

Striking a balance with concussion assessment: Use of the Wii balance board to evaluate
postural control

by

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Bachelor of Kinesiology (Honours), Acadia University, 2013

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Abstract

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Background: Concussion assessments rely on a multifaceted approach where evaluation of balance and postural control plays an important role. Following a concussion, 67% of individuals report dizziness as a persistent symptom and 30% experience balance impairments. Studies incorporating the common Balance Error Scoring System (BESS) tool suggest that these impairments return to pre-injury baselines within ten days of incident. In contrast, however, studies incorporating more advanced posturography methods observe significant differences in balance up to one year following injury. While the BESS is consistently associated with low sensitivity and poor reliability scores, advanced posturography systems using force plates are not practical or accessible in most recreational sports environments. Recently, the Wii Balance Board (WBB) has been identified as a potential force plate proxy. Research confirms that the WBB is both valid and reliable in collecting center of pressure data. Thus, the WBB may be useful for investigating post-concussion balance deficits. **Objective:** The purpose of this study was to investigate the potential utility of a customized WBB program to assess postural balance in an athletic population. The study aimed to assess change in postural balance using the clinical BESS and WBB assessment tools to evaluate balance at fixed intervals during a regular athletic season and following concussion. **Design:** Prospective partial

cohort. **Methods:** Balance was assessed at baseline, mid-, and post-season. Individuals who sustained a concussion during the study period were further assessed weekly for four weeks post-injury. **Results:** No significant differences were observed in raw BESS scores across regular season or post-concussion time points. In contrast, significant differences in several WBB outcome measures were observed. In the single stance condition, COP_{ML} worsened by 24% and COP_T worsened by 9% between baseline and post-season time points ($p=.002$ and $p=.007$). In contrast, participants improved by 14% on a timed dynamic task ($p=.003$) between baseline and post-season time points. Following concussion, only the WBB dynamic outcome measures were found to be statistically significant. A positive trend was observed post-concussion, suggesting that a learning effect exists with the dynamic WBB program. **Conclusion:** Study results emphasize the importance of considering the progression of athletic season when interpreting baseline and post-concussion balance measurements. Study results support the use of a quantitative balance assessment, such as with a WBB, to improve measurement of static and dynamic postural balance.

Keywords: concussion; balance; Wii Balance Board, Balance Error Scoring System.

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List of Abbreviations

- CISG – Concussion in Sport Group
- PCSS – Post-Concussion Symptom Scale
- RTP – Return to Play
- COP – Center of Pressure
- SCAT-3 – Sport Concussion Assessment Tool (3)
- BESS – Balance Error Scoring System
- mBESS – Modified Balance Error Scoring System
- SOT – Sensory Organization Test
- WBB – Wii Balance Board
- COP_{ML} – COP Path Length in X (medial-lateral) direction
- COP_{AP} – COP Path Length in Y (anterior-posterior) direction
- COP_T – Total COP Path Length
- t_{Target} – Time to Target (WBB dynamic)
- t_{Center} – Time to Center (WBB dynamic)
- t_{Total} – Total Time (WBB dynamic)
- RM-ANOVA – Repeated Measures Analysis of Variance
- PC1, PC2, PC3, PC4 – Post-Concussion 1 (2, 3, 4)

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Dedication

I dedicate this work to my grandmother, Daphne Cullen, whose spirit I love, wisdom I value, and strength I admire.

Chapter One: Review of Literature

1.1 Introduction to Sport-Related Concussion

Sport-related concussion has gained attention in medical science communities and popular media as a growing public health concern. While a popular topic of study, researchers and clinicians have yet to reach consensus on protocols for concussion assessment, diagnosis, and management. The International Concussion in Sport Group (CISG) defines concussion as a brain injury caused by direct or indirect biomechanical impact resulting in linear or rotational force being translated onto the brain (McCrory, Meeuwisse, Aubry, Cantu, Dvorak, et al., 2013). The injury may or may not result in loss of consciousness. Concussions are identified by a common set of signs and symptoms that are often accompanied by cognitive and/or motor function impairments. While structural abnormalities are not identified by traditional neuroimaging techniques [e.g. computed tomography (CT) and magnetic resonance imaging (MRI)], a functional disturbance exists with the brain following concussion. This disturbance results in acute or gradual onset of somatic symptoms, neurocognitive impairments, and / or postural instability (Guskiewicz, 2001).

The exact pathophysiology of concussion is not well understood. The metabolic crisis of concussion was first described in a 2001 *Journal of Athletic Training* publication (Giza & Hovda, 2001). When damaged, potassium ions leave the neuron causing it to be flooded with calcium ions. This requires the neuron to expend more energy to resolve an imbalance in salt and electrolytes. This energy mismatch results in general dysfunction where neurotransmission is impaired and affected cells are susceptible to chronic dysfunction or death. This pathology manifests clinically as impaired cognitive function and neurobehaviour. Location of damaged neurons within the brain influence what

symptoms are experienced (e.g. headache, nausea, poor balance, etc.) (Giza, Hovda, Angeles, Angeles, & Angeles, 2014).

Recent epidemiological research suggests that concussion injury rates have reached epidemic status over the past decade (Hootman, Dick, & Agel, 2007). Injury rates are likely underreported, however, due to challenges related to injury recognition and diagnosis (McCreary, Hammeke, Olsen, Leo, & Guskiewicz, 2004). The Canadian Federal/Provincial/Territorial Working Group on Concussions in Sport (2015) reports that 39% of emergency room visits for sports-related head injuries in youth 10-18 years result in a confirmed concussion diagnosis and an additional 24% result in a suspected concussion diagnosis. The Canadian government's 2013 report on Sport Participation indicates that more than half (54%) of Canadians between 15-19 years and one-third (37%) of Canadians between 20-24 years are regular participants of sporting activities (*Canadian Heritage Sport Participation 2010*, 2013). A significant proportion of Canadians participate in sports with higher risk of concussion incidence (e.g. ice hockey, rugby, etc.) where injury is more likely to occur in game environments than practice.

Clinical symptoms of concussion are divided into five domains: 1) somatic symptoms, 2) physical signs, 3) behavioural changes, 4) cognitive impairment, and 5) sleep disturbance (McCrary, Meeuwisse, Aubry, Cantu, Dvorák, et al., 2013). Symptoms are, at times, difficult to assess because they vary significantly among individuals, may develop over several minutes, hours, or even days following injury, and are ambiguous in nature so may mimic another condition or disease. The Post-Concussion Symptom Scale (PCSS) is highlighted in Figure 1. Of the 22 symptoms listed in the PCSS, headache (86%), dizziness (67%), and confusion (59%) are the most commonly reported following

concussion (Guskiewicz, Weaver, Padua, & Garrett, 2000). Reporting of psychometric properties of concussion symptom scales is mixed in the literature, where sensitivity scores range from 76.9-89.4% and specificity scores range from 77.0-84.4% (Patricios et al., 2017). Concussion-related symptoms may affect ability to participate in sport safely and effectively which may put athletes at higher risk of sustaining subsequent injury (King et al., 2014), where repeat injury is most common within ten days of injury (Giza et al., 2013).

Instructions: The athlete should fill out the form, on his or her own, in order to give a subjective value for each symptom.							
Symptom	None	Mild	Moderate	Severe			
Headache	0	1	2	3	4	5	6
Nausea	0	1	2	3	4	5	6
Vomiting	0	1	2	3	4	5	6
Balance Problems	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Fatigue	0	1	2	3	4	5	6
Trouble Falling Asleep	0	1	2	3	4	5	6
Sleeping More Than Usual	0	1	2	3	4	5	6
Sleeping Less Than Usual	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Sensitivity to Light	0	1	2	3	4	5	6
Sensitivity to Noise	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervousness	0	1	2	3	4	5	6
Feeling More Emotional	0	1	2	3	4	5	6
Numbness or Tingling	0	1	2	3	4	5	6
Feeling Slowed Down	0	1	2	3	4	5	6
Feeling Mentally "Foggy"	0	1	2	3	4	5	6
Difficulty Concentrating	0	1	2	3	4	5	6
Difficulty Remembering	0	1	2	3	4	5	6
Visual Problems	0	1	2	3	4	5	6

Figure 1. Post-Concussion Symptom Scale

Definitions of clinical recovery vary in the literature, though return to baseline performance on assessment tools administered pre-injury is used as a general indicator.

Return to clinical baseline, however, is not necessarily indicative of physiological recovery and significant symptoms and impairments may persist beyond this time point. Subjective symptom ratings have been found to be considerably greater than baseline at three months and even one year following injury (Røe, Sveen, Alvsåker, & Bautz-Holter, 2009). Potential disparity between clinical and physiological recovery presents a great challenge for clinicians. This is further complicated by periods of unknown vulnerability post-injury and concerns for long-term physical and mental health outcomes.

Published data suggests the majority (80-90%) of those with concussion achieve clinical recovery within 7-10 days of injury (McCrory, Meeuwisse, Aubry, Cantu, Dvorak, et al., 2013). Clinical recovery timelines have increased significantly in the last decade, perhaps in response to the CISG's 2008 recommendations outlining a graded Return to Play (RTP) protocol. Following these recommendations, more conservative approaches were adopted, including rules prohibiting same-day RTP after suspected injury. These recommendations are echoed in both the 2012 and 2016 CISG consensus statements and have resulted in legislation regarding concussion appropriate management (ex. Rowan's Law and Lystedt Law). Further, more conservative RTP timelines may be associated with awareness and anxiety regarding the importance of injury recognition and assessment by trained medical professionals. Lack of definitive guidelines regarding long-term negative health outcomes of concussion may also influence more conservative RTP action plans.

Protracted recovery is inconsistently defined in the literature, with some studies suggesting symptoms lasting longer than ten days indicate protracted recovery, while others suggest persistent symptoms past 21 days to three months (Lau, Kontos, Collins,

Mucha, & Lovell, 2011). Some individuals may develop post-concussion syndrome, characterized by persistent symptoms lasting months or even years after injury (Ryan & Warden, 2003). A study by Lau and colleagues (2011) investigated the relationship between acute symptoms at injury time with protracted recovery. They found that the presence of on-field dizziness immediately following injury was strongly and positively associated with protracted recovery (Lau et al., 2011). Similarly, higher symptom number and severity scores were associated with longer recovery and the presence of headache, neck pain, feeling slowed down, and being nervous or anxious are symptoms positively and significantly associated with length of time before being symptom-free and achieving RTP (McCrary, Meeuwisse, Aubry, Cantu, Dvorák, et al., 2013). Individuals who are slow to recover from concussion often have a vestibular or oculomotor component to their persistent symptomology (Broglio, Collins, Williams, Mucha, & Kontos, 2015).

1.2 Introduction to Human Postural Balance

Postural balance requires maintaining the center of mass within the base of support (Winter, 1995). Functional goals of balance can be divided into two areas: orientation and equilibrium (Horak, 2006). Postural orientation requires one to maintain balance in a static context while standing still on a stable surface (Horak, 2006). In contrast, postural equilibrium requires the maintenance of balance in a dynamic context where stability is challenged by self-initiated or externally triggered disturbances, for example, when you lift one foot off the ground or are bumped while walking down the street (Horak, 2006). Maintenance of balance equilibrium in static and dynamic contexts requires that somatosensory, visual, and vestibular information be gathered first by the peripheral nervous system and then integrated by the central nervous system (cerebellum,

cerebral cortex, and brainstem). Then, motor outputs and compensatory mechanisms coordinate skeletal muscle contractions to maintain postural stability (Figure 2) (Guskiewicz, 2001).



Figure 2. Maintenance of postural control

The central nervous system uses information from the visual, vestibular, and somatosensory systems to inform appropriate timing, direction, and amplitude of muscle contractions to maintain postural control (Guskiewicz, 2001). These systems gather important information about an individual's external environment to inform motor outputs. The vestibular system is comprised of semicircular canals and otolith organs in the inner ear, which gather information about movement, equilibrium, and orientation. The somatosensory system uses receptors in the skin, muscles, joints, and fascia to gather information about touch, temperature, position, etc. Information from these three systems is received by the cerebellum, which is integral in the coordination of postural control and balance reactions (Guskiewicz, 2001). When balance is disturbed, compensatory mechanisms are initiated to re-establish equilibrium and avoid falling.

Variations in the environment test our ability to maintain postural control and requires quick and appropriate reweighting of sensory information (Bryan L. Riemann & Guskiewicz, 2000). Postural control relies most heavily on somatosensory information where relative weighting of information for sensory integration is 70% somatosensory, 20% vestibular, and 10% visual (Horak, 2006). This is inconsequential for healthy

individuals as they can initiate compensatory movement strategies within 100ms of perturbation (Horak, 2006). Compensatory movement strategies are selected based on the nature of the support surface (e.g. the floor) and amplitude of disturbance to balance equilibrium (Figure 3). Ankle strategies are elicited when standing on a stable surface and results in the body moving as an inverted pendulum (Horak, 2006). Hip strategies are initiated when standing on a narrow surface or when the center of mass has to be moved rapidly to avoid falling (Horak, 2006). Healthy individuals can efficiently integrate sensory information and initiate appropriate motor outputs in response to this information. Concussion, however, is associated with impaired balance where dizziness is associated with protracted recovery and development of post-concussion syndrome (Hides et al., 2017).

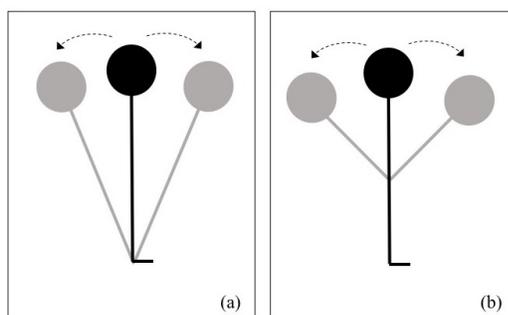


Figure 3. Balance compensatory strategies: (a) ankle strategy, and (b) hip strategy

1.3 Concussion Related Balance Impairments

Good balance is a prerequisite for the many complex motor skills required to successfully and safely participate in sport. Unfortunately, impaired brain function following concussion is known to negatively affect balance (Gagnon, Swaine, Friedman, & Forget, 2004; Geurts, Ribbers, Knoop, & Limbeek, 1996; Vagnozzi et al., 2010). Poor balance and motor control increase vulnerability for repeat injury and also negatively

affects athletic performance (King et al., 2014). While some research suggests that balance returns to baseline values 3-10 days post-injury (Guskiewicz, 2011), others suggest that symptoms of impaired balance may persist more than two weeks post-injury and even after clinical recovery (Buckley, Oldham, & Caccese, 2016). Further, the presence of balance impairment and dizziness may be indicative of protracted recovery timelines (Lau et al., 2011). Howell and colleagues (2015) found that even at RTP, nineteen youth participants with concussions displayed significant increases in medial-lateral and anterior-posterior displacement ($p=.009$) and peak velocity ($p=.048$) during a dual-task gait assessment (D. Howell, Osternig, & Chou, 2015). Similar results were recorded by Powers and colleagues (2014), where nine collegiate football athletes adopted more conservative gait patterns following concussion (Powers, Kalmar, & Cinelli, 2014). Regarding static balance, individuals with concussion demonstrated increased COP displacement in the anterior-posterior direction following injury, but these deficits resolved by RTP (Powers et al., 2014). Participant COP velocity, however, remained abnormal at RTP in the same group participants (Powers et al., 2014). This observation suggests that while participants may have achieved clinical recovery according to CISG guidelines, balance impairments persisted where COP_{AP} velocity at RTP was ~40% greater than controls, and COP_{ML} velocity at RTP was ~30% greater than controls. Taken together, these data suggest that these participants returned to play prematurely. Similarly, Slobounov and colleagues (2007) observed balance impairments up to 30 days following injury. These authors also observed that participants with a history of previous concussion were slower to recover balance when compared to participants who had sustained only one concussion (Slobounov, Slobounov,

Sebastianelli, Cao, & Newell, 2007). Results of these studies draw attention to two emergent themes in concussion research: 1) methodologies incorporating more sensitive and objective measures indicate longer recovery timelines, and 2) there is a risk of premature RTP without reliable assessments.

