitry and; therefore, one can be impaired without affecting the other (Mucha et al., 2014). The vestibulo-ocular system maintains visual stability while the head moves, and the vestibulo-spinal system controls posture (Cullen, 2012). Due to the potential vestibulo-ocular impairments that could be sustained when concussed the ability to move the head independently of the trunk and hold images stable may be impaired; thus, possibly creating a need to decrease the degrees of freedom required to rotate the head independently of the trunk during dual-task environments (Assaiante, 1998; Mucha et al., 2014).

The assessment of dual-tasking in concussion rehab could result in identification of symptoms as it simulates the demands of daily activities and tasks (Fabri et al., 2017; Teel, Register-Mihalik, Blackburn & Guskiewicz, 2013). Testing cognition and balance in a dual task paradigm is an accepted method to assess and evaluate individuals’ interaction between

cognition and balance (Snijders, Verstappen, Munneke & Bloem, 2007). When performing the two tasks simultaneously the addition of the secondary task can exceed the limit of cognitive capacity resulting in postural instability and the decline of overall performance of each of the individual tasks (Kleiner et al., 2018). Due to the variability of concussion and concussive symptoms there is no one clinical measure or assessment to conclusively diagnosis a concussion; therefore, the diagnosis and treatment of concussion falls on multidisciplinary assessments (Harmon et al., 2013; Marshall et al., 2015; McCrory et al., 2012; Quality Standards Subcommittee of the American Academy of Neurology 1997). Dual-task assessment is an important component in the diagnosis and rehabilitation of concussion, with much value due to its replication of many everyday activities (Kleiner et al., 2018).

Rochefort Walters-Stewart, Aglipay, Barrowman, Zemek, and Sveistrup (2017) examined balance markers in adolescents at one-month post-concussion and within their study observed a subgroup of concussed participants that stabilized their head on their trunk while performing the dual-task condition. This visual observation was also evident in the centre of pressure data (COP) as the correlations demonstrated that this subgroup of participants' 95% ellipses were related to the medio-lateral velocity during the dual-task condition and the anterior-posterior directions for the eyes-open and eyes-closed conditions (Rochefort, Walters, et al., 2017). These observations indicated that further research was necessary to determine if a subgroup of concussed adolescents use the trunk stabilized to head (TSH) movement strategy when performing a dual-task condition (Rochefort, Walters, et al., 2017).

One approach to document how the head is controlled is with the Anchoring Index (AI). This measure quantifies how one body segment is stabilized in relation to another and to an external axis (Sveistrup et al., 2008). The AI is used to identify head stabilized in space or head

stabilized to trunk movement strategies in tasks where the trunk is moving and adapts to perturbations, while the head remains either stable in space or adapts to the perturbations with the trunk as one stiff unit (Assaiante & Amblard, 1993). For the present study the term to identify a positive AI value, head stabilized in space, was modified to “trunk stabilized in space” (TSS) and the term to identify a negative anchoring index, head stabilized to trunk, was modified to “trunk stabilized to head” (TSH). The authors decided to change this terminology to better describe the movement strategy that the modified AI equation was to identify (Rocheffort, Walters, et al., 2017). A positive anchoring index indicates that the head is moving independently of the trunk, the head moves and rotates as the trunk remains still. A negative anchoring index indicates that the head and trunk move as one stiff unit, the head moves in conjunction with the trunk (Assaiante & Amblard, 1995).

The purpose of this study was to determine if there is a difference between the strategies used to control the head and trunk during different dual-task conditions in concussed and healthy typically developing adolescents. To our knowledge this is the first study to examine the effect of concussion on head stabilization and body movement strategies in youth performing a dual-task. We hypothesized that a subgroup of the concussed participants would use a stiffening strategy to decrease the degrees of freedom in order to maintain control (TSH) during dual-task performance, while healthy typically developing participants would be able to integrate additional degrees of freedom during dual-task performance (TSS). The AI, COP velocity, and 95% ellipse were used to characterize behaviors during dual-task conditions in both the concussed and control groups.

2. Methods

2.1 Research Design

A case control study research design was utilized to examine the response strategy of adolescents with Post Concussive Syndrome (PCS) and healthy typically developing adolescents during three different dual-task conditions.

2.2 Participants

A total of 54 participants between the ages of 11 and 17 who met the study criteria were recruited. Twenty-four of the participants were diagnosed with PCS and were recruited from the Children's Hospital of Eastern Ontario's (CHEO) Concussion Clinic. Participants in both the Control and Concussed groups had no musculoskeletal injuries, balance impairments due to an unrelated condition other than the concussion for the concussed group, or visual impairments that were either mild or could be corrected with contact lenses. Control participants were excluded if they had been concussed within the past year (refer to Appendix H, I, J, K, L).

2.3 Instrumentation

A Wii Balance Board (WBB) was used to measure COP velocity and 95% ellipse, while an Ascension 3D Guidance TrakSTAR was used to measure movements of the participants' head, trunk, and pelvis during three different dual-task conditions (refer to appendix A). The Stroop Colour-word test, used to evaluate executive function through the measure of verbal response time and response inhibition (Homach & Riccio, 2003) was used as the secondary task, to the primary balance component, for each condition.

2.4 Experimental Protocol

This study was approved by the CHEO Hospital Research Ethics Board and the University of Ottawa Research Ethics Board (refer to appendix Q). All concussed participants completed one

thirty-minute session between the first and third month post concussive impact, while all Control participants completed one thirty-minute session.

Participants were instructed to stand, feet shoulder width apart, on a WBB, with their hands on their hips; while simultaneously completing one trial of each of three dual-task conditions. The three conditions included: dual-task cognitive (DTcognitive), dual-task visual (DTvisual), and dual-task combined (DTcombined). These were completed in randomized order,

For each condition, the balance task remained the primary task, while the Stroop Colour-word test was the secondary task. Each Stroop Colour-word test consisted strictly of the words and colours “red”, “blue”, “yellow” and “green”. DTcognitive consisted of the Stroop Colour-word test being displayed on a tablet 60cm in distance from the participant. One hundred words were displayed in an incongruent ink colour to the participant, where the next word appeared as soon as the participant articulated their response. DTvisual and DTcombined consisted of the Stroop Colour-word tests displayed on a board 60cm in distance from the participant. Each condition consisted of 20 rows of five words. DTvisual consisted of a congruent Stroop Colour-word test and DTcombined consisted of an incongruent Stroop Colour-word test (figure 3).

Figure 3. Dual-Task Conditions

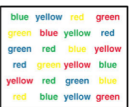
DTvisual	DTcombined	DTcognitive
		

Figure 3. A visual representation of the three dual-task conditions.

2.5 Data Analysis

Groups (Concussed and Control) and Conditions (DTcognitive, DTvisual, DTcombined) were identified as the independent variables. The dependent variables were defined as: anchoring index of the head on trunk and trunk on pelvis in the yaw and roll plane, 95% ellipse, COP medio-lateral velocity, and COP anterior-posterior velocity (refer to appendix B).

Data analysis was completed using Mathworks MATLAB_R2017a (refer to appendix N). The AI was computed using the position of the trunk in relation to the head in the yaw and roll planes according to the formula: Modified AI = $\frac{\sigma(\theta_r^t) - \sigma(\theta_a^t)}{\sigma(\theta_r^t) + \sigma(\theta_a^t)}$. For this equation $\sigma(\theta_r^t)$ represented the standard deviation of the angular distribution of the trunk movements in relation to the head, while $\sigma(\theta_a^t)$ represented the standard deviation of the absolute angular distribution of the trunk movements in space, keeping in mind external axes (Sveistrup et al., 2008). Traditional AI has been utilized to examine movement strategies in tasks like walking, jumping, or reaching; the traditional AI paradigm works on the assumption that the trunk is moving, and the head remains stable, either in space or strapped to the trunk (Assaiante & Amblard, 1993). For the present study a dual-task requiring a stationary trunk and a moving head was utilized. To compensate for the stationary trunk task the equation was modified to account for trunk movement in relation to the head.

The COP medio-lateral and anterior-posterior velocity was calculated using the following formula (Avanzini, 1994; Ruhe, Fejer, & Walker, 2010).

$$\begin{aligned} \text{M/L velocity} &= \text{sum (absolute difference (COP}_{\text{M/L}})) \\ &\quad * \text{frequency/length (COP}_{\text{M/L}}) \end{aligned}$$

$$\begin{aligned} \text{A/P velocity} &= \text{sum (absolute difference (COP}_{\text{A/P}})) \\ &\quad * \text{frequency/length (COP}_{\text{A/P}}) \end{aligned}$$

A 95% ellipse was calculated using COP trajectory with the formula (Duarte & Freitas, 2010).

$$[\text{vec}, \text{val}] = \text{eig}(\text{cov}(\text{COP}_{A/P}, \text{COP}_{M/L}))$$

$$95\% \text{ ellipse} = \pi * \text{prod}(2.4478 * \text{sqrt}(\text{svd}(\text{val})))$$

Data were collected during performance of the three dual-task conditions: DTvisual, DTcognitive, and DTcombined.

2.6 Statistical Analysis

Statistical analysis was completed using SPSS 25 (SPSS Inc.). For each dependent variable, a two-way (between-within) repeated measures analysis of variance (ANOVA), one between factor-group and one within factor-condition, was used to determine the differences between the three conditions (DTcognitive, DTvisual, and DTcombined) and between Control and Concussed groups. T-tests were used where appropriate to identify conditions where there was a significant main effect. P values were adjusted for number of comparisons ($p = 0.017$). The three comparisons were DTcognitive–Dtvisual, DTcognitive–Dtcombined, and DTvisual–Dtcombined.

3. Results

Data were collected from twenty-four concussed participants (mean age, 13.5 ± 1.9 years; 15 females, 9 males) who completed the protocol once between one month and three months post injury date (mean, 44.25 days). Thirty healthy typically non-injured participants within the same age range (mean age, 14.3 ± 1.7 years; 12 females, 18 males) also completed the protocol once. The protocol took between 20 and 30 minutes, and all participants were given a 30 to 60 second break between each condition.

3.1 Yaw Plane

No significant group differences were obtained in the yaw plane for AI of head on trunk movement ($F(1,52) = 1.811$, $p = 0.184$) or between groups in the yaw plane for AI of trunk on pelvis movement ($F(1,52) = 0.783$, $p = 0.380$) (table 1 and 2) (refer to Appendix H and L).

Table 1. *The number of participants in each condition with positive or negative head on trunk AI – Yaw plane*

Group	AI	Condition	Total Number of Participants
Concussed	Negative	DTcombined	5
		DTvisual	5
		DTcognitive	5
	Positive	DTcombined	19
		DTvisual	19
		DTcognitive	19
Control	Negative	DTcombined	4
		DTvisual	3
		DTcognitive	7
	Positive	DTcombined	26
		DTvisual	27
		DTcognitive	23

Note. Number of participants scoring either negative or positive head on trunk AI in the yaw plane is displayed to demonstrate the low number of negative head on trunk AI values that were present in the concussed population. It is also interesting to note that number of Control participants and Concussed participants scoring negative AI head on trunk values were very similar.

Table 2. *The number of participants in each condition with positive or negative trunk on pelvis AI – Yaw plane*

Group	AI	Condition	Total Number of Participants
Concussed	Negative	DTcombined	21
		DTvisual	22
		DTcognitive	20
	Positive	DTcombined	3
		DTvisual	2
		DTcognitive	4
Control	Negative	DTcombined	29
		DTvisual	24
		DTcognitive	25
	Positive	DTcombined	1
		DTvisual	6
		DTcognitive	5

Note. Number of participants scoring either negative or positive trunk on pelvis AI in the yaw plane is displayed to demonstrate the high number of negative trunk on pelvis AI values that were present in both the Concussed and Control populations.

3.1.1 DTcombined, DTvisual, DTcognitive - Head on Trunk AI

There were no significant differences obtained in the yaw plane examining AI in the DTcombined condition between concussed ($M = 0.175$, $SD = 0.305$) and control ($M = 0.270$, $SD = 0.296$) groups $t(52) = -1.157$, $p = 0.253$, DTvisual condition between concussed ($M = 0.220$, $SD = 0.275$) and control ($M = 0.345$, $SD = 0.285$) groups $t(52) = -1.637$, $p = 0.108$, or DTcognitive condition between concussed ($M = 0.165$, $SD = 0.197$) and control ($M = 0.153$, $SD = 0.217$) groups; $t(52) = 0.204$, $p = 0.83$. However, there were significant differences obtained within the DTcombined condition in the concussed group between positive ($M = 0.294$, $SD = 0.192$) and negative ($M = -0.278$, $SD = 0.209$) AI; $t(22) = 5.824$, $p = 0.000$, and within the

control group between positive ($M = 0.365$, $SD = 0.208$) and negative ($M = -0.206$, $SD = 0.185$) AI; $t(28) = 5.7$, $p = 0.000$.

There were however significant differences obtained within the concussed group between positive ($M = 0.302$, $SD = 0.205$) and negative ($M = -0.191$, $SD = 0.211$) AI in the DTvisual condition; $t(22) = 4.377$, $p = 0.000$, and within the control group between positive ($M = 0.423$, $SD = 0.214$) and negative ($M = -0.157$, $SD = 0.115$) AI; $t(28) = 5.235$, $p = 0.000$. This was also evident in the concussed group between positive ($M = 0.232$, $SD = 0.158$) and negative ($M = -0.091$, $SD = 0.083$) AI in the DTcognitive condition; $t(22) = 4.365$, $p = 0.000$ and within the control group between positive ($M = 0.237$, $SD = 0.164$) and negative ($M = -0.123$, $SD = 0.1137$) AI; $t(28) = 5.394$, $p = 0.000$. This indicates that a TSS movement strategy was preferred in both groups for all three dual-task conditions.

3.2 Roll Plane

No significant group effects were obtained in the roll plane for head on trunk movement ($F(1, 52) = 1.740$, $p = 0.193$) or for trunk on pelvis movement ($F(1, 52) = 0.098$, $p = 0.299$) (table 3 and 4).

Table 3. *The number of participants in each condition with positive or negative head on trunk AI – Roll plane*

Group	AI	Condition	Total Number of Participants
Concussed	Negative	DTcombined	0
		DTvisual	0
		DTcognitive	0
	Positive	DTcombined	24
		DTvisual	24
		DTcognitive	24
Control	Negative	DTcombined	2
		DTvisual	0
		DTcognitive	6
	Positive	DTcombined	28
		DTvisual	30
		DTcognitive	24

Note. Number of participants scoring either negative or positive head on trunk AI in the roll plane is displayed to demonstrate the high number of positive head on trunk AI values that were present in both the Concussed and Control populations.