The exact mechanism of balance disturbance following concussion is not well understood within the current body of literature. Studies comparing individuals with concussion to matched controls have identified largest between-group effects in trials when sensory information is manipulated. Based on these results, researchers theorize that post-concussion balance deficits are likely related to problems integrating sensory information from the somatosensory, vestibular, and visual systems (Camiolo-reddy, Collins, & Lovell, 2010; Guskiewicz, 2001; Bryan L. Riemann & Guskiewicz, 2000). To investigate this topic, experimental methodologies seek to challenge balance by manipulating amounts of reliable sensory information available to participants when they are performing static and dynamic balance tasks. This often involves having participants close their eyes to eliminate visual inputs or by changing the standing surface from stable to unstable.

1.4 Clinical Assessment of Concussion

A concussion is regarded as one of the most difficult injuries to assess, diagnose and manage due to the individual nature of injury presentation and often transient and vague appearance of symptoms. Current assessment protocol relies on a multifaceted approach where assessment focuses on 1) signs and symptoms, 2) cognitive performance, and 3) postural balance (Chang, Levy, Seay, & Goble, 2014). While a variety of assessment tools are available, at this time no single tool has been identified to accurately

and reliably determine diagnosis. The CISG recommends a multifaceted assessment performed in a serial fashion through the acute injury phase to acquire the clearest view of injury manifestation. Ultimately, diagnosis of concussion is based on a comprehensive history, identification of common signs and symptoms, and evaluation of cognitive and motor function that, taken together, informs clinical judgment.

In the absence of a true gold standard, the Sport Concussion Assessment Tool (SCAT-3) has emerged as the most widely researched and applied concussion assessment tool. Developed by the CISG, the SCAT-3 is a sideline screening tool for use by medical professionals such as athletic therapists, physiotherapists, or physicians. The SCAT-3 incorporates the Glasgow Coma Scale, Maddock's Questions, Standardized Assessment of Concussion and a modified version of the Balance Error Scoring System (mBESS). Regarding psychometric properties, the SCAT-2 (previous edition to SCAT-3) has a sensitivity score of 78.1% and specificity score of 95.7% (Patricios et al., 2017). Application of this tool varies significantly among clinicians and is regularly used beyond its intended screening purpose. Some administer the SCAT-3 in its entirety, while others administer only certain sections (e.g. exclude Maddock's Questions or Glasgow Coma Scale). While the total composite score is used most frequently, individual sub-section scores may also be considered. Further research into application of composite and subsection scores, diagnostic thresholds, and utility in rehabilitation is needed as these are not well described currently.

The SCAT-3 suffers from some significant limitations that impact its clinical utility. Some sections (i.e. orientation, immediate memory, delayed recall, and concentration) are subject to significant ceiling effects, indicating that the test itself may

not be challenging enough to describe ability in these areas accurately. Designed for English-speaking athletes and clinicians, the tool suffers from cultural and linguistic challenges. As well, the symptom rating section does not include all domains of somatic symptoms (e.g. behavioural changes) known to be affected by concussion. The SCAT-3 relies heavily on self-reporting of symptoms and accurate assessment of subjective measures, challenging inter- and intra-rater reliability and making interpretation difficult.

Symptom evaluation is an integral part of the SCAT-3. Unfortunately, this relies heavily on accurate athlete reporting of subjective symptoms that may be influenced by internal and external competition related pressures. Symptom evolution, number, and severity differs significantly among people following injury. Further, PCSS symptoms are non-specific to concussion and are often attributed to other conditions. This combination of factors makes analysis of symptoms important, though should not be the cornerstone of assessment. Clinicians should rely more heavily on objective measures (ex. force plate centre of pressure data) when assessing balance to aid in determining diagnosis and recovery status.

Traditionally, concussion assessment has relied on a within-person approach where athletes complete baseline evaluations with a medical professional at the beginning of each season. In the event of a suspected concussion, the same tests are repeated, and baseline scores are used to interpret post-injury scores. The utility of baseline assessments has been an area of recent attention because they are costly in terms of time and resources. Some suggest that normative data comparisons would be more appropriate and economical. Others suggest that normative data is not appropriate for most athletic populations (and concussion injuries in general) given the variance in injury presentation

among athletes. Normative data may be difficult to obtain and also apply with confidence given the range of athletic abilities (recreational to elite) and activities (e.g. football, basketball, soccer, etc.). To further confound this issue, there are numerous concussion modifiers (e.g. sex, age, history, etc.) and concussion assessment tools are being created and revised at a significant rate. Given the novelty of most concussion assessment tools (many less than a decade old) and the regular rate at which they are revised, normative data describing sufficient sample sizes for each tool may not be feasible.

Based on the challenges associated with subjective measures, and current concussion assessment tools' reliance on these types of measures, investigation into more objective tools is warranted. Suitable application of tools must consider practicality, sensitivity, specificity, reliability, validity and, ultimately, diagnostic utility.

1.5 Clinical Assessment of Concussion Related Balance Impairment

The CISG, National Athletic Trainers Association and American Medical Society recommend that motor control and balance is an important component of comprehensive sidelines and clinical assessments. Within the current body of literature, the NeuroCom Balance Manager Sensory Organization Test (SOT) and Balance Error Scoring System (BESS) are the most widely researched tools used to assess concussion-related balance impairments. The SOT is an instrumented test that provides objective and quantitative information about an individual's use of somatosensory, visual, and vestibular information. This is done by manipulating available somatosensory information through a visual screen and moveable standing surface. Use of the SOT, however, is limited due to accessibility and practicality with set-up costs ranging from \$80,000-\$180,000 and test duration upwards of 30 minutes. In contrast, the BESS is a non-instrumented test

developed specifically for concussion. The BESS assesses balance based on a subjective outcome measure of error scores. In comparison to the SOT, the BESS may be more desirable because it is cost-effective, requires minimal equipment, and can be quickly and easily administered in sideline and clinical settings. For these reasons, the current review of post-concussion balance assessment will focus on the BESS.

The BESS provides a subjective quantitative evaluation of static balance based on a subjective analysis of balance errors. The test purposes to challenge balance control by manipulating visual and somatosensory information. Static balance is evaluated in three stances: double leg, single leg, and tandem. Performed on two surfaces (regular floor and medium density foam), the test incorporates six 20 second trials where the participant attempts to maintain stability in each stance with their eyes closed and hands on their hips. A trained clinician counts the number of balance errors made during each trial, where the following are considered errors: 1) hands lifted off iliac crest, 2) opening eyes, 3) step, stumble or fall, 4) moving hip into >30 degrees of abduction, 5) lifting forefoot or heel, and 6) remaining out of test position >5 seconds. Published BESS reliability scores range from 54-98%, sensitivity scores range from 34-64%, and specificity is scored at 91% (Bell, Guskiewicz, Clark, & Padua, 2011; Patricios et al., 2017). Some researchers suggest that the BESS lacks sensitivity because of the small range of scores for each trial and, therefore, data is less likely to be significant (Bryan L. Riemann & Guskiewicz, 2000). A modified Balance Error Scoring System (mBESS) is included in the SCAT-3. The mBESS assesses balance only on a firm surface by eliminating the foam surface condition. The mBESS has a very low reported sensitivity score of 25% but high specificity score of 100% (Putukian 2015).

A systematic review by Bell and colleagues indicates that the BESS has moderate to good reliability to assess static balance (Bell et al., 2011). Regarding BESS total error scores, intertester reliability ranged from 57-98% (Bell et al., 2011). With regards to validity, the BESS is valid to detect changes in postural balance where significant differences are present. The test may have less validity when only subtle variations exist because of low sensitivity scores having been established in the literature. For this reason, the BESS may be useful for concussion assessments in the acute injury phase, where the most significant changes in balance usually present, but is less valid in assessing subtle changes in balance through recovery periods. Therefore, a more sensitive and objective tool is needed to assess small, but potentially clinically relevant, balance impairments in the acute phase as well as lingering balance impairments through recovery periods.

Normative data stratified by age and gender describes a sample of 1236 healthy community-dwelling adults age 20-69 years (Iverson & Koehle, 2013). This normative data suggests that a positive correlation exists between age and BESS error scores ($p=.0001$) and that men perform only slightly better than women ($p=.021$) (Iverson & Koehle, 2013). Unfortunately, this normative data is based on a sample where older age groups are disproportionately represented. Men aged 20-29 ($n=26$) had BESS scores as follows: mean = 10.4, median = 10.0, SD = 4.4. Guskiewicz and colleagues report a minimum detectable change score of 7.3 (intra-rater) and 9.4 (inter-rater) for the BESS (Guskiewicz et al., 2013).

Appropriate interpretation of BESS error scores relies on the assumption that these remain consistent over time, however, the BESS is known to be influenced by many variables. BESS error scores are influenced by fatigue (Wilkins, Mcleod, Perrin, &

Gansneder, 2004), dehydration, sleep loss, foam surface properties, testing surface, chronic functional ankle instability (Docherty, Valovich Mcleod, & Shultz, 2006), age (Iverson et al., 2016), ankle support, and testing environment. The literature is somewhat heterogeneous regarding BESS exposure effects. One study found no significant change in BESS scores over 30 days with five exposures (experimental group) nor with only two exposures (control group) (Valovich, Perrin, & Gansneder, 2003). In contrast, significant changes in error scores over a 90 day study period, with early BESS exposures on day 2, 3, 5, and 7, have been reported (Mancuso, Guskiewicz, & Onate, 2002). A similar study found clinically and statistically significant improvements in BESS total scores in 55 females over a 13-week regular athletic season. Participant scores improved by a mean 1.04 errors (SD = 2.38) from pre-season to post-season (Burk, 2010). BESS error scores are also known to be negatively affected by concussion.

The BESS protocol suggests that any increase in error scores following injury is a positive indication of concussion and research indicates that individuals with concussion demonstrate worse balance when compared to controls. These studies highlight differences in error scores between concussion and control groups ranging from 6-9 errors (McCrea, Guskiewicz, Marshall, Barr, Randolph, Cantu, Onate, Kelly, & Page, 2003; Bryan L. Riemann & Guskiewicz, 2000). A study by Riemann and colleagues (2000) suggests that individuals with concussion perform poorly on the BESS on the day of injury when compared to intra-individual baseline values (Bryan L. Riemann & Guskiewicz, 2000). In athletic populations, mean post-concussion errors range from 15.00-19.00 (Guskiewicz, 2001; McCrea, Guskiewicz, Marshall, Barr, Randolph, Cantu, Onate, Kelly, Page, et al., 2003) compared to mean baseline errors range from 8.4-12.73

(McCrea, Guskiewicz, Marshall, Barr, Randolph, Cantu, Onate, Kelly, Page, et al., 2003; Bryan L. Riemann & Guskiewicz, 2000). Total error scores for these participants, however, return to baseline at day 3 (floor condition) or day 5 (foam condition) (McCrea, Guskiewicz, Marshall, Barr, Randolph, Cantu, Onate, Kelly, & Page, 2003). These studies report that, when compared to baseline values, athletes achieve 3-6 more BESS errors after concussion.

While the BESS is quickly and easily administered, it suffers major shortcomings because of reliance on a clinicians' subjective evaluation of errors during short trials. While the BESS has high specificity (91%), assessments of sensitivity are reported as low as 34% (Patricios et al., 2017). Considering some fundamental limitations of the BESS there is a clear need for more sensitive tools incorporating objective outcome measures in post-concussion assessment batteries.

1.6 Application of Wii Balance Board in Balance Assessments

The Nintendo Wii Fit and Wii Fit Plus software have sold a combined 43 million copies worldwide ("Top Selling Software Sales Units," n.d.). Initially designed as a game to encourage at home fitness activities many Wii Fit programs require the use of the Wii Balance Board (WBB) accessory (Figure 4). Purchased separately from the Wii console package, the WBB has an approximate retail value of \$100. The WBB is similar to scientific grade force plates in that it measures users' Center of Pressure (COP) through vertical ground reaction force data. These data are collected by a single force transducer in each corner of the WBB and are transmitted wirelessly through Bluetooth technology. The WBB acts as a periphery device to the Wii Fit game and uses COP data to provide user biofeedback for programs focusing on joint flexibility, muscle strength and standing

posture. With a weight capacity of 150 Kg, usable surface dimensions of 45cm x 26.5cm, and maximum sampling frequency of 50Hz, the WBB is limited in some environments and applications. Regardless, the WBB is often viewed as a suitable alternative for more expensive scientific grade force plates. The WBB represents a cost-effective and accessible option for individuals seeking objective COP measures of balance when compared to a scientific grade force platform, which has set-up costs several magnitudes higher than that of the WBB. The WBB can be quickly and reliably synced to Bluetooth compatible devices. Using this technology, the WBB can be effectively “unlocked” with customized software (e.g. LabVIEW, MATLAB, etc.), allowing it to be used for applications beyond its intended function as a gaming accessory. Because of its low cost, portable nature and ability to be customized, the WBB has generated interest as a potential tool for assessment and rehabilitation of motor control (Goble, Cone, & Fling, 2014).

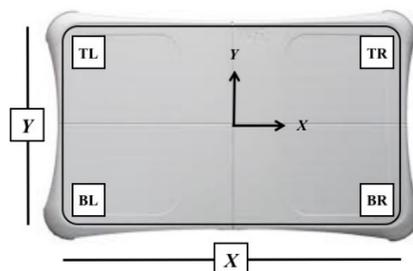


Figure 4. Top view of the Nintendo® Wii Fit™ balance board (WBB): illustrating four force sensor locations: TL (Top Left), Top Right (TR), Bottom Left (BL), and Bottom Right (BR) [Modified from (Leach, Mancini, Peterka, Hayes, & Horak, 2014)]

Over the past decade, meaningful investigation has been undertaken to determine validity and reliability of the WBB. Clarke and colleague’s preliminary investigation determined that COP total path lengths derived from WBB data were valid and reliable

when compared to those of a scientific grade force plate (Clark et al., 2010). Validity was evidenced by high correlation of WBB and force plate metrics during 10-30 second static balance trials (n=12) with eyes opened and eyes closed in single and double leg stance conditions. Reliability was evidenced by between trial comparison through interclass correlations (ICC=.66-.94) (Clark et al., 2010).

This work has also been applied to clinical populations. Safety is of paramount importance when assessing balance in research and clinical contexts. As such, use of a body weight support harness may be required to ensure participant safety when performing balance tasks. Should a body weight support harness be required, it is important to consider the potential influence it may have on performance. Preliminary research at the University of Victoria suggests that use of a body weight support harness has a positively influences participants' balance performance during a dynamic WBB task (Cullen, Sun, Christie, & Zehr, 2016). A WBB study without body weight support investigated its use in 53 adults with stroke and 144 adults without stroke (Llorens, Latorre, Noe, & Keshner, 2016). Results confirmed moderate to high concurrent validity between the WBB and one particular posturography system (NedSVE/IBV 4.0) and numerous clinical measures of balance (i.e. Berg Balance Scale, Functional Reach Test, Step Test, 30-second Chair-to-Stand Test, Timed "Up-and-go" Test, Timed Up and Down Stair Test, and 10 Meter Walking Test). This study found that the WBB could distinguish stroke participants from non-stroke participants. A similar study sought to determine validity, reliability, and objectivity of the WBB when compared to objective balance measures obtained from a force plate and subjective measures from the BESS clinical measure (Chang et al., 2014). Total COP path lengths obtained from the WBB

was found to be highly correlated with those obtained from the force plate ($r=.99$) and had excellent test-retest reliability ($r=.88$). The BESS, however, was found to be far less correlated ($r=.10-.52$) to force plate measures and had lower test-retest reliability ($r=.61-.78$). Based on these data, authors concluded that the WBB is a far more accurate and reliable tool for assessing balance when compared to the BESS.

While the WBB is capable of collecting valid and reliable data, research suggests that Wii Fit program software is not. Wii Fit balance assessments calculate a Wii Fit “age” from data derived from a center of balance assessment, body control test, and a dynamic dual task game. Reed-Jones and colleagues (2012) investigated how well two Wii Fit assessments (“Basic Balance Test” and “Prediction Test”) correlated with standard clinical measures in an older adult population ($n=34$) (Reed-Jones, Dorgo, Hitchings, & Bader, 2012). Results suggest that little correlation exists between Wii Fit metrics and clinical measures. Another study found that the Wii Fit outcome measures lacked concurrent validity when compared to a scientific force plate (Wikstrom, 2012). One study engaging 24 youth with concussion found that while Wii Fit programs may be used to challenge exertion through a game following injury, these programs are not valid to measure balance impairments (DeMatteo, Greenspoon, Levac, Harper, & Rubinoff, 2014). A literature review summarizing 127 articles found no significant evidence to support the use of the Wii Fit program in adult or older adult populations (Taylor, 2011).

The WBB demonstrates promising utility for concussion assessments, where more sensitive and objective measures of postural balance are desired. Preliminary work in this area support this application. Practicality and efficiency are two important factors to

consider when investigating feasibility of an assessment tool. The WBB satisfies both needs but remains largely untested in application to sport-related concussion.

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Chapter Two: Manuscript

Striking a balance with concussion assessment: Use of the Wii balance board to evaluate postural control

2.1 Introduction

Sports-related concussion (concussion) has gained significant attention as a growing public health concern. While a popular topic of study, researchers and clinicians have yet to reach consensus on protocols for concussion assessment, diagnosis, and rehabilitation management. A concussion is a type of brain injury caused by direct or indirect biomechanical impact that results in linear or rotational force being translated onto the brain (McCrory, Meeuwisse, Aubry, Cantu, Dvorak, et al., 2013). Functional disturbance in the brain results in acute or gradual onset of somatic symptoms, neurocognitive impairments, and postural instability following injury (Guskiewicz, 2001). While most individuals' symptoms subside within seven days of injury (Frommer et al., 2011; MacDonald et al., 2014; Makdissi et al., 2010), this is not necessarily indicative of complete recovery, since balance and cognitive impairments may persist (Geurts et al., 1996; Kaufman et al., 2006; Rinne et al., 2006).

Impaired neurological function affects postural balance post-concussion (Vagnozzi et al., 2010). Research shows that the balance assessment tool most often used in concussion evaluations is unable to detect balance deficits more than three days post injury (Murray, Salvatore, Powell, & Reed-Jones, 2014). Given that these evaluations influence Return to Play (RTP) decisions and premature RTP may lead to subsequent injury (Vagnozzi et al., 2010), a more sensitive and commonly accessible tool is required. Use of the Wii Balance Board gaming accessory may fill this need.

The Wii Balance Board is valid and reliable in measuring variations in center of pressure (COP) when compared to a gold-standard biomechanical force plate (Chang et al., 2014). This low-cost and easy to use technology may have potential utility for assessing post-concussion balance deficits. In general, these opportunities are understudied and warrant further investigation.

Therefore, the current study proposed to investigate potential utility of a WBB program to provide objective and sensitive measure of balance in an athletic male young adult population. Study objectives were to 1) investigate the sensitivity of a customized WBB program to detect change in postural balance, when compared to the BESS clinical measure; and 2) investigate the influence of time on WBB and BESS outcome measures through repeated administration at fixed intervals across a regular athletic season and post-concussion period.

2.2 Methods

2.2.1 Experimental Design

The study employed a prospective time series design with repeated measures.

2.2.2 Participants

Initially, 38 participants were recruited for study participation. A final sample size of 25 male participants (age = 19.48 ± 2.77 years; height = 182.98 ± 7.09 cm; weight = 85.62 ± 11.41 kg) resulted as 13 potential participants were excluded because they did not meet inclusion criterion, were not interested in being a part of the study, or did not complete the required number of sessions. Individuals were eligible for study participation if they were competitive male athletes free of chronic disease, acute lower-

limb injuries affecting balance, and neurologic impairments. Participants were screened for disorders affecting visual, vestibular, or balance performance through questions regarding pre-existing diagnosed conditions. Individuals who had sustained a diagnosed concussion in the three months before the study were excluded from participation. Individuals with a history of more than six diagnosed concussions were also excluded. Of the 25 participants, 52% were competitive ice hockey athletes from the Vancouver Island Junior Hockey Association and 48% were varsity level competitive rugby athletes from the University of Victoria. In total, 14 participants (56%) were identified as having a history of at least one medically diagnosed concussion with a mean recovery period of 17.92 days (\pm 14.06) for their most recent concussion. Number of previous medically diagnosed concussions ranged from 0-4 with a mode of 1. All but one participant was right foot dominant, and all but two were right hand dominant.

2.2.3 Study Procedure

This study was approved by the University Research Ethics Board (Appendix A). All data were collected in a laboratory research setting at the University of Victoria (Figure 5). Eligible and consenting participants attended three one-hour data collection appointments at defined intervals during their regular athletic season: 1) *baseline*, 2) *mid-season*, and 3) *post-season*. Those who sustained a concussion during the study period were referred for four post-concussion (PC) assessments. The first was within 72 hours of injury (*PC1*), and follow-up assessments were once per week (*PC2-PC4*). Concussion injuries were first identified by team medical staff and then referred to a physician for assessment and diagnosis according to consensus statement guidelines (McCrory, Meeuwisse, Aubry, Cantu, Dvorák, et al., 2013). Clinical diagnosis and RTP

determinations were made by independent physicians not associated with this study.

Recovery up to 30 days was recorded.

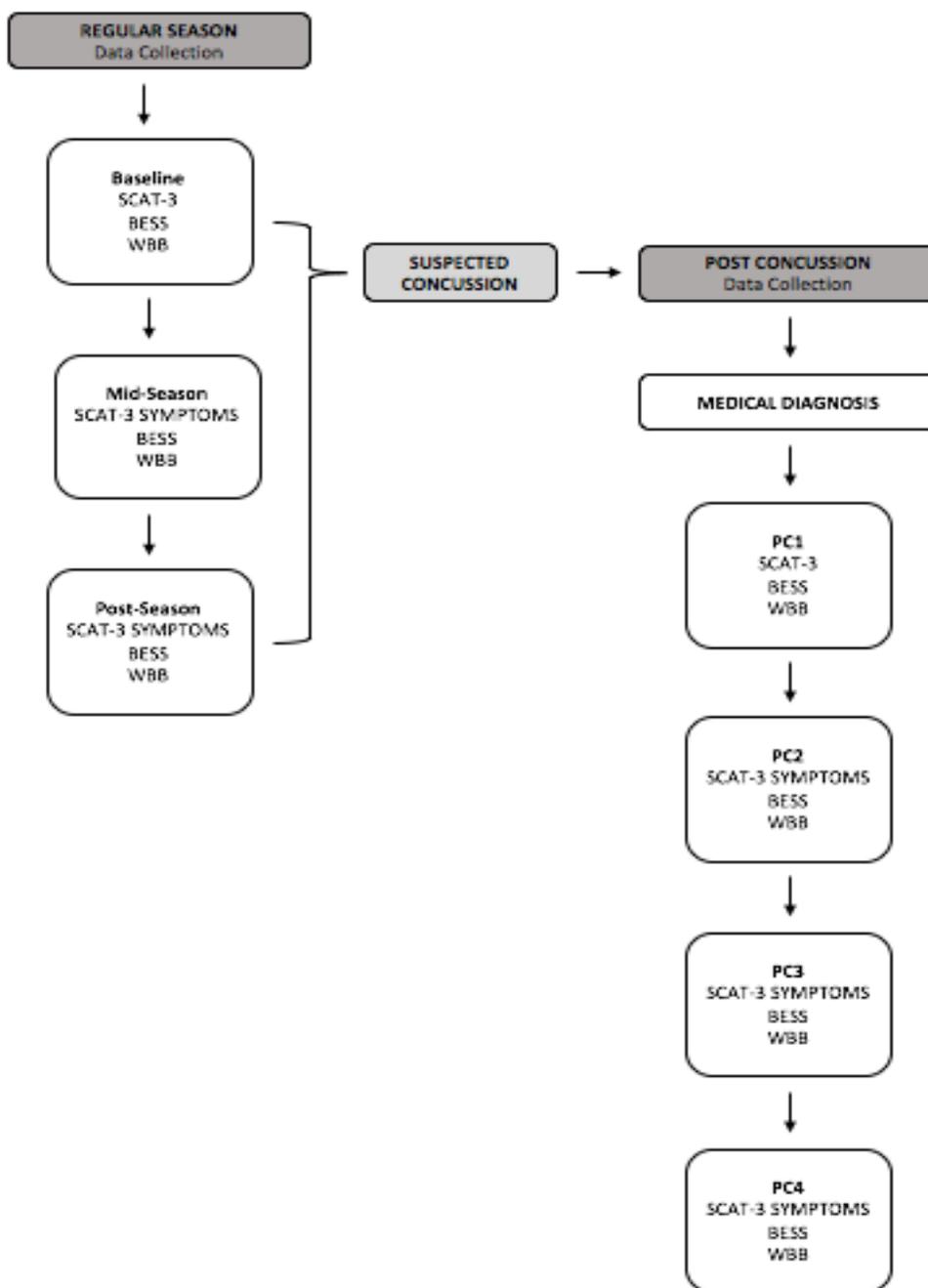


Figure 5. Data collection sequence

2.2.4 Instruments & Outcome Measures

Nine instruments were used for data collection purposes. Research assistants involved in data collection were trained in instrument administration by a certified Athletic Therapist. All questionnaires were scored by a single researcher.

Participants completed the demographic questionnaire (Appendix B), Godin Leisure-Time Exercise Questionnaire (Appendix C), Physical Activity Readiness Questionnaire (Appendix D), Waterloo Footedness Questionnaire (Appendix E), and Activities-specific Balance Confidence Scale (Appendix F) as part of study intake. Participants completed the BESS (Appendix H), static WBB, and dynamic WBB measures at *baseline*, *mid-season*, and *post-season*, and *PC1-PC4* assessments. The full SCAT-3 (Appendix G) measure was administered at *baseline*, *post-season*, and *PC1* assessments while only SCAT-3 symptoms were administered at *mid-season* and *PC2-PC4*. Electromyography data were collected for participants from the hockey group only, due to feasibility. Less challenging measures were completed first to limit the influence of confounding factors (e.g. fatigue) on subsequent measures. This order was consistent for all participants and all testing sessions.

2.4.1 Demographic Questionnaire

Participants completed a demographic questionnaire during the *baseline* data collection appointment. This questionnaire gathered information about participants' general characteristics (e.g. age, height, weight, etc.) and more detailed information about athletic and medical history (e.g. concussion history, previous sport participation, etc.).

2.4.2 Godin Leisure-Time Exercise Questionnaire

Participants self-administered the Godin Leisure-Time Exercise Questionnaire according to guidelines outlined in the Journal of Medicine & Science in Sports &

Exercise (Godin, 1997). Weekly Leisure Activity Scores (WLAS) were calculated according to standard guidelines to quantify participant physical activity levels.

2.4.3 Physical Activity Readiness Questionnaire

Participants self-administered the Physical Activity Readiness Questionnaire (PAR-Q) according to guidelines published by the Canadian Society for Exercise Physiology (Canadian Society for Exercise Physiology, 2002). The PAR-Q was used to determine participant eligibility where participants who selected “yes” for any of the screening questions were excluded from study participation or required medical clearance before participation.

2.4.4 Waterloo Footedness Questionnaire

Participants self-administered the Waterloo Footedness Questionnaire according to guidelines outlined in *Neuropsychologia* (Elias, Bryden, & Bulman-Fleming, 1998). This questionnaire was used to confirm participant foot and leg dominance. Questionnaires were scored according to Elias and colleagues’ guidelines where each response was scored on a -2 to +2 scale where a total score of -20 was “strongly left foot dominant” and a total score of +20 was “strongly right foot dominant.”

2.4.5 Activities-specific Balance Confidence Scale

Participants self-administered the Activities-specific Balance Confidence (ABC) Scale according to guidelines outlined by Powell and Myers (Powell & Myers, 1995). This questionnaire was used to determine participants’ perceived confidence in their ability to maintain postural control and avoid falling in various task and situational contexts. Scores were calculated by averaging participant responses to the sixteen item

questionnaire. These were compared to standard ratings proposed by Myers and colleagues (Myers, Fletcher, Myers, & Sherk, 1998):

- >80% = high level of physical functioning
- 50-80% = moderate level of physical functioning
- <50% = low level of physical functioning.

2.4.6 Sport Concussion Assessment Tool – 3rd Edition

The SCAT-3 was administered and scored according to guidelines published with the 2012 Consensus Statement on Concussion in Sport in the British Journal of Sports Medicine (McCrory, Meeuwisse, Aubry, Cantu, Dvorak, et al., 2013). This tool was used to assess somatic symptoms, cognitive ability, and balance control. Sections one (Glasgow Coma Scale), two (Maddocks Score), and five (Neck Examination) were omitted as these were not clinically relevant to participants without concussion. Section six (Balance Examination) was omitted as the full BESS was administered in its stead. The SCAT-3 was scored according to CISG guidelines.

2.4.7 Balance Error Scoring System

The BESS was administered and scored according to CISG guidelines (McCrory, Meeuwisse, Aubry, Cantu, Dvorák, et al., 2013). Participants performed the following balance stances for 20 seconds with eyes closed and hands placed firmly on the hips: double leg (*double*), non-dominant single leg (*single*), and tandem leg (*tandem*). Stances were performed without footwear under two testing surface conditions: hard floor (*floor*) and medium density foam (*foam*) (AIREX Balance Pad Elite 81002, 50.08 cm x 40.64 cm x 6.35 cm). A trained research assistant assessed BESS performance where the following were considered errors: 1) hands lifted off iliac crest, 2) opening eyes, 3) step,

stumble or fall, 4) moving hip into >30 degrees of abduction, 5) lifting forefoot or heel, and 6) remaining out of test position >5 seconds (McCroory, Meeuwisse, Aubry, Cantu, Dvorák, et al., 2013).

Total BESS error score and individual trial scores were the outcome measures of interest where errors were summed for each stance (i.e. *double*, *single*, and *tandem*) under each surface condition (i.e. *floor*, *foam*). Total BESS error score ($BESS_{Total}$) was calculated by summing the total number of errors in each trial under both surface conditions (Equation 2).

$$BESS_{Total} = BESS_{Foam} + BESS_{Floor}$$

Equation 1. *BESS total error score ($BESS_{Total}$)*

2.4.8 Wii Balance Board Program

A Nintendo Wii Fit Balance Board (WBB) was interfaced with a laptop computer (Microsoft Windows 10 operating system) via Bluetooth using customized software (LabVIEW 2011 National Instruments, Austin, TX, USA) (Holmes, Jenkins, Johnson, Hunt, & Clark, 2012). The WBB was calibrated using customized software (LabVIEW 2011 National Instruments, Austin, TX, USA). Data was sampled at 10Hz. The WBB program incorporated both static and dynamic balance components.

Static Balance: During the static portion of the WBB program participants performed one 20-second trial of each BESS stance (i.e. *double*, *single*, and *tandem*) while standing on the WBB without footwear, with eyes closed and with hands placed firmly on the hips. Participants were allowed appropriate rest time between trials.