Table 4. *The number of participants in each condition with positive or negative trunk on pelvis AI – Roll plane*

Group	AI	Condition	Total Number of Participants
Concussed	Negative	DTcombined	3
		DTvisual	1
		DTcognitive	3
	Positive	DTcombined	21
		DTvisual	23
		DTcognitive	21
Control	Negative	DTcombined	6
		DTvisual	6
		DTcognitive	2
	Positive	DTcombined	24
		DTvisual	24
		DTcognitive	28

Note. Number of participants scoring either negative or positive head on trunk AI in the roll plane is displayed to demonstrate the high number of positive trunk on pelvis AI values that were present in both the Concussed and Control populations.

3.2.1 DTcombined, DTvisual, and DTcognitive - Head on Trunk AI

There were no significant differences obtained in the roll plane examining AI in the DTcombined condition between concussed ($M = 0.492$, $SD = 0.169$) and control ($M = 0.407$, $SD = 0.228$) groups; $t(52) = 1.521$, $p = 0.134$, DTvisual condition between concussed ($M = 0.490$, $SD = 0.237$) and control ($M = 0.454$, $SD = 0.249$) groups; $t(52) = 0.542$, $p = 0.590$, or DTcognitive condition between concussed ($M = 0.354$, $SD = 0.213$) and control ($M = 0.311$, $SD = 0.275$) groups; $t(52) = 0.629$, $p = 0.532$.

3.3 95% Ellipse

For the 95% ellipse there was no significant main effect of group between Concussed and Control ($F = 0.471$, $p = 0.626$). However, there was a significant main effect of condition ($F = 10.889$, $p = 0.000$). Post hoc analysis of the condition effect showed there were significant differences between DTcognitive and DTcombined ($p = 0.000$), DTvisual and DTcombined ($p = 0.001$), but not between DTcognitive and DTvisual ($p = 0.662$) (figure 4).

Figure 4. Condition Effect - DTcognitive, DTvisual, and DTcombined

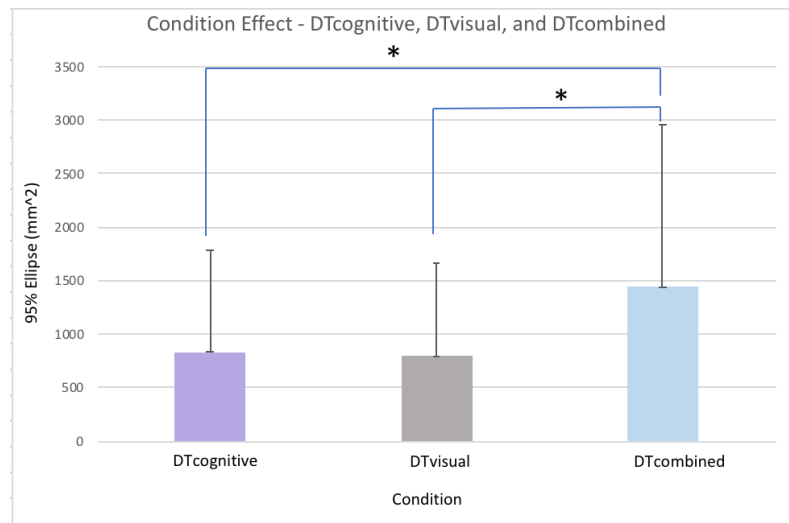


Figure 4. Mean $\pm$ SD for each condition. Groups have been collapsed for one effect group to show differences between conditions.

Within the 95% ellipse only seven of the twenty-four participants 95% ellipse fell above two standard deviations of the control group. This indicates that within the overall concussed group very few had balance issues still persisting. It was also identified that four of the healthy typically developing control participants fell above two standard deviations of the mean of the 95% ellipse data within their own group. This suggests that these individual adolescents may have had a balance issue that could not have been predicted. A relationship between the 95% ellipse data and a negative AI were identified with only one concussed participant displaying balance issues in both the DTcombined and the DTvisual conditions that also scored a negative AI value for both those conditions (table 5).

Table 5. 95% Ellipse - Balance Impairments

Group	95% Ellipse	Condition	Total Number of Participants
Concussed	+/- 2 std	DTcombined	2
		DTvisual	1
		DTcombined/DTvisual	4
Control	+/- 2 std	DTcombined	2
		DTvisual	1
		DTcombined/DTvisual	1

3.4 Centre of Pressure A/P and M/L Velocity

There were no significant differences between the Concussed and Control groups in COP A/P velocity or COP M/L velocity.

3.5 Between Dual-Task Conditions

Significant effects were obtained between the three dual-task conditions for head on trunk movements ($F(2,104) = 3.903$, $p < 0.05$), as well as for trunk on pelvis movement ($F(2,104) = 3.86$, $p < 0.05$). Thus, concluding that when examining dual-task conditions participants scored differently for each dual-task.

3.6 Summary

In summary these results demonstrate that there were no significant differences between the concussed participants and the control participants in the use of either the TSH or TSS movement strategy. An overall preference to employ a TSS movement strategy was identified in both groups for each of the three dual-task conditions in the yaw and roll planes. The COP results suggest that there were no significant differences between the Concussed and Control groups in balance impairments.

4. Discussion

Rocheffort et al (2017) noticed that during a dual-task condition, a subgroup of the concussed participants moved their head and trunk as one segment suggesting the use of an HST/‘en bloc’ movement strategy. The objective of this study was to explore these observations further and describe movement strategies used by adolescents with post-concussion syndrome (PCS) when performing three different dual-tasks. Although 24 youth with concussion were included in this study, a subgroup of participants did not use an HST/“en bloc” movement strategy. We identified key important factors that could have affected these results.

In Rocheffort et al.’s (2017) study they found significant group differences on three balance measures (i.e., 95% ellipse, A/P velocity, and M/L velocity) when participants were asked to perform two-minute trials with their eyes open, eyes closed, and a dual-task condition. This showed that regardless of the task being performed the concussed group swayed faster and over a greater area than the control group of healthy typically developing adolescents (Rocheffort et al., 2017). In the present study, no significant differences in the M/L velocity or A/P velocity between groups in any of the conditions were found. Although there were significant differences between conditions in the 95% ellipse, no significant group effects were found concluding that the Concussed and Control groups had no significant differences in balance impairment.

It was identified that four control participants fell above two standard deviations of the mean of the 95% ellipse data within their own group (refer to Appendix L). Healthy typically developing control participants were recruited from Ashbury College and the community. Interestingly, the four participants that fell outside two standard deviations of the mean of the 95% ellipse for the control data were all from the community. It is important to note that they

were all documented to play on the same wrestling team but remained within the study's participant inclusion and exclusion criteria.

Connections between the 95% ellipse data and a negative AI were examined finding only one concussed participant that displayed balance issues in both the DTcombined and the DTvisual conditions that also scored a negative AI value for both affected conditions. Interestingly, this particular participant also performed the study protocol with the least amount of days post concussive impact. The number of days post-concussion in Rochefort et al. (2017) was between twenty-eight and forty days. The present study recruited patients between one and three months post impact with the least amount of days between impact and protocol being 19 days and the most amount being 90 days. It could be possible that due to the length of time between impact date and performing the study protocol the concussed participants balance impairments resolved (Dierijck et al., 2018). This may explain the small number of concussed participants with balance impairments.

Medical history along with demographic factors and their relationship to the concussed participants head on trunk AI performance in the yaw plane was collected to identify any connections involving: symptom reporting, number of previous concussions, age, sex, and days post injury.

Symptom Reporting Rochefort et al (2017) demonstrated that participants at one month-post concussion are not able to accurately report symptoms pertaining to perceived balance. The Post-Concussion Symptoms Inventory questionnaire information regarding balance, dizziness and clumsiness were compared to 95% ellipse as well as head on trunk AI score in the yaw plane to establish any relationship (refer to appendix K). When the symptom reporting was cross-referenced with the head on trunk AI results in the yaw plane and 95% ellipse data for each

participant it is in close agreement with what Rochefort, Walters, et al. (2017) found, as there was no relationship between either AI score and symptom reporting and symptom reporting and 95% ellipse indications of balance impairments. There were no consistencies in self-reporting and balance issues with a negative head on trunk AI score in the yaw plane. When compared to balance issues all but one participant reported no higher than plus two out of six of increased balance issues (balance, dizziness, and/or clumsy), with the one exception reporting a plus five in dizziness.

When AI was cross-referenced solely with symptom reporting there were no consistencies amongst participants who reported, on the questionnaire, perceived balance impairments and employed a TSH/‘en bloc’ (i.e., negative AI) movement strategy. When examining self-reporting and the relationship to using a TSH/‘en bloc’ movement strategy, participants that reported the highest balance issues did not have a negative anchoring index; interestingly, with the exception of one, these participants employed a TSS movement strategy. These results support what Rochefort, Walters, et al. (2017) reported and provides more evidence that symptom reporting is not a reliable measure of balance impairments.

Number of Previous Concussions AI was also cross-referenced with the number of previous diagnosed concussions each participant had experienced. Of the eight participants that did employ a TSH/‘en bloc’ movement strategy in one or more of the dual-tasks only three had previous concussions, with two who had two previously diagnosed concussions and one who had three previously diagnosed concussions. Of the seven concussed participants that portrayed balance issues, only three had between one and two previously diagnosed concussions, all others had no previously diagnosed concussions (refer to Appendix I and L).

There is evidence that multiple previous concussions have the ability to cause more susceptibility to future concussions (Guskiewicz, et al., 2003) and that multiple concussions result in a greater loss of balance than those who experience their first concussion (Wasserman, Kerr, Zuckerman, & Covassin, 2015). It has also been indicated that postural control difficulties last longer than three to five days post concussive impact, but do not cause long term balance deficits in contact sport athletes (Dierijck et al., 2018). Finding no relationship between number of previous concussions and balance problems, as well as AI, supports Dierijck et al.'s (2018) results suggesting that long term balance deficits may not be affected by multiple concussions.

Age The literature is inconclusive on whether there is a change in ability to perform dual-tasks across different age groups, but for the present study an age group of 11 to 17 was utilized (Saxena et al., 2017). It was identified that the seven participants that had balance issues were between the ages of eleven and fifteen, and the eight participants that scored a negative AI, using a TSH/'en bloc' movement strategy, were between the ages of eleven and fifteen (refer to Appendix H and L). The lower end of the age range used for the present study is where the negative AI scores were seen. There is some evidence that suggests that postural stability may not be fully developed in adolescents between the ages of eight and 14 (Quatman-Yates, 2012). This could help to provide some information as to why the younger portion of the concussed population scored the negative AI values. Like previously mentioned the literature is inconclusive on the effect of age on dual-task abilities, but for the present study a relatively stable age group was chosen to avoid any age-related differences (Saxena et al., 2017).

Sex Of the concussed sample size there were nine males and fifteen females, of which one male and seven females scored negative AI results, employing a TSH/'en bloc' movement strategy, in one or more of the dual-task conditions. Of the healthy typically developing control

participants there were twelve females and eighteen males, where two males and three females employed an TSH/‘en bloc’ movement strategy in one or more of the dual-task conditions. The role of sex in postural stability performance is complex in nature and inconclusive, with some research suggesting that there is no difference in dynamic postural stability performance and other research suggesting it depends on the direction of the movement (Paniccia, et al., 2017).

Days Post Injury Finally, the days post injury was cross referenced with participants to identify any relationship between the number of days between the concussive impact and AI score. As previously stated all participants had to be within one and three months post impact date, but within these guidelines there was much variation. The least amount of days between concussive impact date and performance of the study protocol was 19 days and most was 90 days. Interestingly, the participant that was nineteen days post impact date had balance problems in the DTcombined and DTvisual conditions and scored a negative AI value, employing a TSH/‘en bloc’ movement strategy, for both the DTcombined and DTvisual conditions. This was the only participant that exhibited balance issues for multiple of the dual-task conditions and correspondingly had a negative AI value for the same dual-task conditions. (refer to Appendix J and L).

It is important to note though that the Rochefort et al. (2017) study included participants between 28 and 40 days post impact. It is possible that the participants in the present study were too far into recovery that they no longer exhibited the same magnitude of balance impairments as the participants in Rochefort et al.’s (2017) study. It is also important to note that there was an increased number of participants in Rochefort et al.’s (2017) study that exhibited balance problems in their eyes open, eyes closed, and dual-task conditions. This may be a factor as to why the same type of balance results were not obtained with the present study.

After examining the demographic data and finding no relationships of note, we also assessed the other differences between Rochefort et al. (2017) study and the present study. It was identified that in the attempt to force a reaction the present study moved the dual-tasks to 60 centimeters away from the midline of the participants, where Rochefort et al. (2017) had their participants one meter in distance from the midline when performing their dual-task condition. It may be possible that forcing the participants to move their head to complete two of the three dual-task conditions caused them to force themselves to move their heads independently of their trunks to perform the task. We purposefully designed the paradigm with the hypothesis that by requiring participants to rotate their heads we would in fact be pushing them to use the TSH/‘en bloc’ strategy (refer to appendix C). It is evident that this in fact did not happen. The present study utilized the same dual-task as Rochefort et al. (2017), an incongruent Stroop Colour-word test with 20 rows of five words on a board (DTcombined), with the addition of a congruent Stroop Colour-word test in the same format (DTvisual) and an incongruent Stroop Colour-word test on a tablet at eye level (DTcognitive). The DTcombined condition was examined for both groups of participants to identify any relationship with Rochefort et al.’s (2017) study, but due to their concussed population having more pronounced balance problems, there were no substantial similarities.

Although, the present study did imitate Rochefort et al. (2017) study it is important to note that it may be possible that a TSH/‘en bloc’ movement strategy would be employed by concussed individuals with PCS if the dual-task was more dynamic. By implementing a dual-task that would require a large movement from stationary in one direction or another could activate the need to strap down the head to the trunk and employ an ‘en bloc’ movement strategy. Svesitrup et al. (2008) conducted a study examining head, arm, and trunk coordination in

children while reaching. The task was a natural task similar to self-feeding, where food is grabbed and then put into the mouth. They constructed their task to force the participant to use their bodies, but specifically ensure that a large involvement of the trunk was achieved. By utilizing a large movement where the head and trunk both are required to move may supply better results (Sveistrup et al., 2008).

5. Conclusion

The current study further investigated the use of alternative movement strategies when performing a dual-task in a concussed adolescent population. In our participants, there was no subgroup of adolescents with PCS between one and three months post concussive impact that utilized a TSH/'en bloc' movement strategy. We found that for each individual dual-task condition as well as cumulatively, a TSS movement strategy was preferred, and that between a one and three month post concussive impact range there seems to be less occurrence of prevalent balance impairments in the concussed population.

Furthermore, we were able to modify the AI equation to accurately identify TSH and TSS movement strategies in a stationary task, where the trunk is stable and stationary, and the head moves to perform the task. We utilized this formula to reach the above findings.

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CHAPTER 5

GENERAL DISCUSSION

The current study investigated the use of alternative movement strategies when performing a dual-task in a concussed adolescent population. In the sample of adolescents tested, we did not find any differences between adolescents with concussion and typically developing healthy age-similar adolescents. There was limited use of a TSH/'en bloc' movement strategy even in the adolescents with PCS who were tested between one and three months post concussive impact. We found that for each individual dual-task condition as well as cumulatively, a TSS head and trunk movement strategy was preferred, and that between a one and three months post concussive impact range there seems to be less occurrence of prevalent balance impairments in the concussed population.

Furthermore, we were able to modify the AI equation to accurately identify TSH and TSS movement strategies in a stationary task, where the trunk is stable, and the head moves to perform the task. The manuscript discussed our findings and their relationships in adolescents with concussion in detail; however, additional suggestions are also discussed here.

Future Recommendations

The results from the present study have provided a direction for future research examining effects of concussion on strategies used in balance control during dual-tasks. The present study was seeking to understand unexpected additional results of Rochefort et al. (2017) but was better able to identify explanations as to why a replication of their results was not evident in the present study.

Although Rochefort et al. (2017) subjectively identified a subgroup of concussed participants employing a TSH/'en bloc' movement strategy they were not able to quantify their findings beyond COP results. It could be beneficial to target a concussed population less than 40 days post impact. It is likely that a concussed population within a closer time frame of their concussive impact date may have greater balance issues, whereas with the present study it is possible that balance issues had already resolved themselves in the majority of the concussed participants (Rochefort et al., 2017; Dierijck et al., 2018).

Finally, it would be interesting to determine whether utilizing a more dynamic dual-task would provide better results between groups. The present study used a dual-task that required small movements, but it is possible that a dual-task requiring more dynamic movements in the medio-lateral direction would identify differences between a concussed group and a control group (Sveistrup, et al., 2008).

CONTRIBUTIONS

Dr. Heidi Sveistrup and Coralie Rochefort developed and designed this study and Elizabeth Legace undertook this thesis, the analysis, and writing. Dr. Heidi Sveistrup, Dr. Ryan Graham, and Dr. Kristian Goulet supported this study in its entirety including development, analysis and writing; providing support, advice, and input throughout the entire process, but specifically in reviewing the final product. Dr. Chad Bouley provided engineering expertise with regards to data collection using the Wii Balance Board, along with the MATLAB codes to analyze the Wii Balance Board data. Dr. Ryan Graham assisted with writing the MATLAB code to analyze AI data and provided the electromagnetic tracking device and programming used to collect all head, trunk, and pelvis movement data. Coralie Rochefort also assisted in data processing of the majority of the Wii Balance Board data.

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APPENDICES

Appendix A Electromagnetic Tracking System

Figure 1. Ascension 3D Guidance TrakSTAR Sensor Placement

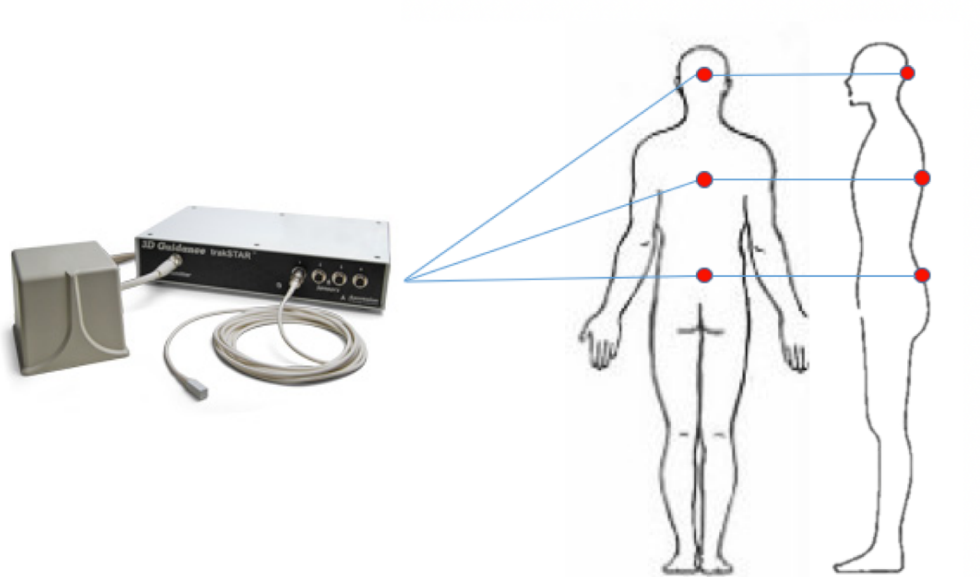


Figure 1. Three sensors, using an electromagnetic tracking system, were placed on the posterior aspect of the participant. One was located at the midline of the base of the skull. The second was located at the midline between the inferior angles of the scapulas (T5). Finally, the third was located at the midline between the iliac crests of the pelvis (L5). All sensor locations were palpated and when identified the sensors were secured onto the participant using tensor bandages and a stretchy head band for the head sensor.

Appendix B Anatomical Planes

Figure 2. Anatomical Planes

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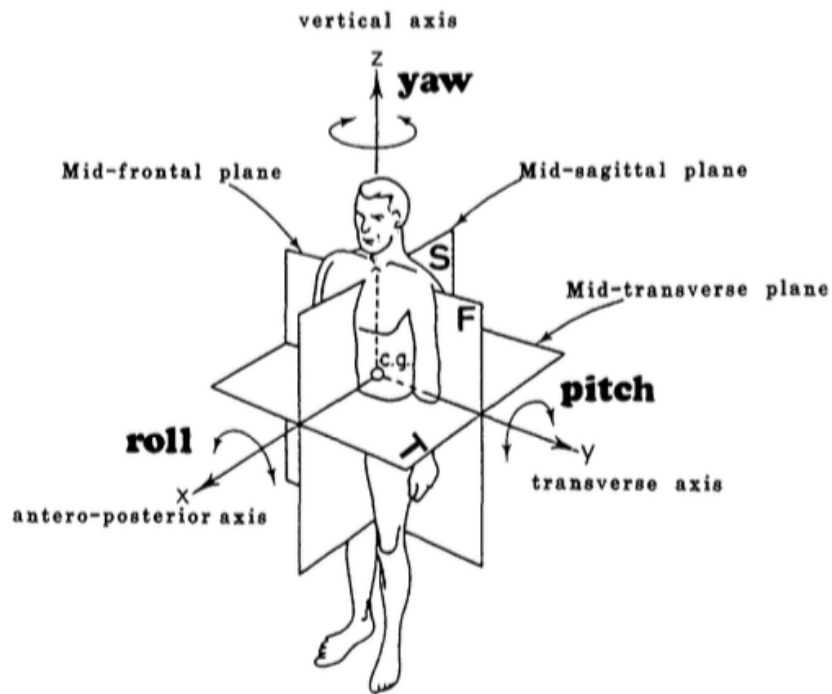


Figure 2. Anchoring index was calculated in yaw and roll planes of rotation. Yaw represents the rotation of the head from right to left and left to right (“no” movement), roll represents the bending of the head reducing and increasing the angles of the head in relation to the shoulders (“maybe” movement), and pitch represents nodding of the head between the anterior and posterior aspects of the body (“yes” movement) (Assaiante & Amblard, 1993).

Appendix C Peripheral Vision Representation

Figure 3. Visual Representation of Peripheral Vision

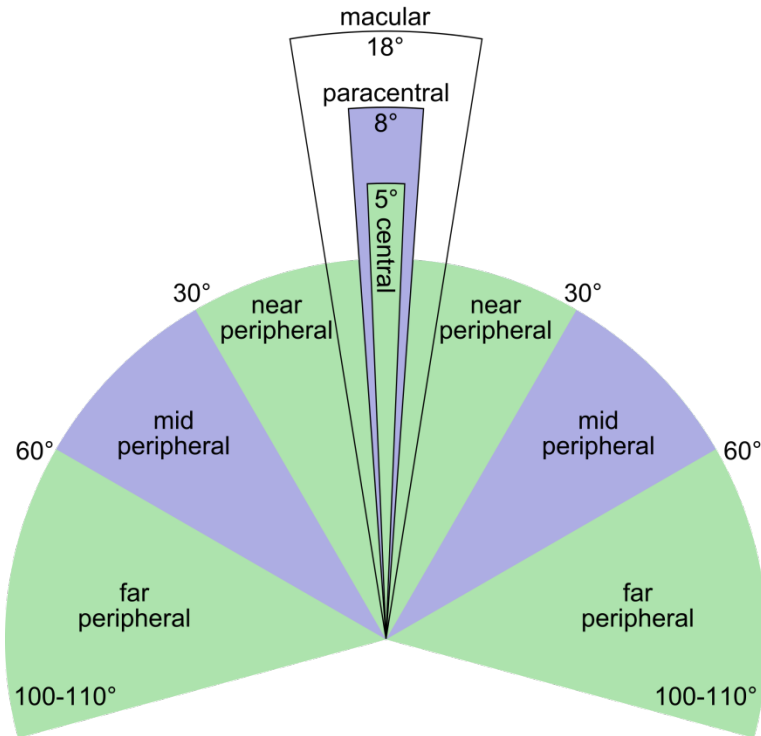
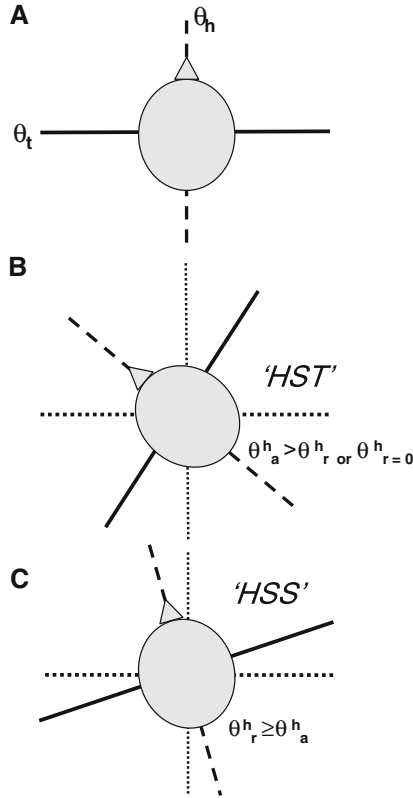


Figure 3. The fovea is the accountable for central vision, also known as, foveal vision. Central vision is necessary for situations where visual detail is the primary objective, for example reading or driving. When reading we use our central vision to identify the words we are reading and then use our peripheral vision to help guide our eyes to where they are to go next (Leigh & Zee, 2006). The board is 40cm from the first word to the last word in width, and the participant stands 60cm away from the board.

Appendix D Traditional Anchoring Index Yaw Plane

Figure 4. Traditional Anchoring Index in the Yaw Plane



$$\text{Traditional Anchoring Index} = \frac{\sigma(\theta_r^h) - \sigma(\theta_a^h)}{\sigma(\theta_r^h) + \sigma(\theta_a^h)}$$

Figure 4. Anchoring index is the “the ratio of the difference between the standard deviation of the relative head – trunk and absolute head angular distributions to their sum.” (Sveistrup et al., 2008). The following figure displays the relationship between the head and shoulders (dashed line and thick lines respectively) in order to calculate the traditional anchoring index (AI) in the transverse plane (Yaw). (A) Illustrates the starting position displaying the relationship between the head and shoulders (B) Represents the head when it is stabilized to the trunk (HST) in an ‘en bloc’ movement strategy. (C) Represents the head stabilized in space (HSS) or the stable platform strategy, when the head is stabilized in space with the neck muscles loose (Sveistrup et al., 2008).

Appendix E Modified Anchoring Index Yaw Plane

Figure 5. Modified Anchoring Index in the Yaw Plane

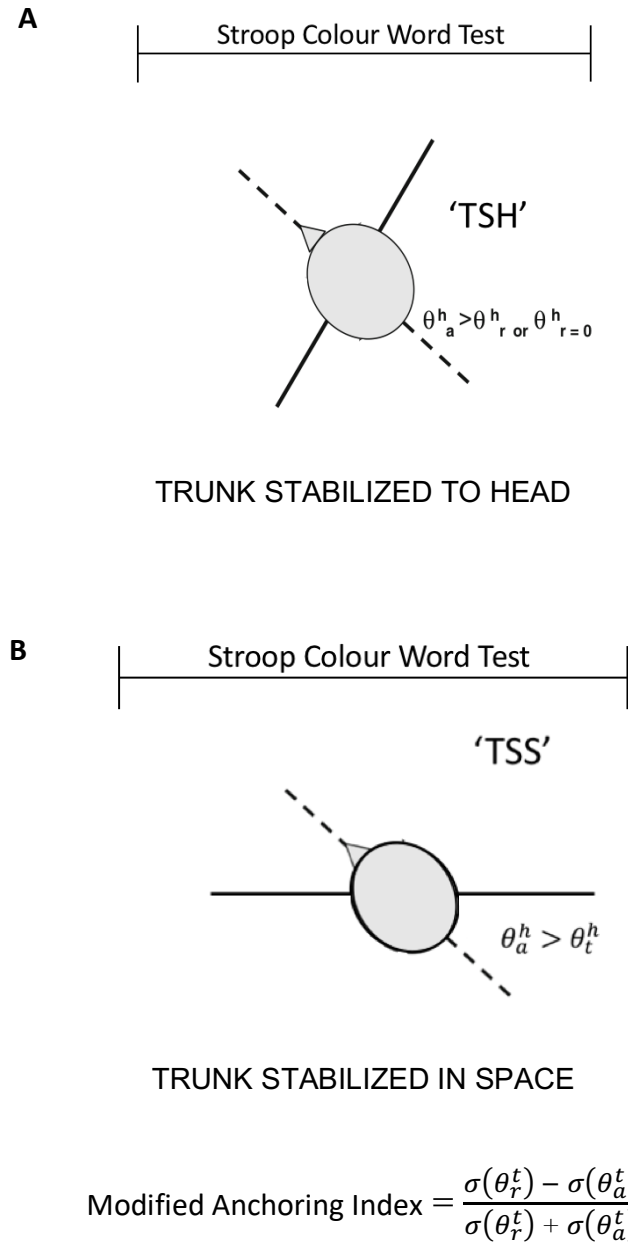
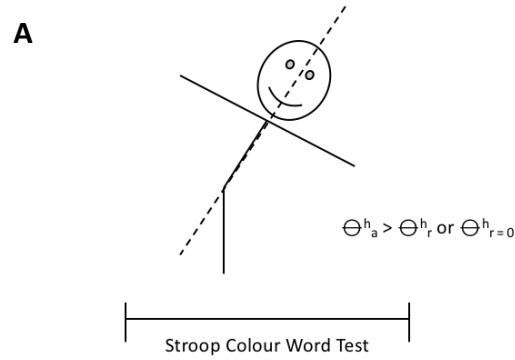