Center of Pressure (COP) was defined as “the point location of the vertical ground reaction force vector [and] represents a weight average of all the pressure over the surface

of area in contact with the ground” (Winter, 1995). Vertical ground reaction forces were measured by uniaxial force transducers located in each corner of the WBB. WBB force data was used to calculate COP_x (Equation 2), COP_y (Equation 3), COP path length in the medial-lateral direction (COP_{ML}) (Equation 4), COP path length in the anterior-posterior direction (COP_{AP}) (Equation 5), and total COP path length (COP_T) (Equation 6).

$$COP_x = \frac{F_{TR} + F_{BR}}{(TR + BR + TL + BL)}$$

Equation 2. Center of Pressure X (COP_x)

$$COP_y = \frac{F_{TL} + F_{TR}}{(TR + BR + TL + BL)}$$

Equation 3. Center of Pressure Y (COP_y)

$$COP_{ML} = | \sum COP_x (n + 1) - COP_x (n) |$$

Equation 4. Center of Pressure medial-lateral path length (COP_{ML})

$$COP_{AP} = | \sum COP_y (n + 1) - COP_y (n) |$$

Equation 5. Center of Pressure anterior-posterior path length (COP_{AP})

$$COP_T = \sum \sqrt{[COP_x (n) - COP_x (n + 1)]^2 + [COP_y (n) - COP_y (n + 1)]^2}$$

Equation 6. Center of Pressure total path length (COP_T)

Dynamic Balance: During the dynamic balance portion of the WBB program participants stood comfortably on the WBB with feet hip-width apart without footwear and hands placed firmly on the hips. COP was presented as a dot on a laptop screen placed at chest height directly in front of the participant. During each trial (n=6) a target dot moved on the screen in random sequence among eight cardinal and ordinal directions. Participants were instructed to redistribute their weight on the WBB to meet the target on the screen as quickly as possible. Trial 1 was a practice trial to allow participants to become familiarized with program procedure and was not used for data analysis purposes. Data was recorded for Trials 2-6 and averaged. Participants were allowed

appropriate rest time between trials. Recovery time to virtual perturbation was the outcome measure of interest for the dynamic WBB assessment. Time to reach each target (t_{Target}) and time to return to center (t_{Center}) were recorded. These were summed to compute t_{Total} (Equation 7).

$$t_{Total} = t_{Target} + t_{Centre}$$

Equation 7. Total recovery time (t_{TOTAL})

2.4.9 Electromyography

Electromyography (EMG) was recorded from the medial gastrocnemius (MG), peroneus longus (PL), and tibialis anterior (TA) muscles in accordance to Surface EMG for Non-Invasive Assessment of Muscles (SENIAM) procedures (Hermens et al., 1999). Participant skin was cleaned with alcohol in preparation for electrode application. Using anatomical landmarks, a single researcher applied bipolar surface electrodes bilaterally along the middle muscle belly. A ground electrode was placed on the left patella. Using the Noraxon Telemetry (Noraxon, U.S.A. Inc.) wireless system, EMG signals were collected with a sampling rate of 1000 Hz, filtered by a dual-pass 4th order Butterworth filter with a cutoff frequency of 100 Hz. Integrated EMG was the outcome measure of interest and reflects the total EMG amplitude over trial time (20 seconds).

2.2.5 Statistical Analysis

All statistical analysis was performed using Statistical Package for the Social Sciences (IBM SPSS Statistics for Macintosh, Version 24.0. Armonk, NY: IBM Corp) with the level of significance set at $p < .05$. Data were first visually inspected for completeness. Little's Test was used to determine if missing data was missing completely at random. Missing data fell below a 10% exclusionary score. Such data was treated

through multiple imputation incorporating all variables where five data sets were imputed, and statistical analysis was based on pooled data. Data was further assessed to ensure assumptions of parametric analyses were met. In cases where the assumption of sphericity was violated, degrees of freedom were adjusted using the Greenhouse-Geisser correction. Descriptive statistics and Pearson Product-Moment Correlations were computed. One-Way Repeated Measures Analysis of Variance (RM-ANOVA) with Bonferroni post-hoc pairwise comparisons were completed to examine significant within-subject contrasts across time points. Main effect of time was assessed at regular study time points (*baseline*, *mid-season*, and *post-season*) for all study participants. Cohen's *d* effect size comparisons between *baseline* and *post-season* time points were computed to determine practical significance. Data of individuals who sustained a concussion during the study period were assessed further. Paired Samples t-Tests were performed to examine post-injury differences in outcome measures between *baseline* and *PCI-PC4*. Cohen's *d* effect size comparisons between *baseline* and *PCI* time points were computed to determine practical significance. Using statistical significance of regular season data as a guide, analysis of post-concussion data included SCAT-3 symptom ratings, BESS total scores, and WBB balance outcome measures found to be sensitive to performance change between time points.

2.3 Results

2.3.1 Participant Characteristics

Participant characteristics are summarized in Table 1.

Table 1: Baseline participant characteristics

	M ± SD
Age (years)	19.48 ± 2.77
Height (cm)	182.98 ± 7.09
Weight (kg)	85.62 ± 11.41
BMI (m/kg ²)	25.54 ± 2.78
Weekly Leisure Time	77.44 ± 37.86
Strenuous	4.80 ± 2.21
Moderate	4.04 ± 2.41
Light	4.68 ± 4.06
ABC Scale	93.4 ± 2.31
Right Hand Dominant	92%
Right Foot Dominant	96%
History of Diagnosed Concussion	56%
Number of Previous Concussions	.84 ± .99
Recovery from Recent Concussion (days)	17.92 ± 24.06

Note: M = Mean; SD = Standard Deviation; BMI = Body Mass Index; ABC Scale = Activities-specific Balance Confidence Scale.

2.3.2 Regular Season Data

Little's Test resulted in a chi-square = 23.040 (df = 1899; p = 1.00) indicating that missing data was missing completely at random.

2.3.2.1 Sport Concussion Assessment Tool – 3rd Edition

There were no statistically significant differences between time points for SCAT-3 symptom number scores ($p=.616$), symptom severity scores ($p=.670$), orientation

($p=.168$), immediate memory ($p=.736$), concentration ($p=.868$), coordination ($p=.050$) or delayed recall ($p=.512$). Though non-significant, symptom number ($d=.28$) and severity ($d=.26$) scores each worsened by 55% from *baseline* to *post-season*.

Table 2: Sport Concussion Assessment Tool (3) scores through regular athletic season

	<i>Baseline</i>	<i>Mid-Season</i>	<i>Post-Season</i>	<i>Effect Size</i>
Symptom Number	2.48 ± 4.86	3.22 ± 5.26	3.84 ± 4.85	.28
Symptom Severity	3.40 ± 7.35	5.32 ± 10.82	5.28 ± 7.34	.26
Orientation	4.92 ± .28	--	4.75 ± .52	.41
Immediate Memory	14.56 ± 1.00	--	14.61 ± .59	.06
Concentration	3.68 ± 1.03	--	3.68 ± 1.25	.00
Coordination	1.00 ± .00	--	.87 ± .31	--
Delayed Recall	4.04 ± 1.14	--	3.81 ± 1.18	.20

Note: Cohen's d effect size comparing *baseline* to *post-season*.

2.3.2.2 Balance Error Scoring System

There were no statistically significant differences between time points for BESS total scores ($p=.670$). No statistically significant differences were observed between time points for total errors in the *floor* condition ($p=.697$) nor any of the stances within the *floor* condition: *double* ($p=.128$), *single* ($p=.436$), and *tandem* ($p=.719$). No statistically significant differences were observed between time points for total errors in the *foam* condition ($p=.878$) nor any of the stances within the *foam* condition: *double* ($p=.134$), *single* ($p=.794$) and *tandem* ($p=.661$). BESS total error scores and individual trial scores across study time points are outlined in Table 4. Though not statistically significant,

BESS_{Total} worsened by 5% ($d=.19$), BESS_{Floor} worsened by 12% ($d=.19$), and BESS_{Foam} worsened by 3% ($d=.10$) from baseline to post-season.

Table 3: Balance Error Scoring System scores through regular athletic season

	<i>Baseline</i>	<i>Mid-Season</i>	<i>Post-Season</i>	<i>Effect Size</i>
BESS _{Total}	17.87 ± 4.72	17.54 ± 6.63	18.81 ± 5.41	.19
BESS _{Floor}	3.78 ± 2.03	4.14 ± 2.63	4.25 ± 2.83	.19
<i>double</i>	.00 ± .00	.07 ± .22	.00 ± .00	--
<i>single</i>	2.54 ± 1.47	2.76 ± 1.58	3.08 ± 2.10	.31
<i>tandem</i>	1.15 ± .87	1.35 ± 1.35	1.36 ± 1.40	.18
BESS _{Foam}	14.09 ± 4.36	14.37 ± 4.72	14.56 ± 4.93	.10
<i>double</i>	.00 ± .00	.13 ± .30	.13 ± .29	--
<i>single</i>	8.43 ± 3.01	8.39 ± 2.06	8.72 ± 1.57	.12
<i>tandem</i>	5.65 ± 3.35	5.75 ± 3.53	6.33 ± 2.90	.22

Note: Cohen's d effect size comparing *baseline* to *post-season*.

2.3.2.3 Wii Balance Board Program

Static WBB: Statistically significant differences between time points for some static WBB outcome measures were detected, mostly in the *single* stance condition. For *double* stance, no differences were observed between time points for COP_{ML} ($p=.535$) or COP_{AP} ($p=.087$). In contrast, mean COP_T was statistically significantly different between time points in *double* stance ($p=.036$). Post-hoc tests using Bonferroni pairwise comparisons revealed significant differences between *mid-season* and *post-season* ($p=.041$) but not between *baseline* and *mid-season* ($p=.137$) or *baseline* and *post-season* ($p=1.00$). No differences were observed between time points for any static WBB outcome

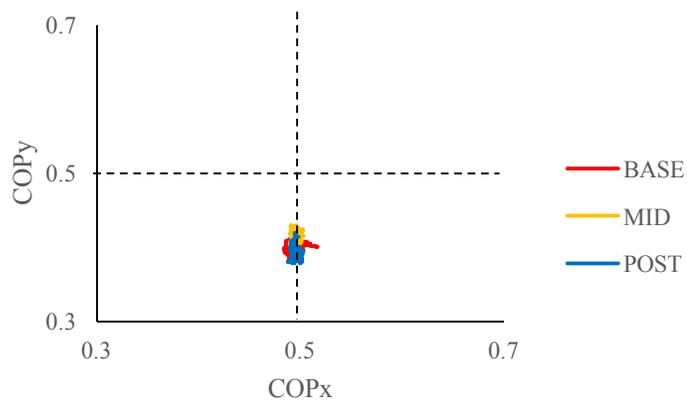
measures in *tandem* stance: COP_{ML} ($p=.280$), COP_{AP} ($p=.500$), or COP_T ($p=.891$). Significant differences were observed between time points for nearly all static WBB outcome measures for *single* stance. Mean COP_{ML} were statistically significantly different between time points ($p=.000$). Post-hoc tests using the Bonferroni method revealed significant pairwise comparisons between *baseline* and *post-season* ($p=.002$) and between *baseline* and *mid-season* ($p=.042$) but not between *mid-season* and *post-season* ($p=.167$). Mean COP_{AP} was not statistically significantly different between time points ($p=.057$). Mean COP_T was statistically significantly different between time points ($p=.001$). Post-hoc tests revealed significant pairwise comparisons between *baseline* and *post-season* ($p=.007$), and between *baseline* and *mid-season* ($p=.023$) but not between *mid-season* and *post-season* ($p=.939$). These results are outlined in Table 5 and represented in Figure 6. Focusing specifically on the single stance condition, COP_{ML} worsened by 25% ($d=1.07$) and COP_T worsened by 9% ($d=.85$) between *baseline* and *post-season*. There was 0% change in COP_{AP} between *baseline* and *post-season* ($d=.03$).

Table 4: Static WBB outcome measures (COP_{ML} , COP_{AP} , and COP_T) for stance (double, single, and tandem) and surface (floor and foam) conditions through regular athletic season

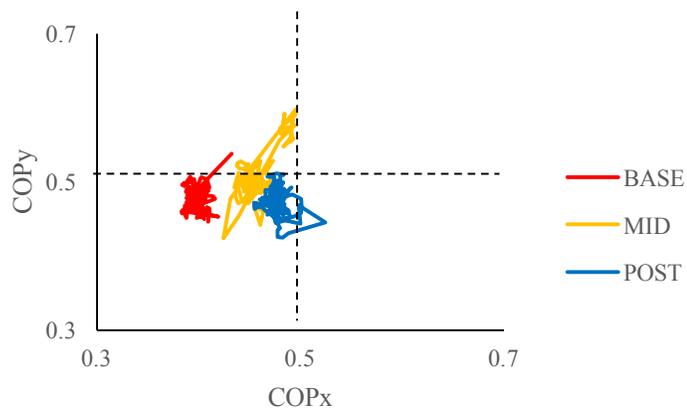
	<i>Baseline</i>	<i>Mid-Season</i>	<i>Post-Season</i>	<i>Effect Size</i>
COP_{ML}				
<i>double</i>	98.28 ± 4.73	99.44 ± 3.89	98.65 ± 2.98	.10
<i>single</i>	76.81 ± 23.98	91.41 ± 13.41	95.74 ± 7.27	1.07
<i>tandem</i>	95.59 ± 8.26	98.69 ± 8.83	95.86 ± 9.45	.03
COP_{AP}				
<i>double</i>	79.79 ± 11.14	83.64 ± 10.27	79.21 ± 11.12	.05
<i>single</i>	95.76 ± 10.28	100.98 ± 9.99	95.42 ± 12.19	.03
<i>tandem</i>	114.62 ± 13.63	112.31 ± 13.06	115.15 ± 13.38	.04
COP_T				
<i>double</i>	127.06 ± 7.62	130.32 ± 7.42	126.88 ± 6.08	.03
<i>single</i>	124.60 ± 16.41	137.18 ± 14.15	136.13 ± 9.94	.85
<i>tandem</i>	149.64 ± 10.52	150.25 ± 11.12	150.57 ± 11.44	.08

Note: Cohen's *d* effect size comparing *baseline* to *post-season*.

a)



b)



c)

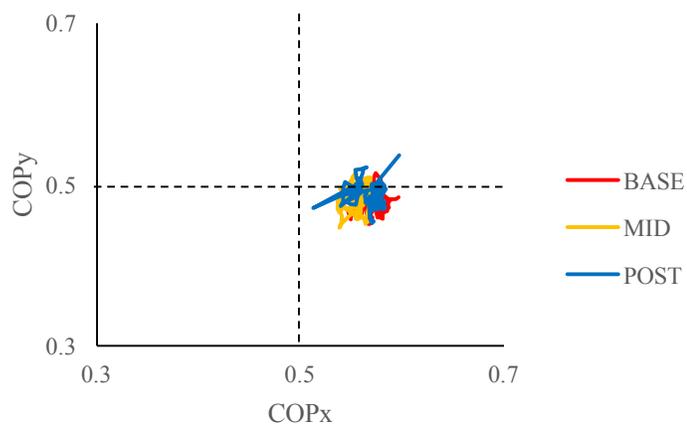


Figure 6. Wii Balance Board Center of Pressure data highlighting variability within and among study time points for a) double, b) single, and c) tandem leg stances

Dynamic WBB: Statistically significant differences between time points were observed for all dynamic WBB outcome measures where *tTarget*, *tCenter* and *tTotal* performance all improved over the study period. Mean *tTarget* was statistically significantly different between time points ($p=.009$). Post-hoc tests revealed significant pairwise comparisons between *baseline* and *post-season* ($p=.009$) but not between *baseline* and *mid-season* ($p=.668$) or *mid-season* and *post-season* ($p=.266$). Mean *tCenter* was significantly different between time points ($p=.000$). Post-hoc tests revealed significant pairwise comparisons between *baseline* and *post-season* ($p=.000$) and between *baseline* and *mid-season* ($p=.000$) but not between *mid-season* and *post-season* ($p=.313$). Mean *tTotal* was significantly different between time points ($p=.000$). Post-hoc tests revealed significant pairwise comparisons between *baseline* and *post-season* ($p=.003$) but not between *baseline* and *mid-season* ($p=.149$) or between *mid-season* and *post-season* ($p=.248$). These results are outlined in Table 6. Between *baseline* and *post-season* *tTarget* improved by 12% ($d=.93$), *tCenter* improved by 24% ($d=1.28$), and *tTotal* improved by 14% ($d=1.08$).

Table 5: Dynamic WBB outcome measures (*tTarget*, *tCentre*, and *tTotal*) through regular athletic season

	<i>Baseline</i>	<i>Mid-Season</i>	<i>Post-Season</i>	<i>Effect Size</i>
<i>tTarget</i>	1.22 ± .15	1.18 ± .19	1.08 ± .15	.93
<i>tCentre</i>	.76 ± .13	.64 ± .17	.58 ± .15	1.28
<i>tTotal</i>	1.96 ± .23	1.82 ± .32	1.69 ± .27	1.08

Note: Cohen's *d* effect size comparing *baseline* to *post-season*.

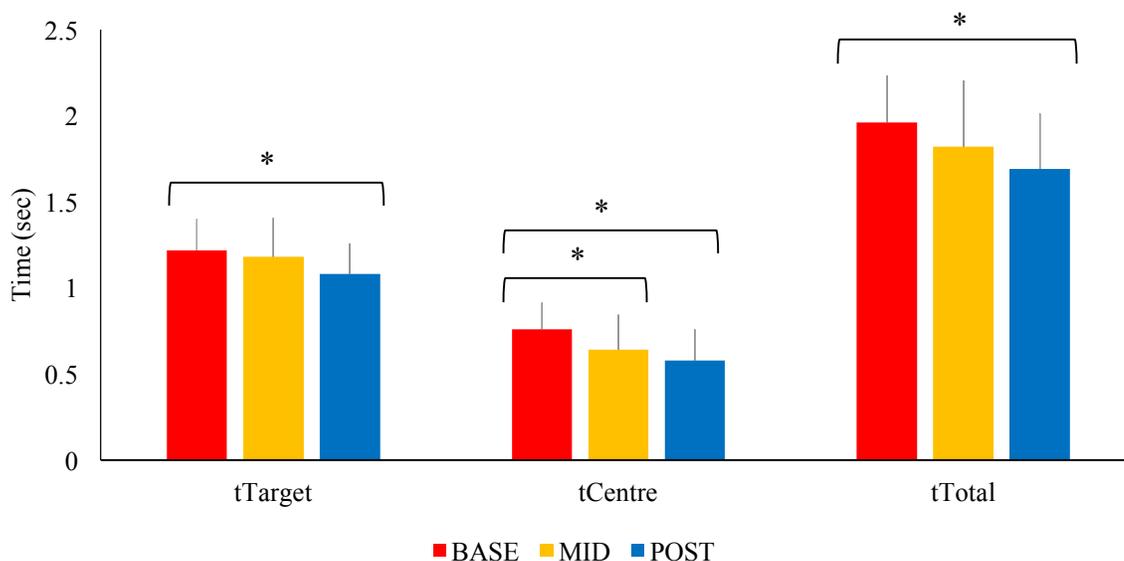


Figure 7. Regular season Wii Balance Board dynamic recovery time. * denotes RM-ANOVA significance at $p < .05$.

2.3.2.4 Correlations between BESS and WBB Outcome Measures

Few significant correlations were revealed between BESS and WBB outcome measures across regular season time points. At *baseline* there was a moderate negative correlation between $BESS_{Total}$ and COP_{AP} ($r(25) = -.477, p = .017$) for *single* stance. At *mid-season* there was a moderate negative correlation between $BESS_{Foam}$ and COP_{ML} ($r(25) = -.412, p = .043$) for *tandem* stance. At *post-season* there was a moderate negative correlation for $BESS_{Floor}$ and COP_{AP} ($r(25) = -.416, p = .040$) for *double* stance. Also at *post-season* there was a moderate negative correlation between $BESS_{Total}$ & COP_{AP} ($r(25) = -.420, p = .036$), $BESS_{Floor}$ and COP_{AP} ($r(25) = -.514, p = .012$) and $BESS_{Floor}$ and COP_T ($r(25) = -.444, p = .031$) for *single* stance.

2.3.2.6 Integrated Electromyography for Dynamic WBB

No statistically significant differences were detected between regular study time points for bilateral integrated EMG. A RM-ANOVA revealed no significant effect of time for left leg medial gastrocnemius ($p = .130$), peroneus longus ($p = .232$), or tibialis anterior

($p=.300$) integrated EMG, nor for right leg medial gastrocnemius ($p=.273$), peroneus longus ($p=.069$) or tibialis anterior ($p=.725$) integrated EMG (Figures 8-10).

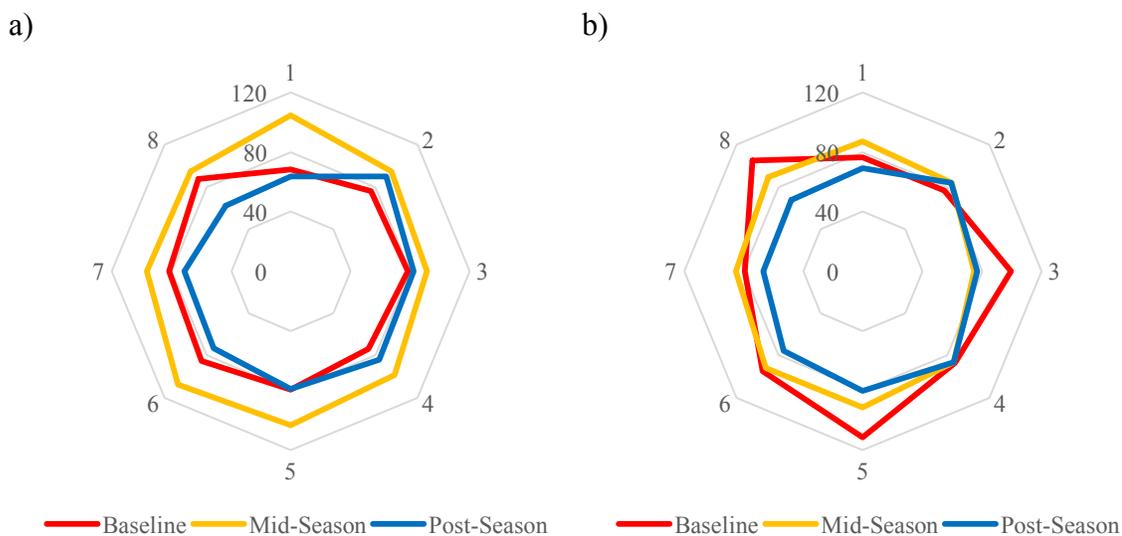


Figure 8. Regular season integrated EMG during the WBB dynamic task across time points for a) left medial gastrocnemius, and b) right medial gastrocnemius

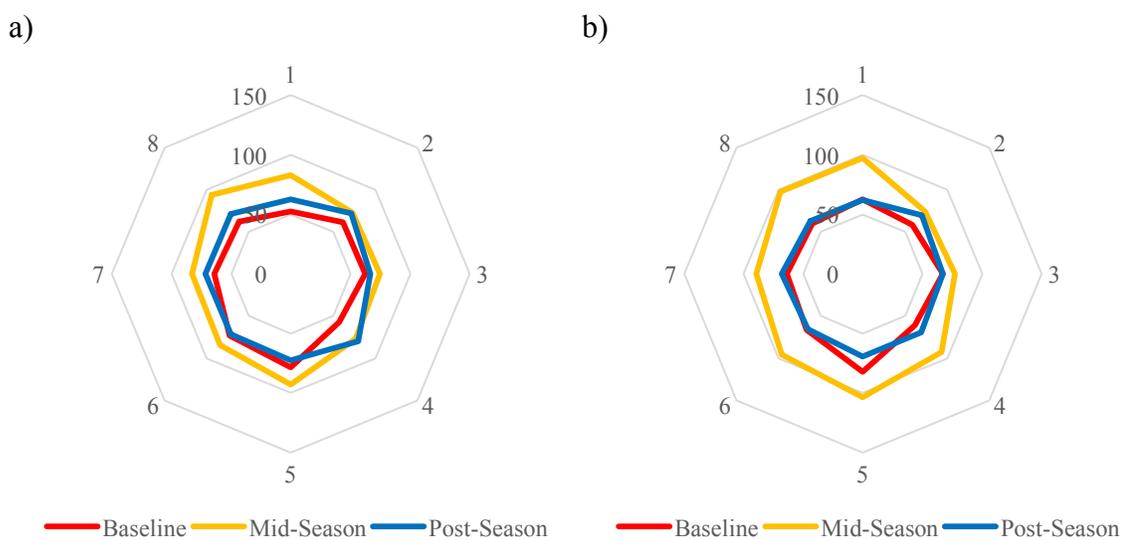


Figure 9. Regular season integrated EMG during the WBB dynamic task across time points for a) left peroneus longus, and b) right peroneus longus

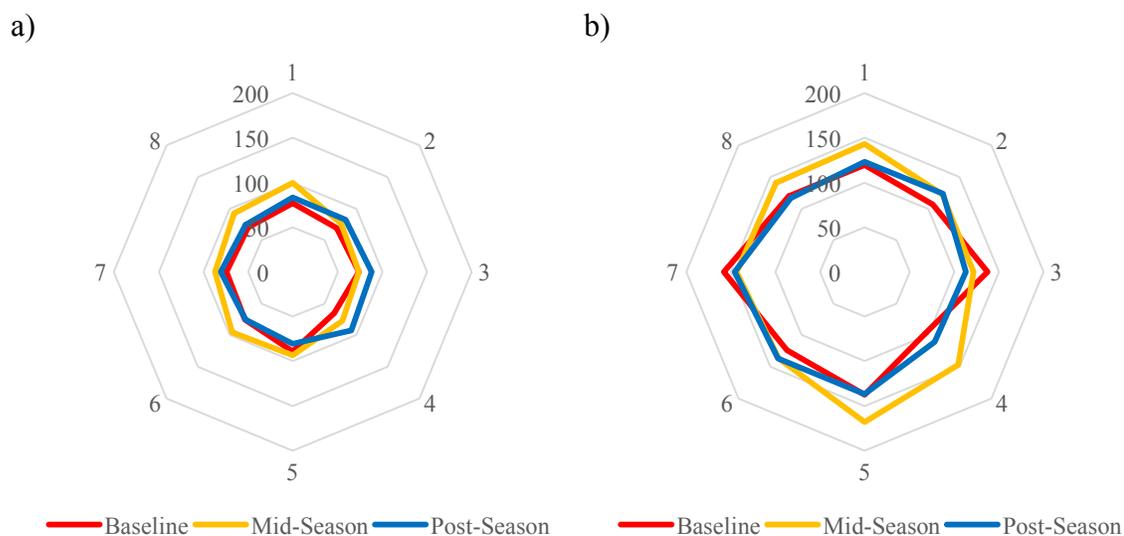


Figure 10. Regular season integrated EMG during the WBB dynamic task across time points for a) left tibialis anterior, and b) right tibialis anterior

2.3.3 Post-Concussion Results

Five participants sustained a single concussion during the study period (20% of sample). No participant sustained multiple concussions. Return to Play (RTP) timelines ranged from 7 to 30 days post injury (mean = 21.60, SD = 12.46). Mean RTP occurred the week of PC3 data collection. Little's Test resulted in a chi-square = 2.771 (df = 1697; $p = 1.000$) indicating that missing data was missing completely at random. Percentage of missing data fell below the 10% exclusionary score.

2.3.3.1 Sport Concussion Assessment Tool – 3rd Edition

Paired t-Test results indicate that there was no statistically significant difference in SCAT-3 symptom rating between *baseline* and *PC1-PC4* (Table 8). Symptom number results are as follows: *baseline* and *PC1* ($p=.417$), *PC2* ($p=.684$), *PC3* ($p=.938$), and *PC4* ($p=.280$). Symptom severity results are as follows: *baseline* and *PC1* ($p=.580$), *PC2* ($p=.511$), *PC3* ($p=.887$), and *PC4* ($p=.192$) (Figure 11). Symptom number increased by

78% ($d=-.256$) and symptom severity increased by 50% ($d=-.182$) between *baseline* and *PC1*.

Table 6: Sport Concussion Assessment Tool (3) symptom rating scores from PC1-PC4

	<i>Baseline</i>	<i>PC1</i>	<i>PC2</i>	<i>PC3</i>	<i>PC4</i>
Symp Number	5.20 ± 9.47	9.27 ± 5.24	7.98 ± 8.03	5.69 ± 6.64	.07 ± .51
Symp Severity	9.20 ± 15.02	9.02 ± 17.32	17.32 ± 17.09	10.81 ± 14.52	.60 ± .41

Note: Symp = Symptom; *PC1* = Post-Concussion 1; *PC2* = Post-Concussion 2; *PC3* = Post-Concussion 3; *PC4* = Post-Concussion 4.

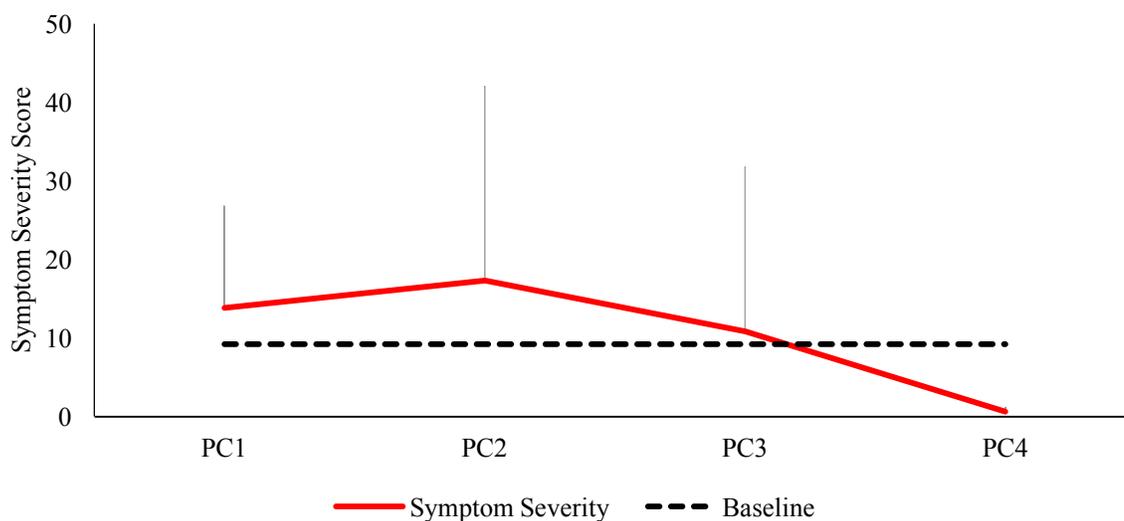


Figure 11. Sport Concussion Assessment Tool (3) symptom severity from PC1-PC4.

2.3.3.2 Balance Error Scoring System

Paired t-tests did not reveal significant differences in any BESS error scores between *baseline* and *PC1-PC4* (Table 7). BESS_{Total} results were *baseline* and *PC1* ($p=.785$), *PC2* ($p=.575$), *PC3* ($p=.405$), and *PC4* ($p=.972$). BESS_{Floor} results were *baseline* and *PC1* ($p=.529$), *PC2* ($p=.186$), *PC3* ($p=.171$), and *PC4* ($p=.874$). BESS_{Foam} results were *baseline* and *PC1* ($p=.680$), *PC2* ($p=.945$), *PC3* ($p=.751$), and *PC4* ($p=.859$).

Between *baseline* and *PC1* $BESS_{Total}$ worsened by 7% ($d=.16$), $BESS_{Floor}$ improved by 15% ($d=.21$), and $BESS_{Foam}$ worsened by 12% ($d=.28$).

Table 7: Balance Error Scoring System scores from PC1-PC4

	<i>Baseline</i>	<i>PC1</i>	<i>PC2</i>	<i>PC3</i>	<i>PC4</i>
$BESS_{Total}$	18.20 ± 7.53	19.47 ± 8.32	16.25 ± 5.13	21.46 ± 9.68	18.09 ± 1.93
$BESS_{Floor}$	4.40 ± 3.36	3.75 ± 2.73	2.37 ± 2.06	6.86 ± 5.36	4.61 ± 1.88
<i>double</i>	.00 ± .00	.27 ± .47	.00 ± .00	.00 ± .00	.00 ± .00
<i>single</i>	3.20 ± 2.17	2.77 ± 1.19	1.34 ± 1.34	3.98 ± 1.63	3.75 ± 1.22
<i>tandem</i>	1.20 ± 1.30	1.09 ± 1.73	1.21 ± 1.34	3.09 ± 4.54	.97 ± .89
$BESS_{Foam}$	13.80 ± 5.97	15.49 ± 5.99	14.04 ± 4.30	14.63 ± 4.33	13.25 ± 1.48
<i>double</i>	.00 ± .00	.25 ± .45	.24 ± .51	.30 ± .45	.00 ± .00
<i>single</i>	8.20 ± 4.02	8.41 ± 2.79	7.51 ± 2.30	8.68 ± 2.16	9.17 ± 1.02
<i>tandem</i>	6.68 ± 2.39	6.35 ± 3.62	6.26 ± 1.99	5.63 ± 2.78	3.97 ± 2.20

Note: PC1 = Post-Concussion 1; PC2 = Post-Concussion 2; PC3 = Post-Concussion 3; PC4 = Post-Concussion 4.