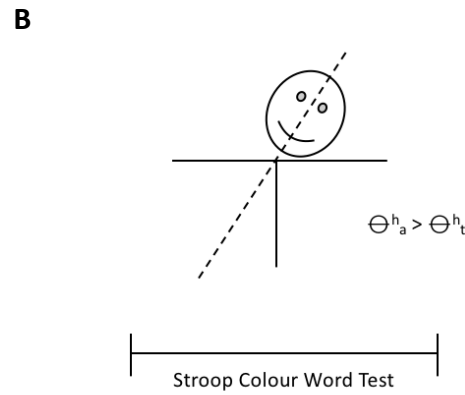
Figure 5. (A) Illustrates the trunk stabilized to head (TSH) movement strategy in the yaw plane. Where the head and trunk move as one stiff unit, also referred to as an 'en bloc' movement strategy. (B) Illustrates the trunk stabilized in space (TSS) movement strategy in the yaw plane. Where the head and trunk move independently of one another with the neck muscles loose

Appendix F Modified Anchoring Index Roll Plane

Figure 6. Modified Anchoring Index in the Roll Plane



TRUNK STABILIZED TO HEAD



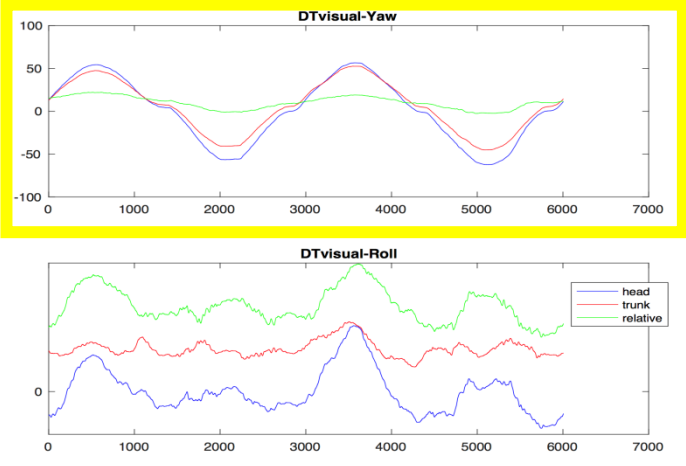
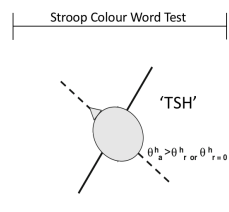
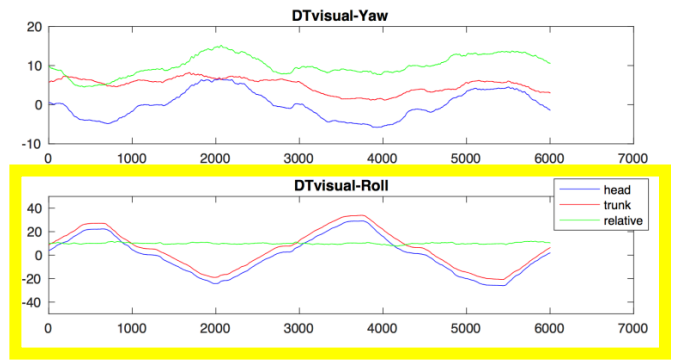
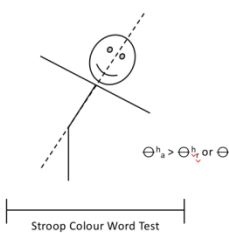
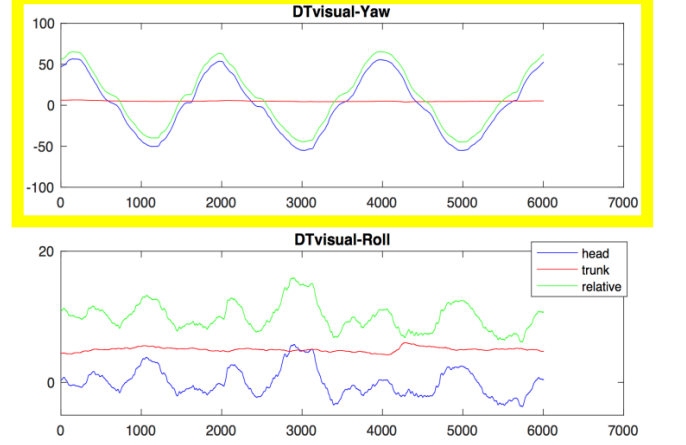
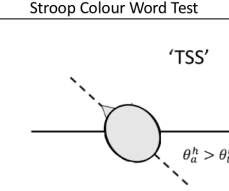
TRUNK STABILIZED IN SPACE

$$\text{Modified Anchoring Index} = \frac{\sigma(\theta_r^t) - \sigma(\theta_a^t)}{\sigma(\theta_r^t) + \sigma(\theta_a^t)}$$

Figure 6. (A) Illustrates the trunk stabilized to head (TSH) movement strategy in the roll plane. Where the head and trunk move as one stiff unit, also referred to as an ‘en bloc’ movement strategy. (B) Illustrates the trunk stabilized in space (TSS) movement strategy in the roll plane. Where the head and trunk move independently of one another with the neck muscles loose (Sveistrup et al., 2008).

Appendix G Modified Anchoring Index Validation

Table 1. Modified Anchoring Index Equation Validation

Movement	Graph	Figure	AI Original Equation Value	AI Modified Equation Value
TSH – Trunk Stabilized to Head, Head and Trunk Rotate (No)			-0.6703	- 0.6071
TSH – Trunk Stabilized to Head, Head and Trunk Tilt (Maybe)			-0.9164	- 0.9166
TSS – Trunk Stabilized in Space, Head Rotates (No)			-0.0040	0.9716

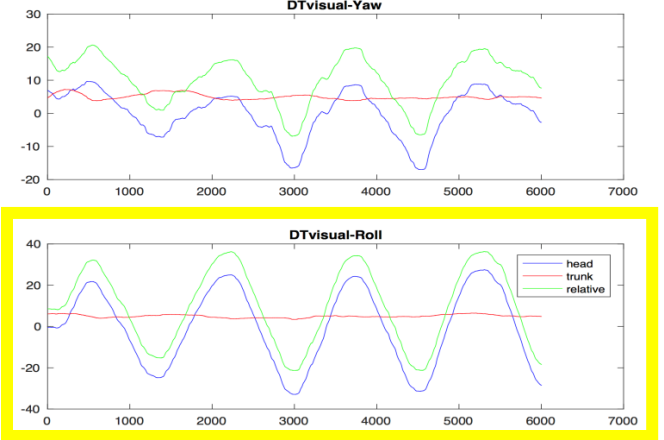
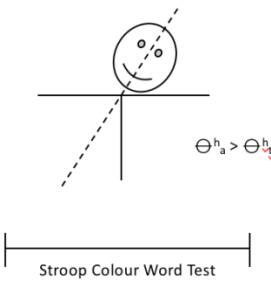
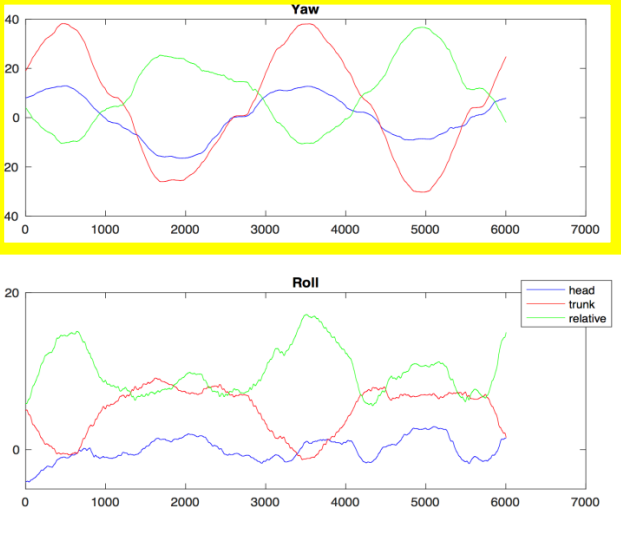
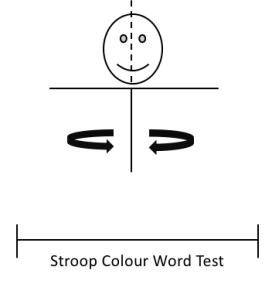
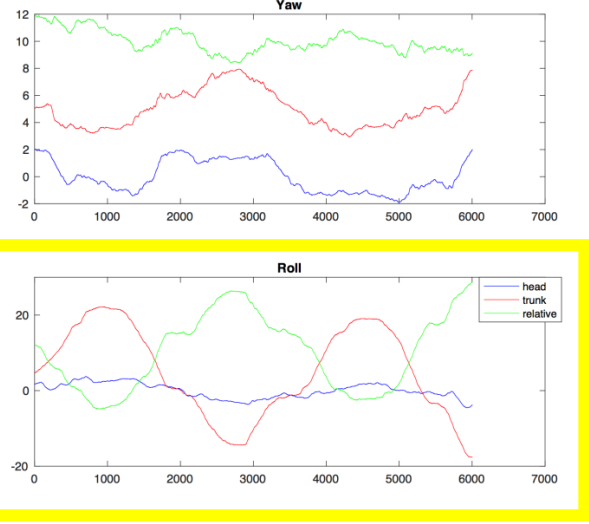
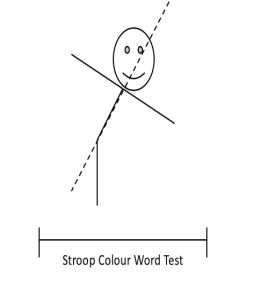
TSS - Trunk Stabilized in Space, Head Tilts (Maybe)			-0.0031	0.9238
HSS - Head Stable in Space, Trunk Rotates (No)			0.2015	-0.2356
HSS - Head Stable in Space, Trunk Tilts (Maybe)			0.6695	-0.0806

Table1. To determine whether the AI modified equation would provide the appropriate output to quantify both TSH and TSS, optimal large isolated movements were recorded, and the data run

through both the original AI equation and the modified AI equation. The values were then compared to one another. The original AI equation would give a positive value close to +1 to indicate a HSS movement and a value close to -1 to indicate a HST movement. The flipped AI equation would give us a positive value close to +1 to indicate a TSS movement and a value close to -1 to indicate a TSH movement. To then determine if the modified equation is consistent with the traditional AI equation both the traditional AI equation output value and the modified AI equation output value should be similar for the TSH movements. When compared both sets of values: the traditional AI equation and the modified AI equation outputted are similar enough (No: ± 0.04 /Maybe: ± 0.0001).

Appendix H Concussion Demographics

Table 2. Concussion Group Complete Demographic Data

Participant # (Concussed)	Age	Sex	Days from Head Impact	# of Previous Concussions	Symptoms Change from Pre to Post				Anchoring Index						Balance Problem (± 2 std)
					Total (120)	Balance			DTcombined		DTvisual		DTcognitive		
						Balance	Dizziness	Clumsy	Head/ Trunk	Trunk/ Pelvis	Head/ Trunk	Trunk/ Pelvis	Head/ Trunk	Trunk/ Pelvis	
M12	15	M	73	0	19	+1	+1	+1	-0.4021	-0.6875	-0.1985	-0.6676	0.027	-0.3547	
M13	14	M	30	3	34	+1	+2	+1	0.2559	-0.446	0.4933	-0.2062	0.2677	-0.1244	
M14	15	M	28	2	41	0	+1	0	0.5187	-0.4503	0.6035	-0.4272	-0.2085	-0.5405	DTvisual, DTcombined
M15	11	F	29	0	22	+1	+2	-	0.0621	-0.6175	0.1379	-0.6533	0.2674	-0.3142	DTcombined
M16	13	M	31	1	72	+4	+5	+2	0.4838	-0.2932	0.2636	-0.5369	0.2701	-0.2152	
M17	11	M	32	4	-	-	-	-	0.1604	-0.4123	0.0712	-0.3564	-0.0087	-0.0941	
M19	12	M	84	0	13	+2	+2	-	0.3752	-0.2932	0.1668	-0.2723	0.0356	-0.3156	DTcombined
M20	11	M	33	0	17	0	+1	-	0.5431	-0.4178	0.3231	-0.4369	0.1542	-0.3038	
M21	14	F	90	1	31	0	+5	0	0.0654	-0.4488	0.1574	-0.6934	-0.117	-0.5132	DTvisual DTcombined
M22	11	F	48	0	22	+1	+2	-	-0.0412	-0.3792	0.0526	-0.5081	0.0457	0.0383	DTvisual, DTcombined
M23	16	F	36	0	33	0	+3	0	0.3095	-0.4983	0.4847	8.51E-04	0.1025	-0.0554	
M24	15	F	35	3	25	+1	+1	0	-0.1872	-0.6123	0.1713	-0.1531	0.3858	-0.1049	
M25	16	F	47	2	48	+2	+4	+2	-0.1881	-0.7016	-0.0044	-0.6082	0.4258	-0.1796	
M26	15	F	34	1	10	0	+3	0	0.2675	-0.1138	0.1941	0.0356	0.2024	0.1164	
M27	16	F	80	0	26	0	+4	0	0.4701	-0.2427	0.5551	-0.111	0.2889	-0.0012	
M28	12	M	50	2	4	0	0	-	0.6057	0.2353	0.5767	-0.0136	0.1124	0.2268	
M29	14	F	34	4	52	+2	+2	+1	0.225	-0.7102	0.1555	-0.774	0.5797	-0.5815	
M30	11	F	37	1	-	-	-	-	0.0654	-0.7612	-0.0705	-0.596	-0.1065	-0.517	
M31	13	F	77	0	28	0	+2	0	-0.0412	-0.4983	0.312	-0.2439	0.0081	-0.2245	DTvisual
M33	13	F	19	2	14	0	+2	0	-0.5717	-0.6123	-0.4853	-0.5395	0.2368	-0.1593	DTvisual, DTcombined
M34	15	F	35	0	16	+3	0	+1	0.2021	-0.7016	0.3342	-0.4956	0.207	-0.5327	
M35	16	F	36	2	52	0	+3	+3	0.0031	-0.1138	-0.0112	-0.3883	-0.0142	-0.4821	
M36	13	F	33	0	-	-	-	-	0.3342	-0.2427	0.7105	-0.3566	0.4347	-0.0746	
M37	15	M	31	3	41	+1	+2	+1	0.0573	0.2353	0.2738	-0.278	0.3506	-0.0929	

Table 2. All demographic, medical history, and symptom reporting pertinent to the present study for the concussion group is displayed. The highlighted line for M33 is the only participant that had a relationship between days post-concussion, AI, and balance problems.