2.3.3.3 Wii Balance Board Program

There was no statistical difference in any WBB static outcome measures (i.e. COP_{ML} , COP_{AP} , or COP_T) for *single* stance condition between *baseline* and *PC1-PC4* (Table 8). There was not a significant difference in COP_{ML} *single* scores between *baseline* and *PC1* ($p=.065$), *PC2* ($p=.488$), *PC3* ($p=.248$), or *PC4* ($p=.194$). There was not a significant difference in COP_{AP} *single* scores between *baseline* and *PC1* ($p=.655$), *PC2* ($p=.438$), *PC3* ($p=.418$), or *PC4* ($p=.461$). There was not a significant difference in COP_T *single* scores between *baseline* and *PC1* ($p=.345$), *PC2* ($p=.957$), *PC3* ($p=.498$), or

PC4 ($p=.352$). Between *baseline* and *PC1* COP_{ML} worsened by 19% ($d=1.19$), COP_{AP} improved by 3% ($d=.23$), and COP_T worsened by 6% ($d=.57$).

Table 8: Static WBB outcome measures (COP_{ML} , COP_{AP} , and COP_T) for stance (double, single, and tandem) and surface (floor and foam) conditions from *PC1-PC4*

	<i>Baseline</i>	<i>PC1</i>	<i>PC2</i>	<i>PC3</i>	<i>PC4</i>
COP_{ML}	80.16 ± 17.41	95.65 ± 5.95	87.89 ± 13.32	92.11 ± 11.06	95.98 ± 14.51
COP_{AP}	97.26 ± 13.91	94.48 ± 10.25	92.10 ± 10.30	93.61 ± 10.48	94.41 ± 9.59
COP_T	127.78 ± 17.71	135.38 ± 6.43	128.30 ± 11.23	132.13 ± 9.52	135.86 ± 9.85

Note: PC1 = Post-Concussion 1; PC2 = Post-Concussion 2; PC3 = Post-Concussion 3; PC4 = Post-Concussion 4.

Paired t-tests revealed significant differences in t_{Target} , t_{Center} , and t_{Total} between *baseline* and *PC1-PC4* (Table 9). There was significant improvement in t_{Target} scores between *baseline* and *PC1* ($p=.028$), *PC2* ($p=.024$), *PC3* ($p=.001$), and *PC4* ($p=.005$). There was significant improvement in t_{Center} scores between *baseline* and *PC1* ($p=.012$), *PC3* ($p=.020$), and *PC4* ($p=.000$). There was not a significant difference in t_{Center} scores between *baseline* and *PC2* ($p=.168$). There was a significant difference in t_{Total} scores between *baseline* and *PC1* ($p=.014$), *PC3* ($p=.003$), and *PC4* ($p=.000$). There was not a significant difference in t_{Total} scores between *baseline* and *PC2* ($p=.077$). t_{Target} improved by 7% ($d=.68$), t_{Center} improved by 15% ($d=.62$), and t_{Total} improved by 10% ($d=.63$) between *baseline* and *PC1*.

Table 9: Dynamic Wii Balance Board outcome measures (tTarget, tCentre, and tTotal) scores from PC1-PC4

	<i>Baseline</i>	<i>PC1</i>	<i>PC2</i>	<i>PC3</i>	<i>PC4</i>
tTarget	1.21 ± .15	1.12 ± .11	1.11 ± .09	1.04 ± .11	1.30 ± .05
tCenter	.75 ± .15	.64 ± .20	.65 ± .23	.60 ± .25	.44 ± .19
tTotal	1.96 ± .29	1.77 ± .31	1.76 ± .30	1.64 ± .35	1.50 ± .24

Note: PC1 = Post-Concussion 1; PC2 = Post-Concussion 2; PC3 = Post-Concussion 3; PC4 = Post-Concussion 4.

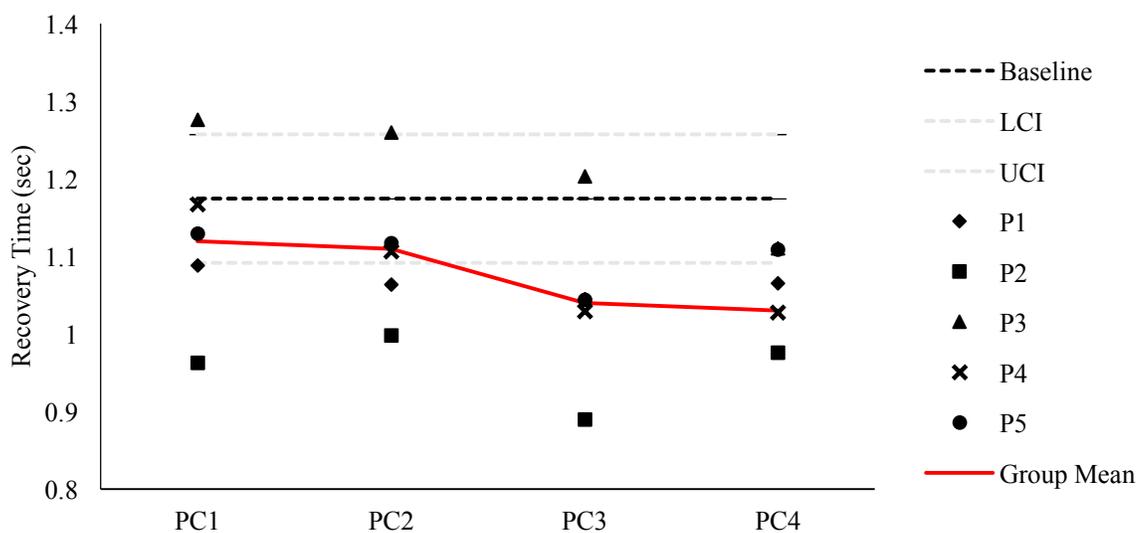


Figure 12. WBB dynamic tTarget from PC1 - PC4.

Note: P1 = Participant 1; P2 = Participant 2; P3 = Participant 3; P4 = Participant 4; P5 = Participant 5; LCI = Lower Confidence Interval; UCI = Upper Confidence Interval.

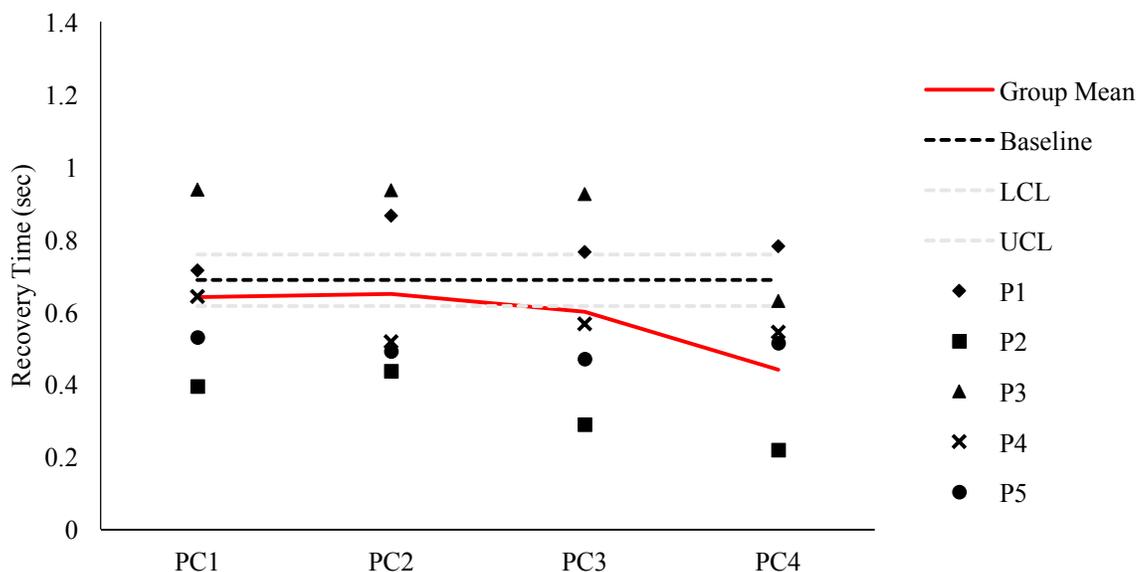


Figure 13. WBB dynamic t_{Center} from PC1 – PC4

Note: P1 = Participant 1; P2 = Participant 2; P3 = Participant 3; P4 = Participant 4; P5 = Participant 5; LCL = Lower Confidence Limit; UCL = Upper Confidence Limit.

2.4 Discussion

The purpose of this prospective study was to investigate potential utility of a customized WBB program to provide sensitive and objective measures of postural balance in an athletic population. Two main findings emerged through data analysis: 1) the WBB provides a more sensitive and objective measure of postural balance, when compared to the BESS; and 2) trends in some aspects of postural balance suggest that, in general, a negative effect of time on performance across a regular athletic season.

2.4.1 WBB tool provides more sensitive measure of postural balance than BESS

Our data suggests that the WBB tool provides more sensitive measurement of postural balance when compared to the BESS. Statistically significant differences in most WBB outcome measures indicated that variations in postural control occurred between study time points, however, analysis of BESS error scores did not reveal significant change over time. Taken together, this suggests that the WBB is capable of more precise

measure of postural balance than the BESS. Low BESS sensitivity scores are well described in the current body of literature, highlighting challenges associated with non-instrumented assessment tools that rely on subjective measures (Patricios et al., 2017).

The WBB has been shown to collect valid and reliable COP data when compared to a scientific grade force platform (Chang et al., 2014). COP has repeatedly been shown to be an appropriate representation of centre of mass to give insight into motor control and postural balance. Raw COP data derived from the WBB may be analyzed to describe variations in both medial-lateral and anterior-posterior directions. These data can be further assessed to quantify velocity of an individual's movements. This information is valuable to clinicians seeking objective evidence to inform diagnostic decisions and rehabilitation practices. Clinicians may interpret this information to provide more objective information postural control where increased COP path length may indicate impairment.

In contrast to the WBB's sensitive and objective COP outcome measures, the BESS assesses balance impairment by tallying subjective errors during a 20-second trial. While this produces a quantitative measure of balance impairment, the nature of impairment remains unspecified and BESS error scores provide clinicians with limited information about how balance is functionally impaired. Beyond the inherent limitations of the BESS error list, the tool itself suffers from low validity and interrater reliability scores. This represents a limitation of the BESS and negatively affects its clinical utility. Our results agree with these judgments.

The BESS benefits from an economical, efficient and easy administration that requires minimal equipment and no technology. This ease and economic efficiency,

however, comes at a cost in areas of sensitivity and specificity. While the BESS is certainly feasible for applications in athletic environments, a more valid and reliable tool incorporating objective, rather than subjective, outcome measures would give clinicians more useful information on which to base concussion diagnostic and RTP judgments.

Our data suggests that there is very little correlation between regular season BESS error scores and WBB metrics. In contrast, however, a study following similar design found that postural sway force plate data for 111 participants was correlated with five of the six BESS stances (BL L Riemann, Guskiewicz, & Shields, 1999). The fact that our results are not consistent with those in the literature may first be explained by our limited sample size. These results may also be explained by the different method by which each tool assesses balance and contrasting nature of outcome measures. While both tools purpose to quantify postural control, the BESS relies on subjective measure of this control through error scores while the WBB objectively measures variations in COP.

It is interesting to note that the single stance static balance condition saw most significant change over season. More demanding tasks are more sensitive to post-concussion deficits because of challenges associated with sensory integration. Manipulating stance and standing surface alters the amount of available somatosensory information, thus forcing the individual to reassess their reliance on visual, proprioception, and vestibular information through sensory integration. Less reliable somatosensory information is available when participants are standing on only one foot with their eyes closed. This presents a greater cognitive challenge, which is thought to be more difficult for individuals with concussion.

The majority of our post-concussion balance measures did not indicate statistically significant differences between *baseline* and PC1 time points. Nevertheless, post-concussion symptom severity remained elevated above baseline values until PC3, which corresponded to average RTP for the five individuals who sustained concussions. While symptom severity scores followed a steady downward trajectory from *PC1-PC4*, BESS error scores were inconsistent through the recovery period. Though not statistically significant, BESS total error scores varied through the post-concussion period where they were elevated slightly at *PC1*, dropped below baseline at *PC2*, spiked above baseline at PC3 and then matched baseline values at *PC4*. These results do not agree with the current body of literature where BESS total error scores are reported to return to baseline 3-5 days following injury (Guskiewicz, 2001; McCrea, Guskiewicz, Marshall, Barr, Randolph, Cantu, Onate, Kelly, & Page, 2003). Given that our data illustrates unstable recovery trends in postural balance lasting up to one month following injury, it may be wise to perform follow-up balance assessments even after the athlete has achieved clinical recovery according to BESS protocol.

Taken together, our data suggests that the WBB is more sensitive to change in postural balance control. The WBB's cost-effective nature makes this type of technology more accessible. Thus, this technology may be appropriate to integrate into sideline and clinical concussion assessments to inform diagnostic design making.

2.4.2 Negative influence of time on balance

Study participants demonstrated balance impairments over the course of their regular athletic season where some balance assessment measures worsened significantly from *baseline* to *post-season*. More specifically, participants experienced meaningful

negative change in both COP_{ML} and COP_T outcome measures in the single stance condition. Similar trends were observed in subjective symptom ratings and BESS outcome measures of balance, though these were non-significant. Taken together, results suggest that normal activities associated with athletic training and competition had a net negative effect on some aspects of balance and somatic symptoms and these differences are more apparent when using objective rather than subjective outcome measures.

Study participants were competitive athletes in good physical condition, thus we did not expect the static BESS stances to be very challenging for them. Training programs focusing on dynamic muscle control, proprioception, and visual-motor skills should have a positive effect on one's ability to maintain postural control without deviating outside their base of support. While we might expect increased fitness levels and focused training programs to have a positive effect on balance performance over the course of the regular athletic season, it is important to consider the negative impact other activities associated with regular sport participation may counter these benefits and result in a net negative change. It is worth noting, however, that our study participants had baseline BESS scores well outside norms suggested by Iverson and colleague's data summary (Iverson et al., 2016). This may be partly explained by the fact that this normative data set describes data from only 26 participants in the same age group as our study participants. Therefore, this normative data may not be truly representative.

Participant electromyography data did not reveal statistically significant difference in bilateral lower-limb muscle activity across regular study time points. EMG amplitude is a global measure of motor unit recruitment and firing rates within a muscle. Increased EMG amplitude between time points may suggest that positive gains in muscle

activation through the number of individual motor units being recruited and the firing frequency of these motor units. Our data highlights a slight (but non-significant) increase in EMG at mid-season. Increased physical training through the athletic season should encourage muscle and strength development which may increase efficiencies of neural pathways that control these. The influence of neuromuscular fatigue may, however, hinder muscle activity and mitigate some of these gains as athletic season progresses. Neuromuscular fatigue, then, may explain the relative decrease in EMG activity observed at post-season when compared to mid-season. Individuals may have been suffering from cumulative negative effects of fatigue at post-season, more so than at baseline and mid-season time points. This fatigue may translate to decreased performance. While this is one physiological explanation to decreased performance at post-season, psychological components may have also influenced study outcome measures. While not formally assessed through study design, motivation may have influenced study outcomes.

Looking more closely at WBB outcome measures, our data highlights increased COP path lengths in the medial-lateral direction following concussion. This is evidenced by 66% of individuals with concussion having COP_{ML} values above the upper bound of the interquartile range at the *PC4* appointment. This data provides some introduction to post-injury postural balance status compared to baseline values. These data are calculated based on group means, though, and should be interpreted with caution due to the individual nature of concussion injuries.