Appendix I Concussion Group Previous Concussions

Table 3. Concussion Group Number of Previous Concussions

Participant # (Concussed)	Age	Sex	# of Previous Concussions	Anchoring Index			Balance Problem (± 2 std)
				DTcombined	DTvisual	DTcognitive	
				Head/ Trunk	Head/ Trunk	Head/ Trunk	
M12	15	M	0	- 0.4021	-0.1985	0.027	
M13	14	M	3	0.2559	0.4933	0.2677	
M14	15	M	2	0.5187	0.6035	-0.2085	DTvisual, DTcombined
M15	11	F	0	0.0621	0.1379	0.2674	DTcombined
M16	13	M	1	0.4838	0.2636	0.2701	
M17	11	M	4	0.1604	0.0712	-0.0087	
M19	12	M	0	0.3752	0.1668	0.0356	DTcombined
M20	11	M	0	0.5431	0.3231	0.1542	
M21	14	F	1	0.0654	0.1574	-0.117	DTvisual DTcombined
M22	11	F	0	-0.0412	0.0526	0.0457	DTvisual, DTcombined
M23	16	F	0	0.3095	0.4847	0.1025	
M24	15	F	3	- 0.1872	0.1713	0.3858	
M25	16	F	2	- 0.1881	-0.0044	0.4258	
M26	15	F	1	0.2675	0.1941	0.2024	
M27	16	F	0	0.4701	0.5551	0.2889	
M28	12	M	2	0.6057	0.5767	0.1124	
M29	14	F	4	0.225	0.1555	0.5797	
M30	11	F	1	0.0654	-0.0705	-0.1065	
M31	13	F	0	-0.0412	0.312	0.0081	DTvisual
M33	13	F	2	-0.5717	-0.4853	0.2368	DTvisual, DTcombined
M34	15	F	0	0.2021	0.3342	0.207	
M35	16	F	2	0.0031	-0.0112	-0.0142	
M36	13	F	0	0.3342	0.7105	0.4347	
M37	15	M	3	0.0573	0.2738	0.3506	

Table 3. Number of previous concussions for participants in the concussion group are isolated with AI and balance problems.

Appendix J Concussion Group Days Post Impact

Table 4. Concussion Group Days Post Injury

Participant # (Concussed)	Age	Sex	Days from Head Impact	Anchoring Index			Balance Problem (± 2 std)
				DTcombined	DTvisual	DTcognitive	
				Head/Trunk	Head/Trunk	Head/Trunk	
M12	15	M	73	- 0.4021	-0.1985	0.027	
M13	14	M	30	0.2559	0.4933	0.2677	
M14	15	M	28	0.5187	0.6035	-0.2085	DTvisual, DTcombined
M15	11	F	29	0.0621	0.1379	0.2674	DTcombined
M16	13	M	31	0.4838	0.2636	0.2701	
M17	11	M	32	0.1604	0.0712	-0.0087	
M19	12	M	84	0.3752	0.1668	0.0356	DTcombined
M20	11	M	33	0.5431	0.3231	0.1542	
M21	14	F	90	0.0654	0.1574	-0.117	DTvisual DTcombined
M22	11	F	48	-0.0412	0.0526	0.0457	DTvisual, DTcombined
M23	16	F	36	0.3095	0.4847	0.1025	
M24	15	F	35	- 0.1872	0.1713	0.3858	
M25	16	F	47	- 0.1881	-0.0044	0.4258	
M26	15	F	34	0.2675	0.1941	0.2024	
M27	16	F	80	0.4701	0.5551	0.2889	
M28	12	M	50	0.6057	0.5767	0.1124	
M29	14	F	34	0.225	0.1555	0.5797	
M30	11	F	37	0.0654	-0.0705	-0.1065	
M31	13	F	77	-0.0412	0.312	0.0081	DTvisual
M33	13	F	19	-0.5717	-0.4853	0.2368	DTvisual, DTcombined
M34	15	F	35	0.2021	0.3342	0.207	
M35	16	F	36	0.0031	-0.0112	-0.0142	
M36	13	F	33	0.3342	0.7105	0.4347	
M37	15	M	31	0.0573	0.2738	0.3506	

Table 4. Days post injury for the participants in the concussion group are isolated with AI and balance problems.

Appendix K Concussion Group Symptom Reporting

Table 7. Concussion Group Symptom Reporting

Participant # (Concussed)	Age	Sex	Symptoms Change from Pre to Post				Anchoring Index			Balance Problem (± 2 std)
			Total (120)	Balance			DTcombined Head/ Trunk	DTvisual Head/ Trunk	DTcognitive Head/ Trunk	
M12	15	M	19	+1	+1	+1	- 0.4021	-0.1985	0.027	
M13	14	M	34	+1	+2	+1	0.2559	0.4933	0.2677	
M14	15	M	41	0	+1	0	0.5187	0.6035	-0.2085	DTvisual, DTcombined
M15	11	F	22	+1	+2	-	0.0621	0.1379	0.2674	DTcombined
M16	13	M	72	+4	+5	+2	0.4838	0.2636	0.2701	
M17	11	M	-	-	-	-	0.1604	0.0712	-0.0087	
M19	12	M	13	+2	+2	-	0.3752	0.1668	0.0356	DTcombined
M20	11	M	17	0	+1	-	0.5431	0.3231	0.1542	
M21	14	F	31	0	+5	0	0.0654	0.1574	-0.117	DTvisual DTcombined
M22	11	F	22	+1	+2	-	-0.0412	0.0526	0.0457	DTvisual, DTcombined
M23	16	F	33	0	+3	0	0.3095	0.4847	0.1025	
M24	15	F	25	+1	+1	0	- 0.1872	0.1713	0.3858	
M25	16	F	48	+2	+4	+2	- 0.1881	-0.0044	0.4258	
M26	15	F	10	0	+3	0	0.2675	0.1941	0.2024	
M27	16	F	26	0	+4	0	0.4701	0.5551	0.2889	
M28	12	M	4	0	0	-	0.6057	0.5767	0.1124	
M29	14	F	52	+2	+2	+1	0.225	0.1555	0.5797	
M30	11	F	-	-	-	-	0.0654	-0.0705	-0.1065	
M31	13	F	28	0	+2	0	-0.0412	0.312	0.0081	DTvisual
M33	13	F	14	0	+2	0	-0.5717	-0.4853	0.2368	DTvisual, DTcombined
M34	15	F	16	+3	0	+1	0.2021	0.3342	0.207	
M35	16	F	52	0	+3	+3	0.0031	-0.0112	-0.0142	
M36	13	F	-	-	-	-	0.3342	0.7105	0.4347	
M37	15	M	41	+1	+2	+1	0.0573	0.2738	0.3506	

Table 7. Symptom reporting data for the concussion group is isolated with AI and balance problems.

Appendix L Control Group Demographics

Table 8. Control Group Demographics

Participant # (Control)	Age	Sex	# of Previous Concussions	Anchoring Index						Balance Problem (± 2 std)
				DTcombined		DTvisual		DTcognitive		
				Head/ Trunk	Trunk/ Pelvis	Head/ Trunk	Trunk/ Pelvis	Head/ Trunk	Trunk/ Pelvis	
T29	14	M	0	-0.2585	-0.874	0.4931	-0.3717	0.0021	-0.469	
T30	14	M	0	0.1308	-0.5441	0.2386	-0.3396	-0.2779	-0.5992	
T31	14	M	1	0.3355	-0.3734	0.3253	-0.325	0.3902	0.0957	
T32	14	M	0	0.6249	-0.3273	0.7264	0.2296	-0.1089	-0.4193	
T33	15	M	0	0.5908	-0.3083	0.8023	-0.3712	-0.0248	-0.5013	
T34	15	F	0	-0.0792	-0.5814	-0.1941	-0.6725	0.3169	-0.0536	
T35	15	F	0	-0.4598	-0.8023	-0.1487	-0.6282	0.2258	-0.1381	
T36	17	F	0	0.4834	-0.1435	0.4237	-0.0559	0.4588	0.0641	
T37	17	M	6	0.5297	-0.1723	0.4713	0.0953	-0.151	-0.0628	
T38	16	M	0	0.6128	-0.1269	0.7476	-0.4913	0.2981	-0.2399	
T39	16	M	2	0.4772	-0.5441	0.5985	-0.2505	0.3722	-0.3511	
T40	17	F	0	0.5854	-0.4387	0.437	-0.4472	0.275	0.1785	
T41	14	F	1	0.2837	-0.5129	0.4549	-0.5897	0.247	-0.214	
T42	17	F	0	-0.1472	-0.7868	0.1604	-0.6377	0.151	-0.0665	
T43	17	F	0	0.3709	-0.0234	0.4572	0.0106	-0.081	-0.2094	
T44	13	F	0	0.5019	-0.3953	0.4838	0.0936	0.1928	-0.1334	
T45	14	F	0	0.1686	-0.2273	0.4109	-0.1226	0.1903	-0.1153	
T46	14	M	0	0.4428	-0.3414	0.4678	-0.0383	0.3147	-0.5789	
T47	14	M	0	0.9011	0.2076	0.7747	0.0669	-0.1103	-0.4284	
T49	14	M	1	0.1164	-0.2584	0.2906	-0.2859	0.1364	-0.4062	
T50	12	F	-	0.3195	-0.3813	0.1601	-0.6235	0.251	-0.5601	DTcombined
T51	15	F	-	0.0106	-0.6065	0.1409	-0.5364	0.1063	-0.4357	DTvisual, DTcombined
T52	13	M	-	0.4941	-0.2511	0.8377	0.4892	0.4797	0.1082	
T53	12	M	-	0.4113	-0.3685	0.4109	-0.1179	0.3711	-0.0534	
T54	14	M	-	0.2277	-0.4709	0.4344	-0.4139	-0.0262	-0.1201	
T55	12	M	-	0.5191	-0.4121	-0.0468	-0.0519	0.7142	-0.0983	
T56	11	M	-	0.0256	-0.6281	0.4511	-0.1804	0.4392	-0.4035	DTcombined
T57	14	M	-	0.1051	-0.7189	0.1205	-0.5689	0.0084	-0.6322	
T59	14	M	-	0.409	-0.4209	0.4034	-0.36	0.1897	-0.2403	DTvisual
T60	11	F	-	0.2007	-0.4636	0.0852	-0.5682	0.6614	0.0676	

Table 8. All demographic information pertinent to the present study for the control group is displayed.

Appendix M: Sample Size Calculation

The power analysis was calculated using the following formula for the sample size N:

$$N = \frac{4\sigma^2(Z_{crit} + Z_{pwr})^2}{D^2}$$

σ : represents the assumed standard deviation of each group.

Z_{crit} : represents the z value associated with the desired significance criterion.

Z_{pwr} : represents the z value associated with the desired statistical power.

D = represents the minimum expected difference between the two means.

Appendix N Modified Anchoring Index MATLAB Script

MATLAB Modified Anchoring Index Data Analysis Script Head on Trunk

```
% load file_name
load file_name

%% Deleting the first 5 seconds from Data Sets
A = M22_DTcognitive(1400:end, :);

%% Deleting the last 5 seconds from the Data Sets
lastn=1400;
tst = A(1:end-lastn,:);

%% Break into Segments
head = tst(:,1:6);
trunk = tst(:,7:12);
pelvis = tst(:,13:18);

%% Fix Jumps in Angles
head(:,4:6)= rad2deg(unwrap(deg2rad(head(:,4:6))));
trunk(:,4:6)= rad2deg(unwrap(deg2rad(trunk(:,4:6))));
pelvis(:,4:6)= rad2deg(unwrap(deg2rad(pelvis(:,4:6))));

%% Plot
figure(); hold on;
subplot(3,1,1);
plot(head);
legend('x','y','z','yaw','pitch','roll');
subplot(3,1,2);
plot(trunk);
legend('x','y','z','yaw','pitch','roll');

%% Calculate Relative Angle
relative= trunk - head;

%% Finding Standard Deviations

% Head
stdrollh = std(head(:,6))
stdyawh = std(head(:,4))
stdpitchh = std(head(:,5))

% Trunk
stdrollt = std(trunk(:,6))
stdyawt = std(trunk(:,4))
stdpitcht = std(trunk(:,5))

% Pelvis
stdrollp = std(pelvis(:,6))
stdyawp = std(pelvis(:,4))
stdpitchp = std(pelvis(:,5))

% Relative
stdrollr = std(relative(:,6))
stdyawr = std(relative(:,4))
```

```

stdpitchr = std(relative(:,5))

%% Averaging the Values

Mh = head - mean(head);
Mt = trunk - mean(trunk)+5;
Mp = pelvis - mean(pelvis)+10;
Mr = relative - mean(relative)+15;

%% Calculate Anchoring Index
anchoring_i_pitch = (std(Mr(:,5))-std(Mt(:,5))) / (std(Mr(:,5))+
std(Mt(:,5)))
anchoring_i_yaw = (std(Mr(:,4))-std(Mt(:,4))) / (std(Mr(:,4))+ std(Mt(:,4)))
anchoring_i_roll = (std(Mr(:,6))-std(Mt(:,6))) / (std(Mr(:,6))+ std(Mt(:,6)))

%% Plot
figure
subplot(3,1,1)
plot(Mh(:,5), 'b'); hold on;
plot(Mp(:,5), 'r'); hold on;
plot(Mr(:,5), 'g');
title Pitch

subplot(3,1,2)
plot(Mh(:,4), 'b'); hold on;
plot(Mp(:,4), 'r'); hold on;
plot(Mr(:,4), 'g');
title Yaw

subplot(3,1,3)
plot(Mh(:,6), 'b'); hold on;
plot(Mp(:,6), 'r'); hold on;
plot(Mr(:,6), 'g');
legend('head', 'trunk', 'relative');
title Roll

```

MATLAB Modified Anchoring Index Data Analysis Script Trunk on Pelvis

```
% load file_name
load file name

%% Deleting the first 5 seconds from Data Sets
A = M22_DTcognitive(1400:end, :);

%% Deleting the last 5 seconds from the Data Sets
lastn=1400;
tst = A(1:end-lastn,:);

%% Break into Segments
head = tst(:,1:6);
trunk = tst(:,7:12);
pelvis = tst(:,13:18);

%% Fix Jumps in Angles
head(:,4:6)= rad2deg(unwrap(deg2rad(head(:,4:6))));
trunk(:,4:6)= rad2deg(unwrap(deg2rad(trunk(:,4:6))));
pelvis(:,4:6)= rad2deg(unwrap(deg2rad(pelvis(:,4:6))));

%% Plot
figure(); hold on;
subplot(3,1,1);
plot(head);
legend('x','y','z','yaw','pitch','roll');
subplot(3,1,2);
plot(trunk);
legend('x','y','z','yaw','pitch','roll');

%% Calculate Relative Angle
relative= pelvis - trunk;

%% Finding Standard Deviations

% Head
stdrollh = std(head(:,6))
stdyawh = std(head(:,4))
stdpitchh = std(head(:,5))

% Trunk
stdrollt = std(trunk(:,6))
stdyawt = std(trunk(:,4))
stdpitcht = std(trunk(:,5))

% Pelvis
stdrollp = std(pelvis(:,6))
stdyawp = std(pelvis(:,4))
stdpitchp = std(pelvis(:,5))

% Relative
stdrollr = std(relative(:,6))
stdyawr = std(relative(:,4))
stdpitchr = std(relative(:,5))
```

```
%% Averaging the Values
```

```
Mh = head - mean(head);  
Mt = trunk - mean(trunk)+5;  
Mp = pelvis - mean(pelvis)+10;  
Mr = relative - mean(relative)+15;
```

```
%% Calculate Anchoring Index
```

```
anchoring_i_pitch = (std(Mr(:,5))-std(Mp(:,5))) / (std(Mr(:,5))+  
std(Mp(:,5)))  
anchoring_i_yaw = (std(Mr(:,4))-std(Mp(:,4))) / (std(Mr(:,4))+ std(Mp(:,4)))  
anchoring_i_roll = (std(Mr(:,6))-std(Mp(:,6))) / (std(Mr(:,6))+ std(Mp(:,6)))
```

```
%% Plot
```

```
figure  
subplot(3,1,1)  
plot(Mh(:,5), 'b'); hold on;  
plot(Mp(:,5), 'r'); hold on;  
plot(Mr(:,5), 'g');  
title Pitch
```

```
subplot(3,1,2)  
plot(Mh(:,4), 'b'); hold on;  
plot(Mp(:,4), 'r'); hold on;  
plot(Mr(:,4), 'g');  
title Yaw
```

```
subplot(3,1,3)  
plot(Mh(:,6), 'b'); hold on;  
plot(Mp(:,6), 'r'); hold on;  
plot(Mr(:,6), 'g');  
legend('head', 'trunk', 'relative');  
title Roll
```

Appendix O Letters of Information and Consents

PARENT INFORMED CONSENT CONCUSSION GROUP

Protocol title: Balance Markers and Saccadic Eye Movement Parameters in Children and Adolescents with Concussion

Principal investigator: Gail Macartney, RN(EC), PhD

Address: Children's Hospital of Eastern Ontario
401 Smyth Road, Ottawa, ON, K1H 8L1

Telephone number: (613) 737-7600 ext. 3396

Primary University of Ottawa investigator: Heidi Sveistrup, PhD, 613-562-5800 ext. 7099

You are being invited to join in a research study about the recovery of balance following a concussion. You are being invited to join this study because your child has experienced a concussion. Before agreeing to take part in this study, it is important that you read and understand this document.

Taking part in this study is voluntary. Your decision to participate or not in this study will not affect the care you receive at CHEO, the CHEO concussion clinic and the ActiveCare clinic in Kanata. You are free to withdraw from the study at any time and there will be no penalty to you or your child.

Why is this study being done?

The purpose of this study is to learn more about balance problems and problems with eye movements following a concussion. This study will help determine if it is important to observe eye movements when testing balance. We are also interested in learning more about factors that are linked to recovery following a concussion. In order to do this we will collect information on anxiety and depression.

How many children will participate?

We expect to have 30 children and adolescents who have had a concussion and 60 children and adolescents who have not had a concussion participate. We expect to invite children and adolescents to participate for 6 months. This study is expected to be active for 8 months.

What will my child be asked to do?

If you decide to participate in this study, we will ask you to participate in up to three 30-minute sessions. The first session will take place between 1 and 3 months following the date of your child's concussion, the second session at 2-months following the date of your child's first session and the third session at 5-months following the date of your child's first session. These

sessions will take place at the CHEO concussion clinic (1355 Bank Street, Suite 111) and will be completed between the hours of 8 am and 4 pm from Monday to Friday.

During each session, your child will first be asked to stand on a Nintendo Wii Balance Board and to focus on standing as still as possible for two minutes with their eyes open and with their eyes closed. Your child will then be asked to complete three different cognitive tasks while standing on the Nintendo Wii Balance Board. For these tasks, your child will be presented with a series of the words “red”, “yellow”, “green” and “blue” printed in the correct or incorrect colour. For example, the word “red” could be printed in red or printed in an incorrect colour like blue. Your child will be asked to either read the words or to name the colour of the ink that each word is printed in. While your child completes these tasks, a headband that measures head accelerations will be placed around your child’s head, a strap that measures torso accelerations will be placed around your child’s torso, and your child will be asked to wear a pair of glasses that records eye movements.

During these sessions, your child will also be asked to complete five short questionnaires. These questionnaires will ask your child about how he/she is feeling and about symptoms related to his/her concussion.

Are there any risks to participating?

There is very little risk in participating in this study. At most, your child may become tired while completing the balance tests. However, your child may request to take a rest at anytime.

Are there any benefits to participating?

Your child will not get any personal benefit from being part of this study; however we hope to improve the way balance is assessed following a concussion to take better care of patients in the future.

Will my child be compensated for participating?

If your child participates, he/she will receive one 5\$ Tim Horton’s gift card for each session that he/she completes in recognition of your time and effort.

What if my child gets injured?

In the event that your child suffers injury as a direct result of participating in this study, normal legal rules on compensation will apply. Medical care will be provided to your child. By signing this consent form you are in no way waiving your legal rights or releasing the investigator from their legal and professional responsibilities.

Will I be told about new information?

We will inform you of any new information that might influence your decision to continue to participate in this research project. We will ask you again if you want to be in the study. If this study uncovers information that might be helpful to your child’s current or future health, the investigator will provide this information to your child’s most responsible physician for follow-up. In the event of a positive depression screen, the principle investigator will be notified. We will offer that your child be seen at an emergency department and you will be provided with the phone number for a crisis line.

Will my child's records be kept private and confidential?

Your child's personal information will be kept strictly confidential. For this study we will be collecting gender and Date Of Birth (DOB) for the research purposes described in this consent form. Representatives from the CHEO research Ethics Board may look at your records at the site where these records are held, to check that the study is following the proper laws and guidelines.

The data produced from this study will be stored in a secured locked location. Only members of the research team and the individuals described above will have access to the data. Following completion of the research study the data will be kept for 7 years after the last publication of this study. They will then be destroyed.

Any information that would indicate that a child was being harmed or at risk of such harm, would not be kept confidential and instead be disclosed as appropriate to offset that risk.

Your child will not be identified in any publication or presentation of this study.

A copy of the signed consent form will be provided to you.

Is the research team benefiting from the study?

The research team members are not benefiting personally, financially or in some other way from this study.

What if I have questions?

If you have any questions concerning participation in this study, or if at any time feel that your child has experienced a study-related injury, contact:

Dr. Heidi Sveistrup, (613) 562-5800 ext. 7099

This study have been reviewed and approved by the CHEO Research Ethics Board. The CHEO Research Ethics Board is a committee of the hospital that includes individuals from different professional backgrounds. The Board reviews all human research that takes place at the hospital. Its goal is to ensure the protection of the rights and welfare of people participating in research. The Board's work is not intended to replace a parent or child's judgment about what decisions and choices are best for them. You may contact the Chair of the Research Ethics Board, for information regarding patient's rights in research studies at (613) 737-7600 ext. 3272, although this person cannot provide health-related information about the study.

A summary of the results will be provided to you at the conclusion of the study if you desire.

Consent form signatures

By signing this consent form I agree that:

- I am voluntarily agreeing to participate in this research study;
- I understand the information within this consent form;
- All of the risks and benefits of participation have been explained to me;
- All of my questions have been answered;

- I allow access to my child’s medical records and/or personal information as described in this consent form, and;
- I do not give up my legal rights by signing this form.

**Signature of Parent or
Guardian**

**Name of Parent or
Guardian**

Date

**Witness to Parent or
Guardian’s Signature**

Name of Witness

Date

**Signature of person
Obtaining Informed Consent**

**Name of Person Obtaining
Informed Consent**

Date

PARTICIPANT INFORMED ASSENT (8-11) CONCUSSION GROUP

Protocol title: Balance Markers and Saccadic Eye Movement Parameters in Children and Adolescents with Concussion

Principal investigator: Gail Macartney, RN(EC), PhD

Address: Children's Hospital of Eastern Ontario
401 Smyth Road, Ottawa, ON, K1H 8L1

Telephone number: (613) 737-7600 ext. 3396

Primary University of Ottawa investigator: Heidi Sveistrup, PhD, 613-562-5800 ext. 7099

Why is this study being done?

We would like to invite you to be part of a research study. Research is a way to test new ideas to see if we can do things better. In our study, we want to see how children like you, who have had a concussion, maintain their balance. We also want to look at factors that could affect your recovery. This is why we will also ask you questions about anxiety and depression.

Who will take part?

Children seen at the CHEO concussion clinic and at the ActiveCare clinic in Kanata are being asked to join this study. We expect to have 30 children and teenagers who have had a concussion and 60 children and teenagers who have not had a concussion join the study over the next 6 months.

What will happen during the study?

If you want to do this study, we will measure your balance three times. Each time will take 30-minutes. You will be asked to do the first one today, the second one in two months from now and the third one in five months from now. It is up to you to decide if you want to participate just for today or if you want to come back one or two more times. You will complete these sessions at the CHEO concussion clinic between the hours of 8 am 4pm between Monday and Friday.

Each time, we will ask you to stand on the board for the game Wii Fit and to stand as still as you can for two minutes with your eyes open and with your eyes closed. After this, we will ask you to stand on the board again and we will ask you to complete three different games while you are standing. While you do this, there will be a headband placed around your head, a strap placed around your torso, and you will wear a pair of glasses.

We will also ask you to answer a couple of questions about how you are feeling and about any symptoms from your concussion.

Are there good things that can happen from this study?

Sometimes good things can happen to people when they are in a study. These good things are called “benefits”. This study will help us better understand children who have had a concussion. That is a benefit. There are no other benefits that we think will happen to you if you decide to join this study.

Are there bad things that can happen from this study?

We do not think that anything bad would happen if you decide to join this study.

What if something bad happens?

If something does go wrong, your doctor will be there to take care of you.

Will I receive something for participating?

If you decide to participate, you will receive one 5\$ Tim Horton’s gift card for each time that you do the balance measures.

What if there is new information?

Sometimes during a study, we learn new information. We will talk to your doctors about any new information that might be important to you.

Is this private?

We will keep your information private whether you decide to join this study or not. Any information that would indicate that you are being harmed or at risk of being harmed, will be shared with your doctor.

Can I say no?

You can choose to be a part of this study or not. You can also decide to stop being in this study at any time once you start. Talk to your parents or your doctor if you want to stop being in the study, and they will tell the researchers. No one will be mad at you if you choose not to take part.

What if I have questions?

Please ask us and we will do anything we can to answer your questions.

Your parent may receive a summary of the results at the conclusion of the study if they wish so.

Assent form signatures

If you agree to participate in this research study, please sign the form.

I understand the information that was explained to me and I can ask any questions that I like about the study.

Signature of Participant

Name of Participant

Date

PARTICIPANT INFORMED ASSENT (12-15) CONCUSSION GROUP

Protocol title: Balance Markers and Saccadic Eye Movement Parameters in Children and Adolescents with Concussion

Principal investigator: Gail Macartney, RN(EC), PhD

Address: Children's Hospital of Eastern Ontario
401 Smyth Road, Ottawa, ON, K1H 8L1

Telephone number: (613) 737-7600 ext. 3396

Primary University of Ottawa investigator: Heidi Sveistrup, PhD, 613-562-5800 ext. 7099

Why is this study being done?

We would like to invite you to be part of a research study. Research is a way to test new ideas to see if we can do things better. In our study, we want to see how children and teenagers like you, who have experienced a concussion, maintain their balance. We also want to look at factors that could affect your recovery. This is why we will also ask you questions about anxiety and depression.

Who will take part?

Children and teenagers seen at the CHEO concussion clinic and the ActiveCare clinic in Kanata are being asked to join this study. We expect to have 30 children and teenagers who have had a concussion and 60 children and teenagers who have not had a concussion join the study over the next 6 months.

What will happen during the study?

If you decide to participate in this study, you will be asked to complete up to three 30-minute sessions. You will be asked to do the first one today, the second one in two months from now and the third one in five months from now. It is up to you to decide if you want to participate just for today or if you want to come back one or two more times. You will complete these sessions at the CHEO concussion clinic between the hours of 8 am and 4 pm from Monday to Friday. During each session, you will first be asked to stand on the board for the game Wii Fit and to stand as still as you can for two minutes with your eyes open and with your eyes closed. After this, you will be asked to stand on the board again and we will ask you to complete three different games while you are standing. For these games, you will see the words "red", "yellow", "green" and "blue" on a screen or on a poster in front of you. Some of these words will be printed in the correct colour, like "red" printed in red. Other words will be printed in the incorrect colour, like "red" printed in blue. You will be asked to name the colour of the ink that the words are printed in or just to read the words. While you do this, there will be a headband placed around your head, a strap placed around your torso, and you will wear a pair of glasses.

We will also ask you to complete 5 short questionnaires. These questionnaires will ask you about how you are feeling and about any symptoms from your concussion.

Are there any benefits to participating?

You will not get any personal benefit from being part of this study; however this study will help us better understand children who have had a concussion.

Are there any risks to participating?

We do not think that anything bad would happen if you decide to join this study.

What if something bad happens?

If something does go wrong, your doctor will be there to take care of you.

Will I be compensated for participating?

If you decide to participate, you will receive one 5\$ Tim Horton's gift card for each session that you complete in recognition of your time and effort.

What if there is new information?

Sometimes during a study, we learn new information. We will talk to your doctors about any new information that might be important to you.

Is this private?

We will keep your information private whether you decide to join this study or not. Any information that would indicate that you are being harmed or at risk of being harmed, will be shared with your doctor.

Can I say no?

You can choose to be a part of this study or not. You can also decide to stop being in this study at any time once you start. Talk to your parents or your doctor if you want to stop being in the study, and they will tell the researchers. No one will be mad at you if you choose not to take part.

What if I have questions?

Please ask us and we will do anything we can to answer your questions.

Your parent may receive a summary of the results at the conclusion of the study if they wish so.

Assent form signatures

If you agree to participate in this research study, please sign the form.

I understand the information that was explained to me and I can ask any questions that I like about the study.