In contrast to overall negative trends observed in somatic symptoms, BESS error scores and static WBB balance outcome measures, performance on the WBB dynamic task improved significantly over the course of the athletic season. Surprisingly, t_{Target} ,

tCenter, and tTotal fell below baseline values even after concussion and improved steadily through the four-week post-concussion period. Previous research investigating post-concussion balance deficits has identified benefits of dual-task balance assessments (Catena, van Donkelaar, & Chou, 2011, 2007; D. R. Howell, Osternig, & Chou, 2013). Based on this, we expected individuals to have more difficulty with the dynamic rather than static WBB task following concussion. The opposite was true. One possible explanation for this disparity is that our WBB dynamic balance task may not have been sufficiently challenging for these individuals and, thus, a ceiling effect was present. Regular season data exhibited near-linear improvement in WBB dynamic task performance, suggesting that individuals did not reach a steady baseline plateau on these measures and were still learning the task. Given that this is the first time this particular program has been used outside of pilot study contexts, further investigation into the validity and reliability of this particular program is warranted, with attention paid to exposure effects. Apart from small sample size, improvements in the WBB dynamic task during the regular season and post-concussion periods may be related to task motivation.

Significant variations in some outcome measures across the regular athletic season suggest that baseline values collected during pre-season periods may not be valid throughout the entire athletic season. While consensus in this area suggests that baseline assessments are of value, medical professionals are encouraged to use clinical judgment to inform diagnosis instead of relying solely on baseline and post-injury scores from tools that have yet to be determined as “gold standard.” Somatic symptoms, balance performance, and cognitive function are not static variables resistant to change. The data presented above supports this notion and suggests that pre-season evaluation of these

outcomes may not accurately reflect an individual's ability in these areas as the season progresses.

2.4.9 Conclusion

Concussion is a common sport-related injury that often results in impaired motor control. This impairment may result in increased vulnerability to injury while also negatively impacting athletic performance. The most widely used concussion assessment tool (SCAT-3) includes a modified version of the clinical BESS to assess balance (mBESS). Unfortunately, the BESS and mBESS lack sensitivity to detect smaller changes in balance and rely solely on subjective outcome measures. Results of the current study suggest that a customized program using a WBB provides a more sensitive and objective assessment of balance performance across a regular athletic season and following concussion. Further, study results suggest balance may be negatively affected by regular activities associated with an athletic season. Future work should investigate the effect of time on balance performance through a regular athletic season to provide greater context for interpretation of post-injury assessments. While the current study benefits from a prospective design and serves to fill gaps in the literature regarding mid-season status, small sample size, potential for selection bias, and specific population demographics limits the generalizability of results presented above.

2.5 References

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Appendix A: Certificate of Research Ethics Approval



Office of Research Services | Human Research Ethics Board
 Administrative Services Building, Rm B202, PO Box 1700 STN CSC, Victoria BC, V8W 2Y2 Canada
 T 250-472-4545 | F 250-721-8960 | uvic.ca/research | ethics@uvic.ca

Certificate of Approval

PRINCIPAL INVESTIGATOR:	Hilary Cullen	ETHICS PROTOCOL NUMBER	15-193
Uvic STATUS:	Master's Student	<i>Minimal Risk Review - Board members</i>	
Uvic DEPARTMENT:	EPHE	ORIGINAL APPROVAL DATE:	28-Jul-15
SUPERVISOR:	Dr. Brian Christie; Dr. Paul Zehr	APPROVED ON:	28-Jul-15
		APPROVAL EXPIRY DATE:	27-Jul-16
PROJECT TITLE: Analysis of alternative assessment tools for post-concussion cognitive and balance deficits			
RESEARCH TEAM MEMBERS: Co-principal Investigator: Alison Rodway (Uvic) Research Assistants: Yao Sun (Uvic), Dr. Kristina Kowalski (Uvic and McGill University), Kim Osland (Uvic)			
DECLARED PROJECT FUNDING: Canada Foundation for Innovation (under Dr. Christie); OHR (under Dr. Christie); OHR Canada Masters Students Award (under H. Cullen – pending); Dr. Steve Martin CASEM – New Investigator Grant Application (pending)			
CONDITIONS OF APPROVAL			
This Certificate of Approval is valid for the above term provided there is no change in the protocol.			
Modifications To make any changes to the approved research procedures in your study, please submit a "Request for Modification" form. You must receive ethics approval before proceeding with your modified protocol.			
Renewals Your ethics approval must be current for the period during which you are recruiting participants or collecting data. To renew your protocol, please submit a "Request for Renewal" form before the expiry date on your certificate. You will be sent an emailed reminder prompting you to renew your protocol about six weeks before your expiry date.			
Project Closures When you have completed all data collection activities and will have no further contact with participants, please notify the Human Research Ethics Board by submitting a "Notice of Project Completion" form.			
Certification			
This certifies that the Uvic Human Research Ethics Board has examined this research protocol and concluded that, in all respects, the proposed research meets the appropriate standards of ethics as outlined by the University of Victoria Research Regulations Involving Human Participants.			
 Dr. Rachael Scarth Acting Associate Vice-President, Research			

Certificate Issued On: 04-Aug-15

15-193
 Cullen, Hilary

Appendix B: Demographics Questionnaire

Group		Participant Number	
DOB (mm/dd/yyyy)		Gender	
Date (mm/dd/yyyy)		Baseline or Post-Injury	

PARTICIPANT CONTACT INFORMATION			
First Name		Last Name	
Phone (home)		Phone (cell)	
Email			

EMERGENCY CONTACT INFORMATION			
First Name		Last Name	
Phone (home)		Phone (cell)	
Email			

GENERAL PARTICIPANT INFORMATION			
Height (ft)		Weight (lbs)	
Age		DOB (mm/dd/yyyy)	
Gender		Highest Education Level (1 st Grade, 1 st year, 2 nd year, etc.)	
What is your dominant hand?			
What is your dominant foot?			

MEDICAL INFORMATION			
Have you been diagnosed with ADHD?		Have you been diagnosed with dyslexia?	
Have you been diagnosed with ADD?		Are you colourblind?	
List any medications you are currently taking.			

SPORT	POSITION	TEAM	# OF YEARS

EXTRA-CURRICULAR ACTIVITY INFORMATION	
What instruments do you play?	
How long have you played these instruments?	
How many hours of video games do you play per week?	

Concussion History	
How many concussions have you had in your lifetime?	
How many of your concussions were diagnosed by a Health Care Professional?	
Date of most recent concussion (mm/dd/yyyy)	
Did you lose consciousness during your last concussion? If yes, for how long?	
Were you playing sport when you sustained your most recent concussion?	
How many days did it take you to recover after your most recent concussion?	

SPECIFIC CONCUSSION HISTORY				
Date of Concussion (yyyy/mm/dd)	Did you lose consciousness?	Were you playing sport?	Did you see a Doctor?	How long did it take to Return to Play?

PLEASE CHECK ALL THAT APPLY
<input type="checkbox"/> I have had a lower limb injury in the past six weeks (ex. ankle sprain).
<input type="checkbox"/> I have had more than six diagnosed concussions in my lifetime.
<input type="checkbox"/> I have had a diagnosed concussion in the past three months.

NOTES:

Appendix C: Godin Leisure-Time Exercise Questionnaire

1. During a typical **7-Day period** (a week), how many times on the average do you do the following kinds of exercise for **more than 15 minutes** during your free time (write on each line the appropriate number).

	Times Per Week
<p>a) STRENUOUS EXERCISE (HEART BEATS RAPIDLY) (e.g., running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling)</p>	_____
<p>b) MODERATE EXERCISE (NOT EXHAUSTING) (e.g., fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, popular and folk dancing)</p>	_____
<p>c) MILD EXERCISE (MINIMAL EFFORT) (e.g., yoga, archery, fishing from river bank, bowling, horseshoes, golf, snow-mobiling, easy walking)</p>	_____

2. During a typical **7-Day period** (a week), in your leisure time, how often do you engage in any regular activity **long enough to work up a sweat** (heart beats rapidly)?

OFTEN	SOMETIMES	NEVER/RARELY
1. <input type="checkbox"/>	2. <input type="checkbox"/>	3. <input type="checkbox"/>

Appendix D: Physical Activity Readiness Questionnaire

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
<input type="checkbox"/>	<input type="checkbox"/>	1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
<input type="checkbox"/>	<input type="checkbox"/>	2. Do you feel pain in your chest when you do physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	3. In the past month, have you had chest pain when you were not doing physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
<input type="checkbox"/>	<input type="checkbox"/>	5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
<input type="checkbox"/>	<input type="checkbox"/>	7. Do you know of <u>any other reason</u> why you should not do physical activity?

If
you
answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____

DATE _____

SIGNATURE OF PARENT
or GUARDIAN (for participants under the age of majority) _____

WITNESS _____

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.



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Appendix E: Waterloo Footedness Questionnaire

Instructions: Answer each of the following questions as best you can. If you *always* use one foot to perform the described activity, circle **Ra** or **La** (for **right always** or **left always**). If you **usually** use one foot circle **Ru** or **Lu**, as appropriate. If you use **both** feet **equally often**, circle **Eq**.

Please do not simply circle one answer for all questions, but imagine yourself performing each activity in turn, and then mark the appropriate answer. If necessary, stop and pantomime the activity.

1. Which foot would you use to kick a stationary ball at a target straight in front of you?	La	Lu	Eq	Ru	Ra
2. If you had to stand on one foot, which foot would it be?	La	Lu	Eq	Ru	Ra
3. Which foot would you use to smooth sand at the beach?	La	Lu	Eq	Ru	Ra
4. If you had to step up onto a chair, which foot would you place on the chair first?	La	Lu	Eq	Ru	Ra
5. Which foot would you use to stomp on a fast-moving bug?	La	Lu	Eq	Ru	Ra
6. If you were to balance on one foot on a railway track, which foot would you use?	La	Lu	Eq	Ru	Ra
7. If you wanted to pick up a marble with your toes, which foot would you use?	La	Lu	Eq	Ru	Ra
8. If you had to hop on one foot, which foot would you use?	La	Lu	Eq	Ru	Ra
9. Which foot would you use to help push a shovel into the ground?	La	Lu	Eq	Ru	Ra
10. During relaxed standing, people initially put most of their weight on one foot, leaving the other leg slightly bent. Which foot do you put most of your weight on first?	La	Lu	Eq	Ru	Ra
11. Is there any reason (i.e. injury) why you have changed your foot preference for any of the above activities?	YES	NO	(circle one)		
12. Have you ever been given special training or encouragement to use a particular foot for certain activities?	YES	NO	(circle one)		
13. If you have answered YES for either question 11 or 12, please explain:					

Appendix F: Activities-specific Balance Confidence Scale

The Activities-specific Balance Confidence (ABC) Scale
 For each of the following activities, please indicate your level of self-confidence by choosing a corresponding number from the following rating scale:

0% 10 20 30 40 50 60 70 80 90 100%
no confidence completely confident

“How confident are you that you will not lose your balance or become unsteady when you...

1. ...walk around the house? ____%
2. ...walk up or down stairs? ____%
3. ...bend over and pick up a slipper from the front of a closet floor ____%
4. ...reach for a small can off a shelf at eye level? ____%
5. ...stand on your tiptoes and reach for something above your head? ____%
6. ...stand on a chair and reach for something? ____%
7. ...sweep the floor? ____%
8. ...walk outside the house to a car parked in the driveway? ____%
9. ...get into or out of a car? ____%
- 10....walk across a parking lot to the mall? ____%
- 11....walk up or down a ramp? ____%
- 12....walk in a crowded mall where people rapidly walk past you? ____%
- 13....are bumped into by people as you walk through the mall? ____%
- 14.... step onto or off an escalator while you are holding onto a railing? ____%
- 15.... step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? ____%
- 16....walk outside on icy sidewalks? ____%

Appendix G: Sport Concussion Assessment Tool – 3rd Edition

Downloaded from <http://bjsm.bmj.com/> on June 16, 2016 - Published by group.bmj.com

SCAT3™

Sport Concussion Assessment Tool – 3rd Edition

For use by medical professionals only



Name

Date/Time of Injury:
Date of Assessment:

Examiner:

What is the SCAT3?¹

The SCAT3 is a standardized tool for evaluating injured athletes for concussion and can be used in athletes aged from 13 years and older. It supersedes the original SCAT and the SCAT2 published in 2005 and 2009, respectively². For younger persons, ages 12 and under, please use the Child SCAT3. The SCAT3 is designed for use by medical professionals. If you are not qualified, please use the Sport Concussion Recognition Tool³. Preseason baseline testing with the SCAT3 can be helpful for interpreting post-injury test scores.

Specific instructions for use of the SCAT3 are provided on page 3. If you are not familiar with the SCAT3, please read through these instructions carefully. This tool may be freely copied in its current form for distribution to individuals, teams, groups and organizations. Any revision or any reproduction in a digital form requires approval by the Concussion in Sport Group.

NOTE: The diagnosis of a concussion is a clinical judgment, ideally made by a medical professional. The SCAT3 should not be used solely to make, or exclude, the diagnosis of concussion in the absence of clinical judgement. An athlete may have a concussion even if their SCAT3 is "normal".

What is a concussion?

A concussion is a disturbance in brain function caused by a direct or indirect force to the head. It results in a variety of non-specific signs and/or symptoms (some examples listed below) and most often does not involve loss of consciousness. Concussion should be suspected in the presence of **any one or more** of the following:

- Symptoms (e.g., headache), or
- Physical signs (e.g., unsteadiness), or
- Impaired brain function (e.g. confusion) or
- Abnormal behaviour (e.g., change in personality).

SIDELINE ASSESSMENT

Indications for Emergency Management

NOTE: A hit to the head can sometimes be associated with a more serious brain injury. Any of the following warrants consideration of activating emergency procedures and urgent transportation to the nearest hospital:

- Glasgow Coma score less than 15
- Deteriorating mental status
- Potential spinal injury
- Progressive, worsening symptoms or new neurologic signs

Potential signs of concussion?

If any of the following signs are observed after a direct or indirect blow to the head, the athlete should stop participation, be evaluated by a medical professional and **should not be permitted to return to sport the same day** if a concussion is suspected.

- Any loss of consciousness? Y N
- "If so, how long?" _____
- Balance or motor incoordination (stumbles, slow/laboured movements, etc.)? Y N
- Disorientation or confusion (inability to respond appropriately to questions)? Y N
- Loss of memory: _____
- "If so, how long?" _____
- "Before or after the injury?" _____
- Blank or vacant look: Y N
- Visible facial injury in combination with any of the above: Y N

1 Glasgow coma scale (GCS)

Best eye response (E)

No eye opening	1
Eye opening in response to pain	2
Eye opening to speech	3
Eyes opening spontaneously	4

Best verbal response (V)

No verbal response	1
Incomprehensible sounds	2
Inappropriate words	3
Confused	4
Oriented	5

Best motor response (M)

No motor response	1
Extension to pain	2
Abnormal flexion to pain	3
Flexion/Withdrawal to pain	4
Localizes to pain	5
Obeys commands	6

Glasgow Coma score (E + V + M) _____ of 15

GCS should be recorded for all athletes in case of subsequent deterioration.

2 Maddocks Score³

"I am going to ask you a few questions, please listen carefully and give your best effort."

Modified Maddocks questions (1 point for each correct answer)

What venue are we at today?	0	1
Which half is it now?	0	1
Who scored last in this match?	0	1
What team did you play last week/game?	0	1
Did your team win the last game?	0	1
Maddocks score	_____ of 5	

Maddocks score is validated for sideline diagnosis of concussion only and is not used for serial testing.

Notes: Mechanism of Injury ("tell me what happened?"):

Any athlete with a suspected concussion should be REMOVED FROM PLAY, medically assessed, monitored for deterioration (i.e., should not be left alone) and should not drive a motor vehicle until cleared to do so by a medical professional. No athlete diagnosed with concussion should be returned to sports participation on the day of Injury.