Signature of Participant

Name of Participant

Date

PARTICIPANT INFORMED CONSENT CONCUSSION GROUP

Protocol title: Balance Markers and Saccadic Eye Movement Parameters in Children and Adolescents with Concussion

Principal investigator: Gail Macartney, RN(EC), PhD

Address: Children's Hospital of Eastern Ontario
401 Smyth Road, Ottawa, ON, K1H 8L1

Telephone number: (613) 737-7600 ext. 3396

Primary University of Ottawa investigator: Heidi Sveistrup, PhD, 613-562-5800 ext. 7099

You are being invited to join in a research study about the recovery of balance following a concussion. You are being invited to join this study because you have experienced a concussion. Before agreeing to take part in this study, it is important that you read and understand this document.

Taking part in this study is voluntary. Your decision to participate or not in this study will not affect the care you receive at CHEO, the CHEO concussion clinic and the ActiveCare clinic in Kanata. You are free to withdraw from the study at any time with no penalty.

Why is this study being done?

The purpose of our study is to learn more about balance problems and problems with eye movements following a concussion. This study will help determine if it is important to observe eye movements when testing balance. We are also interested in learning more about factors that are linked to recovery following a concussion. In order to do this we will collect information on anxiety and depression.

How many children will participate?

We expect to have 30 children and teenagers who have had a concussion and 60 children and teenagers who have not had a concussion participate. We expect to invite children and teenagers to participate for 6 months. This study is expected to be active for 8 months.

What will I be asked to do?

If you decide to participate in this study, you will be invited to do up to three 30-minute balance sessions. The first session will take place between 1 and 3 months following the date of your concussion, the second session at 2-months following the date of your first session and the third session at 5-months following the date of your first session. These sessions will take place at the CHEO concussion clinic (1355 Bank Street, Suite 111) and will be completed between the hours of 8 am and 4 pm from Monday to Friday.

During these sessions, you will first be asked to stand on a Nintendo Wii Balance Board and to focus on standing as still as possible for two minutes with your eyes open and with your eyes closed. You will then be asked to complete three different cognitive tasks while standing on the Nintendo Wii Balance Board. For these tasks, you will be presented with a series of the words “red”, “yellow”, “green” and “blue” printed in the correct or incorrect colour. For example, you could see the word “red” printed in red or printed in an incorrect colour like blue. You will be asked to either read the words or to name the colour of the ink that each word is printed in. While you complete these tasks, a headband that measures the accelerations of your head movements will be placed around your head, a strap that measures the accelerations of your torso will be placed around your torso, and you will be asked to wear a pair of glasses that records eye movements.

During these sessions, you will also be asked to complete five short questionnaires. These questionnaires will ask you about how you are feeling and about any symptoms from your concussion.

Are there any risks to participating?

There is very little risk in participating in this study. At most, you may become tired while completing the balance tests. However, you may request to take a rest at anytime.

Are there any benefits to participating?

You will not get any personal benefit from being part of this study; however we hope to improve the way balance is assessed following a concussion to take better care of patients in the future.

Will I be compensated for participating?

If you decide to participate, you will receive one 5\$ Tim Horton’s gift card for each session that you complete in recognition of your time and effort.

What if I get injured?

In the event that you suffer injury as a direct result of participating in this study, normal legal rules on compensation will apply. Medical care will be provided to you. By signing this consent form you are in no way waiving your legal rights or releasing the investigator from their legal and professional responsibilities.

Will I be told about new information?

We will inform you of any new information that might influence your decision to continue to participate in this research project. We will ask you again if you want to be in the study. If this study uncovers information that might be helpful to your current or future health, the investigator will provide this information to your most responsible physician for follow-up. In the event of a positive depression screen, the principle investigator will be notified. We will offer that you be seen at an emergency department and you will be provided with the phone number for a crisis line.

Will my records be kept private and confidential?

Your personal information will be kept strictly confidential. For this study we will be collecting gender and Date Of Birth (DOB) for the research purposes described in this consent form. Representatives from the CHEO research Ethics Board may look at your records at the site where these records are held, to check that the study is following the proper laws and guidelines.

The data produced from this study will be stored in a secured locked location. Only members of the research team and the individuals described above will have access to the data. Following completion of the research study the data will be kept for 7 years after the last publication of this study. They will then be destroyed.

Any information that would indicate that you are being harmed or at risk of being harmed, will be shared with your doctor.

You will not be identified in any publication or presentation of this study.

A copy of the signed consent form will be provided to you.

Is the research team benefiting from the study?

The research team members are not benefiting personally, financially or in some other way from this study.

What if I have questions?

If you have any questions concerning participation in this study, or if at any time feel that you have experienced a study-related injury, contact:

Dr. Heidi Sveistrup, (613) 562-5800 ext. 7099

This study have been reviewed and approved by the CHEO Research Ethics Board. The CHEO Research Ethics Board is a committee of the hospital that includes individuals from different professional backgrounds. The Board reviews all human research that takes place at the hospital. Its goal is to ensure the protection of the rights and welfare of people participating in research. The Board's work is not intended to replace a parent or child's judgment about what decisions and choices are best for them. You may contact the Chair of the Research Ethics Board, for information regarding patient's rights in research studies at (613) 737-7600 ext. 3272, although this person cannot provide health-related information about the study.

A summary of the results of the study will be provided to you at the conclusion of the study if you desire.

Consent form signatures

By signing this consent form I agree that:

- I am voluntarily agreeing to participate in this research study;
- I understand the information within this consent form;
- All of the risks and benefits of participation have been explained to me;
- All of my questions have been answered;

- I allow access to my medical records and/or personal information as described in this consent form, and;
- I do not give up my legal rights by signing this form.

Signature of Participant

Name of Participant

Date

**Witness to Participant's
Signature**

Name of Witness

Date

**Signature of person
Obtaining Informed Consent**

**Name of Person Obtaining
Informed Consent**

Date

PARENT INFORMED CONSENT CONTROL GROUP

Principal investigator: Gail Macartney, RN(EC), PhD

Address: Children's Hospital of Eastern Ontario
401 Smyth Road, Ottawa, ON, K1H 8L1

Telephone number: (613) 737-7600 ext. 3396

Primary University of Ottawa investigator: Heidi Sveistrup, PhD, 613-562-5800 ext. 7099

You are being invited to join in a research study about the recovery of balance following a concussion. You are being invited to join this study because your child has not had a concussion in the last year. This will allow us to compare the maintenance of balance between children who have had a concussion and those that have not. Before agreeing to take part in this study, it is important that you read and understand this document.

Why is this study being done?

The purpose of this study is to learn more about balance problems and problems with eye movements following a concussion. This study will help determine if it is important to look at eye movements when testing balance.

How many children will participate?

We expect to have 30 children and adolescents who have had a concussion and 60 children and adolescents who have not had a concussion to participate. We expect to invite children and adolescents to participate for 6 months. This study is expected to be active for 8 months.

What will my child be asked to do?

If you decide to participate in this study, your child will be asked to complete two 20-minute sessions to be completed approximately 3 weeks apart. These sessions will take place at your child's school or at your home and will be completed during school hours or a time that is convenient for you. During these sessions, your child will first be asked to stand on a Nintendo Wii Balance Board and to focus on standing as still as possible for two minutes with their eyes open and with their eyes closed. Your child will then be asked to stand on the Nintendo Wii Balance Board and to complete three different cognitive tasks. For these tasks, your child will be presented with a series of the words "red", "yellow", "green" and "blue" printed in the correct or incorrect colour. For example, the word "red" could be printed in red or printed in an incorrect colour like blue. Your child will be asked to either read the words or to name the colour of the ink that each word is printed in. While your child completes these tasks, a headband that measures head movement accelerations will be placed around your child's head, a strap that measures accelerations of the torso will be placed around your child's torso, and your child will be asked to wear a pair of glasses that records eye movements.

Are there any risks to participating?

There is very little risk in participating in this study. At most, your child may become tired while completing the balance tests. However, your child may request to take a rest at anytime.

Are there any benefits to participating?

Your child will not get any personal benefit from being part of this study; however we hope to improve the way balance is assessed following a concussion to take better care of patients in the future.

Is my child obligated to participate?

Your child is under no obligation to participate and if he/she chooses to participate, he/she can withdraw from the study at any time and there will be no penalty or consequences. If he/she chooses to withdraw, all data gathered until the time of withdrawal will be destroyed.

Will my child be compensated for participating?

If your child participates, he/she will receive one 5\$ Tim Horton's gift card after completing the first balance testing session and will receive a second 5\$ Time Horton's gift card after completing the second balance testing session.

What if my child gets injured?

In the event that your child suffers injury as a direct result of participating in this study, normal legal rules on compensation will apply. Medical care will be provided to your child. By signing this consent form you are in no way waiving your legal rights or releasing the investigator from their legal and professional responsibilities.

Will my child's records be kept private and confidential?

Your child's personal information will be kept strictly confidential. For this study we will be collecting gender and Date Of Birth (DOB) for the research purposes described in this consent form. Representatives from the CHEO research Ethics Board may look at your records at the site where these records are held, to check that the study is following the proper laws and guidelines.

The data produced from this study will be stored in a secured locked location. Only members of the research team and the individuals described above will have access to the data. Following completion of the research study the data will be kept for 7 years after the last publication of this study. They will then be destroyed.

Your child will not be identified in any publication or presentation of this study.

A copy of the signed consent form will be provided to you.

Is the research team benefiting from the study?

The research team members are not benefiting personally, financially or in some other way from this study.

What if I have questions?

If you have any questions concerning participation in this study, or if at any time feel that you have experienced a study-related injury, contact:

Dr. Heidi Sveistrup, (613) 562-5800 ext. 7099

This study have been reviewed and approved by the CHEO Research Ethics Board. The CHEO Research Ethics Board is a committee of the hospital that includes individuals from different professional backgrounds. The Board reviews all human research that takes place at the hospital. Its goal is to ensure the protection of the rights and welfare of people participating in research. The Board's work is not intended to replace a parent or child's judgment about what decisions and choices are best for them. You may contact the Chair of the Research Ethics Board, for information regarding patient's rights in research studies at (613) 737-7600 ext. 3272, although this person cannot provide health-related information about the study.

A summary of the results will be provided to you at the conclusion of the study if you desire.

Consent form signatures

By signing this consent form I agree that:

- I am voluntarily agreeing to participate in this research study;
- I understand the information within this consent form;
- All of the risks and benefits of participation have been explained to me;
- All of my questions have been answered;
- I allow access to my child's personal information as described in this consent form, and;
- I do not give up my legal rights by signing this form.

Acceptance: I, _____ agree to allow my child _____ to participate in the research study described above.

There are two copies of this consent form provided – please keep one for your own records.

We believe that the data gathered for this study are very important. We would like to continue doing further research to learn more about concussions. We would like to use the data collected for this study to answer additional research questions related to concussions. We may collaborate with researchers at other sites for future concussion research studies; however, the data would not contain any information that could identify you. We would like your permission to use this data for future concussions studies.

_____ **Yes, I agree to the use of my research data in future studies related to concussion**

_____ **No, only use my research data for this study**

**Signature of Parent or
Guardian**

**Name of Parent or
Guardian**

Date

**Witness to Parent or
Guardian's Signature**

Name of Witness

Date

**Signature of person
Obtaining Informed Consent**

**Name of Person Obtaining
Informed Consent**

Date

PARTICIPANT INFORMED ASSENT (8-11) CONTROL GROUP

Protocol title: Balance Markers and Saccadic Eye Movement Parameters in Children and Adolescents with Concussion

Principal investigator: Gail Macartney, RN(EC), PhD

Address: Children's Hospital of Eastern Ontario
401 Smyth Road, Ottawa, ON, K1H 8L1

Telephone number: (613) 737-7600 ext. 3396

Primary University of Ottawa investigator: Heidi Sveistrup, PhD, 613-562-5800 ext. 7099

Why is this study being done?

We would like to invite you to be part of a research study. Research is a way to test new ideas to see if we can do things better. In our study, we want to see how children and teenagers who had had a concussion maintain their balance. To do this, we also need to look at how children and teenagers like you, who have not had a concussion, maintain their balance.

Who will take part?

Children and teenagers who have had a concussion are being asked to join this study. Children and teenagers who have not had a concussion are also being asked to join this study. We expect to have 30 children and teenagers who have had a concussion and 60 children and teenagers who have not had a concussion to join the study over the next 6 months.

What will happen during the study?

If you decide to participate in this study, you will be asked to complete two 20-minute balance sessions. These sessions will take place at your school or your home and will be completed three weeks apart. If you partake at school you will complete these sessions during school hours and if not at school it will take place at a time that is convenient for you. During each session, you will first be asked to stand on the board for the game Wii Fit and to stand as still as you can for two minutes with your eyes open and with your eyes closed. After this, you will be asked to stand on the board again and we will ask you to complete three different games while you are standing. While you do this, there will be a headband placed around your head, a strap placed around your torso, and you will wear a pair of glasses.

Are there good things that can happen from this study?

Sometimes good things can happen to people when they are in a study. These good things are called "benefits". This study will help us better understand children who have had a head injury. That is a benefit. There are no other benefits that we think will happen to you if you decide to join this study.

Are there bad things that can happen from this study?

We do not think that anything bad would happen if you decide to join this study.

What if something bad happens?

If something does go wrong, the researchers will be there to take care of you.

Will I receive something for participating?

If you decide to participate, you will receive one 5\$ Tim Horton's gift card after completing the first session and you will receive a second 5\$ Tim Horton's gift card after you complete the second session.

Is this private?

We will keep your information private whether you decide to join this study or not.

Can I say no?

You can choose to be a part of this study or not. You can also decide to stop being in this study at any time once you start. Talk to your parents or the researchers if you no longer want to take part in this study. No one will be mad at you if you choose not to take part.

What if I have questions?

Please ask us and we will do anything we can to answer your questions.

Your parent may receive a summary of the results at the conclusion of the study if they wish so.

Assent form signatures

If you agree to participate in this research study, please sign the form.

I understand the information that was explained to me and I can ask any questions that I like about the study.

_____	_____	_____
Signature of Participant	Name of Participant	Date

PARTICIPANT INFORMED ASSENT (12-15) CONTROL GROUP

Protocol title: Balance Markers and Saccadic Eye Movement Parameters in Children and Adolescents with Concussion

Principal investigator: Gail Macartney, RN(EC), PhD

Address: Children's Hospital of Eastern Ontario
401 Smyth Road, Ottawa, ON, K1H 8L1

Telephone number: (613) 737-7600 ext. 3396

Primary University of Ottawa investigator: Heidi Sveistrup, PhD, 613-562-5800 ext. 7099

Why is this study being done?

We would like to invite you to be part of a research study. Research is a way to test new ideas to see if we can do things better. In our study, we want to see how children and teenagers who have experienced a concussion keep their balance. In order to complete our study, we also need to look at how children and teenagers like you, who have not experienced a concussion, maintain their balance.

Who will take part?

Children and teenagers who have and have not had a concussion are being asked to join this study. We expect to have 30 children and teenagers who have had a concussion and 60 children and teenagers who have not had a concussion participate in this study over the next 6 months.

What will happen during the study?

If you decide to participate in this study, you will be asked to complete two 20-minute sessions. These sessions will take place at your school or at your home and will be completed three weeks apart. If you partake at school you will complete these sessions during school hours, and if not at school it will take place at a time that is convenient for you. During each session, you will first be asked to stand as still as you can on the board for the game Wii Fit for two minutes with your eyes open and then with your eyes closed. After this, you will be asked to stand on the board again and we will ask you to complete three different games while you are standing. For these games, you will see the words "red", "yellow", "green" and "blue" on a screen or on a poster in front of you. Some of these words will be printed in the correct colour, like "red" printed in red. Other words will be printed in the incorrect colour, like "red" printed in blue. You will be asked to name the colour of the ink that the words are printed in or just to read the words. While you do this, there will be a headband placed around your head, a strap placed around your torso, and you will wear a pair of glasses.

Are there any benefits to participating?

You will not get any personal benefit from being part of this study; however this study will help us better understand children who have had a concussion.

Are there any risks to participating?

We do not think that anything bad would happen if you decide to join this study.

What if something bad happens?

If something does go wrong, the researchers will be there to take care of you.

Will I be compensated for participating?

If you decide to participate in this study, you will receive one 5\$ Tim Horton's gift card after completing the first balance testing session and you will receive a second 5\$ Time Horton's gift card after completing the second balance testing session.

Is this private?

We will keep your information private whether you decide to join this study or not.

Can I say no?

You can choose to be a part of this study or not. You can also decide to stop being in this study at any time once you start. Talk to your parents or the researchers if you no longer want to take part in this study. No one will be mad at you if you choose not to take part.

What if I have questions?

Please ask us and we will do anything we can to answer your questions.

Your parent may receive a summary of the results at the conclusion of the study if they wish so.

Assent form signatures

If you agree to participate in this research study, please sign the form.

I understand the information that was explained to me and I can ask any questions that I like about the study.

Signature of Participant

Name of Participant

Date

PARTICIPANT INFORMED CONSENT CONTROL GROUP

Protocol title: Balance Markers and Saccadic Eye Movement Parameters in Children and Adolescents with Concussion

Principal investigator: Gail Macartney, RN(EC), PhD

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You are being invited to join in a research study about the recovery of balance following a concussion. You are being invited to join this study because you have not had concussion in the last year. This will allow us to compare the maintenance of balance between children who have had a concussion and those that have not. Before agreeing to take part in this study, it is important that you read and understand this document.

Why is this study being done?

The purpose of our study is to learn more about balance problems and problems with eye movements following a concussion. This study will help determine if it is important to look at eye movements when testing balance.

How many children will participate?

We expect to have 30 children and adolescents with a diagnosed concussion and 60 children and adolescents who have not experienced a concussion participate. We expect to invite children and adolescents to participate for 6 months. This study is expected to be active for 8 months.

What will I be asked to do?

If you decide to participate in this study, you will be asked to complete two 20-minute sessions to be completed approximately 3 weeks apart. These sessions will take place at your school and will be completed during school hours or at your home at a time that is convenient for you. During these sessions, you will first be asked to stand on a Nintendo Wii Balance Board and to focus on standing as still as possible for two minutes with your eyes open and with your eyes closed. You will then be asked to stand on the Nintendo Wii Balance Board and to complete three different cognitive tasks. For these tasks, you will be presented with a series of the words "red", "yellow", "green" and "blue" printed in the correct or incorrect colour. For example, you could see the word "red" printed in red or printed in an incorrect colour like blue. You will be asked to either read the words or to name the colour of the ink that each word is printed in. While you complete these tasks, a headband that measures the accelerations of your head movements will be placed around your head, a strap that measures the accelerations

of the movements of your torso will be placed around your torso, and you will be asked to wear a pair of glasses that records eye movements.

Are there any risks to participating?

There is very little risk in participating in this study. At most, you may become tired while completing the balance tests. However, you may request to take a rest at anytime.

Are there any benefits to participating?

You will not get any personal benefit from being part of this study; however we hope to improve the way balance is assessed following a concussion to take better care of patients in the future.

Am I obligated to participate in this study?

You are under no obligation to participate and if you choose to participate, you can withdraw from the study at any time and there will be no penalty or consequences. If you choose to withdraw, all data gathered until the time of withdrawal will be destroyed.

Will I be compensated for participating?

If you decide to participate in this study, you will receive one 5\$ Tim Horton's gift card after completing the first balance testing session and you will receive a second 5\$ Time Horton's gift card after completing the second balance testing session.

What if I get injured?

In the event that you suffer injury as a direct result of participating in this study, normal legal rules on compensation will apply. Medical care will be provided to you. By signing this consent form you are in no way waiving your legal rights or releasing the investigator from their legal and professional responsibilities.

Will my records be kept private and confidential?

Your personal information will be kept strictly confidential. For this study we will be collecting gender and Date Of Birth (DOB) for the research purposes described in this consent form. Representatives from the CHEO research Ethics Board may look at your records at the site where these records are held, to check that the study is following the proper laws and guidelines.

The data produced from this study will be stored in a secured locked location. Only members of the research team and the individuals described above will have access to the data. Following completion of the research study the data will be kept for 7 years after the last publication of this study. They will then be destroyed.

You will not be identified in any publication or presentation of this study.

A copy of the signed consent form will be provided to you.

Is the research team benefiting from the study?

The research team members are not benefiting personally, financially or in some other way from this study.

What if I have questions?

If you have any questions concerning participation in this study, or if at any time feel that you have experienced a study-related injury, contact:

Dr. Heidi Sveistrup, (613) 562-5800 ext. 7099

This study have been reviewed and approved by the CHEO Research Ethics Board. The CHEO Research Ethics Board is a committee of the hospital that includes individuals from different professional backgrounds. The Board reviews all human research that takes place at the hospital. Its goal is to ensure the protection of the rights and welfare of people participating in research. The Board's work is not intended to replace a parent or child's judgment about what decisions and choices are best for them. You may contact the Chair of the Research Ethics Board, for information regarding patient's rights in research studies at (613) 737-7600 ext. 3272, although this person cannot provide health-related information about the study.

A summary of the results will be provided to you at the conclusion of the study if you desire.

Consent form signatures

By signing this consent form I agree that:

- I am voluntarily agreeing to participate in this research study;
- I understand the information within this consent form;
- All of the risks and benefits of participation have been explained to me;
- All of my questions have been answered;
- I allow access to my personal information as described in this consent form, and;
- I do not give up my legal rights by signing this form.

We believe that the data gathered for this study are very important. We would like to continue doing further research to learn more about balance problems following a concussion. We would like to use the data collected for this study to answer additional research questions. We may collaborate with researchers at other sites for future studies; however, the data would not contain any information that could identify you. We would like your permission to use this data for future research studies.

_____ **Yes, I agree to the use of my research data in future studies**

_____ **No, only use my research data for this study**

Signature of Participant

Name of Participant

Date

**Witness to Participant's
Signature**

Name of Witness

Date

**Signature of person
Obtaining Informed Consent**

**Name of Person Obtaining
Informed Consent**

Date

Appendix P Data Collection Sheet

Data Collection Sheet

Participant Data Sheet

Date:

Session Number:

Participant #:

Date of Birth:

Sex:

Height:

Weight:

☐ Participant Consent/Assent Form Read and Signed

☐ Parent Consent Form Read and Signed

Questionnaires:

☐ Post-Concussion Symptom Scale

☐ Pediatric Vestibular Symptom Questionnaire

☐ Generalized Anxiety Disorder Assessment

☐ Kutcher Adolescent Depression Scale

☐ Injury Report

☐ Impact Location Grid

Number of Previous Head Injuries (diagnosed or undiagnosed): _____

Other Conditions That Could Affect Balance: _____

Does the participant wear glasses? _____

Does the participant wear contact lenses? _____

Does the participant have any visual impairment that cannot be corrected with contact lenses or glasses? _____

Dual-Tasks on Wii Balance Board with Eye Tracker and IMU

Condition	Wii File Name	IMU File Name	Time to Complete	Response Accuracy	Notes:
DTcognitive					
DTcombined					

DTvisual					
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Postural Stability on Wii Balance Board with IMU's

Condition	Will File Name	IMU File Name
Double-leg eyes open		
Double-leg eyes closed		

Appendix Q Ethics Approval Documents

uOttawa Ethics Approval



Université d'Ottawa University of Ottawa

Bureau d'éthique et d'intégrité de la recherche Office of Research Ethics and Integrity

March 10th, 2017

Gail Macartney
CHEO Concussion Clinic
gmacartney@cheo.on.ca

Heidi Sveistrup
Professor
Faculty of Health Sciences
University of Ottawa
hsveist@uottawa.ca

Co-Investigators: Kristian Goulet, CHEO Concussion Clinic
Roger Zemek, CHEO
Coralie Rochefort, University of Ottawa
Elizabeth Legace, University of Ottawa

Re: U of O Ethics file no. A03-17-03 – “Balance Makers and Saccadic Eye Movement Parameters in Children and Adolescents with Concussion”

Dear Dr. Macartney, Professor Sveistrup and colleagues,

Thank you for the protocol documents and Certificate of Approval from the CHEO REB (# 16/132X) for your project named above.

This is to confirm that, in accordance with the agreement between the University of Ottawa and CHEO REB, the University of Ottawa has authorized this board to act as Board of Record for the review and oversight of research involving human subjects conducted at or through the hospital.

We remind you of your obligation to:

- Follow all procedures of the CHEO REB including reporting and renewal procedures;
- Submit to the authority of the CHEO REB and that you are subject to CHEO REB requirements, including, without limitation, the requirement to modify or stop the research on demand of the CHEO REB.

If you have any questions, please contact our ethics office at 562-5387.

Sincerely yours,

Catherine Paquet
Director
Office of Research Ethics and Integrity

550, rue Cumberland 550 Cumberland Street
Ottawa (Ontario) K1N 6N5 Canada Ottawa, Ontario K1N 6N5 Canada
(613) 562-5387 • Téléc./Fax (613) 562-5338
<http://www.recherche.uottawa.ca/deontologie/>
<http://www.research.uottawa.ca/ethics/>

Children's Hospital of Eastern Ontario (CHEO) Ethics Approval



CHEO Research Ethics Board Approval - Delegated Review

Principal Investigator: Dr. Gail Macartney

REB Protocol No: 16/132X

Romeo File No: 20160439 **Project Title:** CHEOREB# 16/132X

- Balance markers and saccadic eye movement parameters in children and adolescents with concussion

Primary Affiliation: Clinical Research\Nursing

Protocol Status: Active

Approval Date*: December 15, 2016

Valid Until:** October 15, 2017

Annual Renewal Submission Deadline: 15 September 2017

Documents Reviewed & Approved:

Document Name	Comments	Version Date
Assent Form	Assent 12-15 years of age Control group	2016/11/15
Assent Form	Assent 8-11 years of age Control group	2016/11/15
Assent Form	Assent Concussion group 12-15 years of age	2016/11/15
Assent Form	Assent Concussion group 8-11 years of age	2016/11/15
Consent Form	Parent consent form	2016/12/

		14
Consent Form	Participant consent form	2016/12/14
Consent Form	Parent consent Concussion group	2016/11/15
Consent Form	Participant consent Concussion group	2016/11/15
Other Document	Participant data sheet control group	2016/09/15
Other Document	Participant data sheet concussion group	2016/09/15
Protocol	Protocol	2016/11/15
Questionnaire/Survey	Injury report	2016/09/15
Questionnaire/Survey	Kutcher adolescent depression scale questionnaire	2016/09/15
Questionnaire/Survey	Impact location grid	2016/09/15
Questionnaire/Survey	Generalised anxiety disorder assessment questionnaire	2016/09/15
Questionnaire/Survey	Pediatric vestibular questionnaire	2016/09/15
Questionnaire/Survey	Post-Concussion Symptoms Inventory (13-18 years of age)	2016/09/15
Questionnaire/Survey	Post-Concussion Symptoms Inventory (8-12 years of age)	2016/09/15

This is to notify you that the Children's Hospital of Eastern Ontario Research Ethics Board has granted approval to the above named research study on the date noted above. Your project was reviewed under the delegated review stream, which is reserved for projects that involve no more than minimal risk to human subjects.

Final approval is granted for the above noted study, with the

understanding that the investigator agrees to comply with the following requirements:

- 1 The investigator must conduct the study in compliance with the protocol and any additional conditions set out by the Board.
 - 2 Investigators must submit an annual renewal report to the REB 30 days prior to the expiration date stated above.
 - 3 The investigator must not implement any deviation from, or changes to, the protocol, consents or assents without the approval of the REB.
 - 4 The investigator must, prior to use, submit to the Board changes to the study documentation, e.g., changes to the informed consent letters, recruitment materials.
 - 5 Investigators must provide the Board with French versions of the consent form, unless a waiver has been granted. An interpreter should be offered to participants as required or at the request of the participant throughout the course of research.
 - 6 The investigator must promptly report to the REB all unexpected and untoward occurrences (including the loss or theft of study data and other such privacy breaches).
 - 7 Investigators must notify the REB of any study closures (closed to accrual, temporary, premature or permanent).
 - 8 Investigators must submit a final report at the conclusion of the study.
- Should you have any questions or concerns, please do not hesitate to contact the Research Ethics Board Office at [613-737-7600 ext. 3350](tel:613-737-7600) or 2128.

Regards,

Franco Momoli, Ph.D. Interim Chair, CHEO Research Ethics Board 401 Smyth Road, Ottawa, ON K1H 8L1 Tel: [613-737-7600 ext. 6012](tel:613-737-7600) | Fax/Téléc: [613-738-4875](tel:613-738-4875) | fmomoli@uottawa.ca *The final approval date for initial delegated study applications approved with or without modifications will be the date the REB has determined that the

conditions of approval have been satisfied. **The expiry date of REB approval for initial study application that required no modifications will be as follows: • If the date of review and approval was **on or before** the 15th of the month, the expiry date will be the 15th of the month prior to the date of review and approval by the Chair and/or delegate *in the following year*; • If the date of review and approval was **after** the 15th the expiry date will be the 15th of the month in which the date of review and approval by the REB *in the following year*. The expiry date of REB approval for initial study applications that **require modifications** will be as follows: • If the initial feedback was sent **on or before** the 15th of the month, the expiry date will be the 15th of the month prior to the date the letter of REB feedback is issued to the investigator(s) *in the following year*; • If the initial feedback was sent **after** the 15th the expiry date will be the 15th of the month in which the feedback was sent *in the following year*.