Cognitive & Physical Evaluation

1 Symptom score (from page 1)
22 minus number of symptoms of 22

2 Physical signs score
Was there loss of consciousness or unresponsiveness? Y N
If yes, how long? _____ minutes
Was there a balance problem/unsteadiness? Y N
Physical signs score (1 point for each negative response) of 2

3 Glasgow coma scale (GCS)

Best eye response (E)

No eye opening _____	1
Eye opening in response to pain _____	2
Eye opening to speech _____	3
Eyes opening spontaneously _____	4

Best verbal response (V)

No verbal response _____	1
Incomprehensible sounds _____	2
Inappropriate words _____	3
Confused _____	4
Oriented _____	5

Best motor response (M)

No motor response _____	1
Extension to pain _____	2
Abnormal flexion to pain _____	3
Flexion/Withdrawal to pain _____	4
Localizes to pain _____	5
Obeys commands _____	6

Glasgow Coma score (E + V + M) of 15
GCS should be recorded for all athletes in case of subsequent deterioration.

4 Sideline Assessment – Maddocks Score
“I am going to ask you a few questions, please listen carefully and give your best effort.”

Modified Maddocks questions (1 point for each correct answer)

At what venue are we at today?	0	1
Which half is it now?	0	1
Who scored last in this match?	0	1
What team did you play last week / game?	0	1
Did your team win the last game?	0	1

Maddocks score of 5
Maddocks score is validated for sideline diagnosis of concussion only and is not included in SCAT 2 summary score for serial testing.

5 Cognitive assessment
Standardized Assessment of Concussion (SAC)

Orientation (1 point for each correct answer)

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1

Orientation score of 5

Immediate memory
“I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order.”

Trials 2 & 3:
“I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before.”

Complete all 3 trials regardless of score on trial 1 & 2. Read the words at a rate of one per second. Score 1 pt. for each correct response. Total score equals sum across all 3 trials. Do not inform the athlete that delayed recall will be tested.

List	Trial 1	Trial 2	Trial 3	Alternative word list					
elbow	0	1	0	1	0	1	candle	baby	finger
apple	0	1	0	1	0	1	paper	monkey	penny
carpet	0	1	0	1	0	1	sugar	perfume	blanket
saddle	0	1	0	1	0	1	sandwich	sunset	lemon
bubble	0	1	0	1	0	1	wagon	iron	insect
Total									

Immediate memory score of 15

Concentration
Digits Backward:
“I am going to read you a string of numbers and when I am done, you repeat them back to me backwards, in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.”
If correct, go to next string length. If incorrect, read trial 2. One point possible for each string length. Stop after incorrect on both trials. The digits should be read at the rate of one per second.

	Alternative digit lists
4-9-3	0 1 6-2-9 5-2-6 4-1-5
3-8-1-4	0 1 3-2-7-9 1-7-9-5 4-9-6-8
6-2-9-7-1	0 1 1-5-2-8-6 3-8-5-2-7 6-1-8-4-3
7-1-8-4-6-2	0 1 5-3-9-1-4-8 8-3-1-9-6-4 7-2-4-8-5-6

Months in Reverse Order:
“Now tell me the months of the year in reverse order. Start with the last month and go backward. So you’ll say December, November ... Go ahead”

1 pt. for entire sequence correct

Dec-Nov-Oct-Sept-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan 0 1

Concentration score of 5

¹ This tool has been developed by a group of international experts at the 3rd International Consensus meeting on Concussion in Sport held in Zurich, Switzerland in November 2008. The full details of the conference outcomes and the authors of the tool are published in British Journal of Sports Medicine, 2009, volume 43, supplement 1. The outcome paper will also be simultaneously co-published in the May 2009 issues of Clinical Journal of Sports Medicine, Physical Medicine & Rehabilitation, Journal of Athletic Training, Journal of Clinical Neuroscience, Journal of Science & Medicine in Sport, Neurosurgery, Scandinavian Journal of Science & Medicine in Sport and the Journal of Clinical Sports Medicine.

² McCrory P et al. Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. British Journal of Sports Medicine. 2005; 39: 196-204

³ McCrea M. Standardized mental status testing of acute concussion. Clinical Journal of Sports Medicine. 2001; 11: 176-181

⁴ McCrea M, Randolph C, Kelly J. Standardized Assessment of Concussion: Manual for administration, scoring and interpretation. Waukesha, Wisconsin, USA.

⁵ Maddocks, DL; Dicker, GD; Saling, MM. The assessment of orientation following concussion in athletes. Clin J Sport Med. 1995;5(1):32-3

⁶ Guskiewicz KM. Assessment of postural stability following sport-related concussion. Current Sports Medicine Reports. 2003; 2: 24-30

INSTRUCTIONS

Words in *italics* throughout the SCAT3 are the instructions given to the athlete by the tester.

Symptom Scale

"You should score yourself on the following symptoms, based on how you feel now."

To be completed by the athlete. In situations where the symptom scale is being completed after exercise, it should still be done in a resting state, at least 10 minutes post exercise.

For total number of symptoms, maximum possible is 22.

For Symptom severity score, add all scores in table, maximum possible is $22 \times 6 = 132$.

SAC⁴

Immediate Memory

"I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order."

Trials 2 & 3:

"I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before."

Complete all 3 trials regardless of score on trial 1 & 2. Read the words at a rate of one per second. **Score 1 pt. for each correct response.** Total score equals sum across all 3 trials. Do not inform the athlete that delayed recall will be tested.

Concentration

Digits backward

"I am going to read you a string of numbers and when I am done, you repeat them back to me backwards, in reverse order of how I read them to you. For example, if I say 7-1-3, you would say 3-1-7."

If correct, go to next string length. If incorrect, read trial 2. **One point possible for each string length.** Stop after incorrect on both trials. The digits should be read at the rate of one per second.

Months in reverse order

"Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November ... Go ahead!"

1 pt. for entire sequence correct

Delayed Recall

The delayed recall should be performed after completion of the Balance and Coordination Examination.

"Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order."

Score 1 pt. for each correct response

Balance Examination

Modified Balance Error Scoring System (BESS) testing⁵

This balance testing is based on a modified version of the Balance Error Scoring System (BESS). A stopwatch or watch with a second hand is required for this testing.

"I am now going to test your balance. Please take your shoes off, roll up your pant legs above ankle (if applicable), and remove any ankle taping (if applicable). This test will consist of three twenty-second tests with different stances."

(a) Double leg stance:

"The first stance is standing with your feet together with your hands on your hips and with your eyes closed. You should try to maintain stability in that position for 20 seconds. I will be counting the number of times you move out of this position. I will start timing when you are set and have closed your eyes."

(b) Single leg stance:

"If you were to kick a ball, which foot would you use? (This will be the dominant foot) Now stand on your non-dominant foot. The dominant leg should be held in approximately 30 degrees of hip flexion and 45 degrees of knee flexion. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

(c) Tandem stance:

"Now stand heel-to-toe with your non-dominant foot in back. Your weight should be evenly distributed across both feet. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

Balance testing – types of errors

1. Hands lifted off iliac crest
2. Opening eyes
3. Step, stumble, or fall
4. Moving hip into > 30 degrees abduction
5. Lifting forefoot or heel
6. Remaining out of test position > 5 sec

Each of the 20-second trials is scored by counting the errors, or deviations from the proper stance, accumulated by the athlete. The examiner will begin counting errors only after the individual has assumed the proper start position. **The modified BESS is calculated by adding one error point for each error during the three 20-second tests. The maximum total number of errors for any single condition is 10.** If a athlete commits multiple errors simultaneously, only one error is recorded but the athlete should quickly return to the testing position, and counting should resume once subject is set. Subjects that are unable to maintain the testing procedure for a minimum of **five seconds** at the start are assigned the highest possible score, ten, for that testing condition.

OPTION: For further assessment, the same 3 stances can be performed on a surface of medium density foam (e.g., approximately 50cm x 40cm x 6cm).

Tandem Gait⁶

Participants are instructed to stand with their feet together behind a starting line (the test is best done with footwear removed). Then, they walk in a forward direction as quickly and as accurately as possible along a 38mm wide (sports tape), 3 meter line with an alternate foot heel-to-toe gait ensuring that they approximate their heel and toe on each step. Once they cross the end of the 3m line, they turn 180 degrees and return to the starting point using the same gait. A total of 4 trials are done and the best time is retained. Athletes should complete the test in 14 seconds. Athletes fail the test if they step off the line, have a separation between their heel and toe, or if they touch or grab the examiner or an object. In this case, the time is not recorded and the trial repeated, if appropriate.

Coordination Examination

Upper limb coordination

Finger-to-nose (FTN) task:

"I am going to test your coordination now. Please sit comfortably on the chair with your eyes open and your arm (either right or left) outstretched (shoulder flexed to 90 degrees and elbow and fingers extended), pointing in front of you. When I give a start signal, I would like you to perform five successive finger to nose repetitions using your index finger to touch the tip of the nose, and then return to the starting position, as quickly and as accurately as possible."

Scoring: 5 correct repetitions in < 4 seconds = 1

Note for testers: Athletes fail the test if they do not touch their nose, do not fully extend their elbow or do not perform five repetitions. **Failure should be scored as 0.**

References & Footnotes

1. This tool has been developed by a group of international experts at the 4th International Consensus meeting on Concussion in Sport held in Zurich, Switzerland in November 2012. The full details of the conference outcomes and the authors of the tool are published in The BJSM Injury Prevention and Health Protection, 2013, Volume 47, Issue 5. The outcome paper will also be simultaneously co-published in other leading biomedical journals with the copyright held by the Concussion in Sport Group, to allow unrestricted distribution, providing no alterations are made.
2. McCrory P et al., Consensus Statement on Concussion in Sport – the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. British Journal of Sports Medicine 2009; 43: 176-89.
3. Maddocks, DJ; Dicker, GD; Saling, MM. The assessment of orientation following concussion in athletes. Clinical Journal of Sport Medicine. 1995; 5(1): 32-3.
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6. Schneiders, A.G., Sullivan, S.J., Gray, A., Hammond-Tooke, G. & McCrory, P. Normative values for 16-37 year old subjects for three clinical measures of motor performance used in the assessment of sports concussions. Journal of Science and Medicine in Sport. 2010; 13(2): 196-201.
7. Schneiders, A.G., Sullivan, S.J., Kwamstrom, J.K., Olsson, M., Yden, T. & Marshall, S.W. The effect of footwear and sports-surface on dynamic neurological screening in sport-related concussion. Journal of Science and Medicine in Sport. 2010; 13(4): 382-386

ATHLETE INFORMATION

Any athlete suspected of having a concussion should be removed from play, and then seek medical evaluation.

Signs to watch for

Problems could arise over the first 24–48 hours. The athlete should not be left alone and must go to a hospital at once if they:

- Have a headache that gets worse
- Are very drowsy or can't be awakened
- Can't recognize people or places
- Have repeated vomiting
- Behave unusually or seem confused; are very irritable
- Have seizures (arms and legs jerk uncontrollably)
- Have weak or numb arms or legs
- Are unsteady on their feet; have slurred speech

Remember, it is better to be safe.

Consult your doctor after a suspected concussion.

Return to play

Athletes should not be returned to play the same day of injury. When returning athletes to play, they should be **medically cleared and then follow a stepwise supervised program**, with stages of progression.

For example:

Rehabilitation stage	Functional exercise at each stage of rehabilitation	Objective of each stage
No activity	Physical and cognitive rest	Recovery
Light aerobic exercise	Walking, swimming or stationary cycling, keeping intensity 50% maximum predicted heart rate. No resistance training.	Increase heart rate
Sport-specific exercise	Skating drills in ice hockey, running drills in soccer. No head-impact activities.	Arm movement
Non-contact training drills	Progression to more complex training drills, eg passing drills in football and ice hockey. May start progressive resistance training.	Balance, coordination, and cognitive load
Full contact practice	Following medical clearance participate in normal training activities.	Restore confidence and assess functional skills by coaching staff
Return to play	Normal game play	

There should be at least 24 hours (or longer) for each stage and if symptoms recur the athlete should rest until they resolve once again and then resume the program at the previous asymptomatic stage. Resistance training should only be added in the later stages.

If the athlete is symptomatic for more than 10 days, then consultation by a medical practitioner who is expert in the management of concussion, is recommended.

Medical clearance should be given before return to play.

.....

CONCUSSION INJURY ADVICE

(To be given to the **person monitoring** the concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. Recovery time is variable across individuals and the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, dizziness, worsening headache, double vision or excessive drowsiness, please contact your doctor or the nearest hospital emergency department immediately.

Other important points:

- Rest (physically and mentally), including training or playing sports until symptoms resolve and you are medically cleared
- No alcohol
- No prescription or non-prescription drugs without medical supervision. Specifically:
 - No sleeping tablets
 - Do not use aspirin, anti-inflammatory medication or sedating pain killers
- Do not drive until medically cleared
- Do not train or play sport until medically cleared

Clinic phone number

Scoring Summary:

Test Domain	Score		
	Date: _____	Date: _____	Date: _____
Number of Symptoms of 22			
Symptom Severity Score of 132			
Orientation of 5			
Immediate Memory of 15			
Concentration of 5			
Delayed Recall of 5			
SAC Total			
BESS (total errors)			
Tandem Gait (seconds)			
Coordination of 1			

Notes:

Patient's name _____

Date/time of injury _____

Date/time of medical review _____

Treating physician _____

Contact details or stamp

Appendix H: Balance Error Scoring System

The Balance Error Scoring System (BESS)

Obtain Preseason Baseline Score; Compare with Post-Concussion Score³³⁻³⁴

The Balance Error Scoring System³³⁻³⁴ provides a portable, cost-effective and objective method of assessing static **postural stability**. The BESS can be used to assess the effects of mild head injury on static postural stability. Information obtained from this clinical balance tool can be used to assist clinicians in making return to play decisions following mild head injury. The BESS can be performed in nearly any environment and takes approximately 10 minutes to conduct.

The balance-testing regime consists three stances on two different surfaces. The three stances are **double leg stance**, **single leg stance** and **tandem stance**. The two different surfaces include both a **firm** (ground) and **foam** surface. **Athletes' stance should consist of the hands on the iliac crests, eyes closed and a consistent foot position depending on the stance.** Shoes should not be worn.

In the **double leg stance**, the feet are flat on the testing surface approximately pelvic width apart.

In the **single leg stance** position, the athlete is to stand on the non-dominant leg with the contralateral limb held in approximately 20° of hip flexion, 45° of knee flexion and neutral position in the frontal plane.

In the **tandem stance** testing position, one foot is placed in front of the other with heel of the anterior foot touching the toe of the posterior foot. The athlete's non-dominant leg is in the posterior position. Leg dominance should be determined by the athlete's kicking preference.

Administering the BESS: Establish baseline score prior to the start of the athletic season. After a concussive injury, re-assess the athlete and compare to baseline score. Only consider return to activity if scores are comparable to baseline score. Use with Standardized Symptom Scale Checklist.

Scoring the BESS: Each of the trials is **20 seconds**. Count the number of errors (deviations) from the proper stance. The examiner should begin counting errors only after the individual has assumed the proper testing position.



Double Leg Stance
Firm Surface



Single Leg Stance
Firm Surface



Tandem Stance
Firm Surface



Double Leg Stance
Foam Surface



Single Leg Stance
Foam Surface



Tandem Stance
Foam Surface

Errors:

- Moving the hands off the hips
- Opening the eyes
- Step, stumble or fall
- Abduction or flexion of the hip beyond 30°
- Lifting the forefoot or heel off of the testing surface
- Remaining out of the proper testing position for greater than 5 seconds

The maximum total number of errors for any single condition is 10.

If a subject commits multiple errors simultaneously, only one error is recorded.

B.E.S.S. SCORECARD

Count Number of Errors max of 10 each stance/surface	FIRM Surface	FOAM Surface
Double Leg Stance (feet together)		
Single Leg Stance (non-dominant foot)		
Tandem Stance (non-dominant foot in back)		
TOTAL SCORES: total each column		
B.E.S.S. TOTAL: (Firm+Foam total)		

Airex™ Foam Balance Pads available at www.power-systems.com or through most sporting goods stores.