CONCURRENT VALIDITY AND TEST RETEST RELIABILITY

OF THREE POSTURAL CONTROL ASSESSMENTS

by

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ABSTRACT

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Context: In the United States an estimated 1.6 to 3.8 million sports-related mild traumatic brain injuries occur annually (Broglio, 2008). The accurate and timely diagnosis of concussion using a comprehensive test battery that includes symptom inventories, postural control screening, a physical and neurological screen and a neurocognitive assessment have been recommended. Postural control assessments vary in type, and have a range of reported sensitivities. The Sensory Organization Test (SOT), the Balance Error Scoring System (BESS), and the Stability Evaluation Test (SET) are three measures of postural control. Objective: To determine the test-retest reliability and concurrent validity of three postural control assessments (the Sensory Organization Test [SOT], the Balance Error Scoring System [BESS], and the Stability Evaluation Test [SET]. Participants: Participants consisted of thirty-eight healthy college students (16 male and 22 female) 20 ± 1.6 years of age. Methods Participants were scheduled across four separate time points Day 1, Day 2, Day 45 and Day 50. During day 1 informed consent was obtained and a health history questionnaire was collected, subjects were also familiarized with each test. Approximately 24 hours following the initial appointment each subject returned and was administered the battery of three balance assessments across the remaining three time points. The battery consisted of the NeuroCOM Sensory Organization Test (SOT) the Balance Error Scoring System (BESS) and the Stability Evaluation Test (SET). Main Outcome Measurements: The SOT calculates five composite score: Composite Balance, Somatosensory Input, Vestibular Input, Visual Input and Visual Conflict. The BESS provides a composite error score. The SET provides a composite sway score in degrees per second. Participants were grouped randomly into four groups and given each test in a different order. Repeated Measures ANOVA's were run for each test composite score and condition between each testing period. Post-hoc paired t-tests were used to determine change between time periods. Intraclass correlations were calculated for each test to determine test-retest reliability by comparing scores across each time period. Concurrent Validity was determined by calculating Pearson's r-values for each composite score given by each test.

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CHAPTER 1
INTRODUCTION

1.1 Background

During the past three decades sport-related concussions have become an increasing concern of the sports medicine community. (Guskiewicz K. M., Balance Assessment in the Management of Sport-related Concussion, 2011) In the United States an estimated 1.6 to 3.8 million sports-related mild traumatic brain injuries occur annually (Broglio S. P., 2008). In pediatric age groups across the United States an estimated 136,000 concussions occur in high schools each academic year of play (Broglio, Macciocchi, & Ferrara, 2007). Rapid assessment and interventions are vital in accurately identifying and treating incidences of mild sports-related traumatic brain injury. Coaching staff and on-site certified athletic trainers trained in how to assess concussions are rapidly becoming commonplace, yet the incidence of undiagnosed concussions is estimated to be as high as 50% (Covassin, Elbin, & Nakayama, 2010). Rapid clinical assessment and accurate clinical diagnosis of concussion are key issues facing clinicians and coaches.

A concussion, by definition, is a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces to the head, neck or body. (Broglio, Sosnoff, Rosengren, & McShane,2009). Diagnosis involves a comprehensive battery of tests administered to measure neurocognitive function, postural stability, self-reported symptoms, and a physical/neurological examination (Broglio, Macciocchi, & Ferrara, 2007) (Guskiewicz, et., 2004) (Guskiewicz K. M., Balance Assessment in the Management of Sport-related (Concussion, 2011) (Mcrory P, 2013). When administered separately, the sensitivity for each of the aforementioned measures ranges from 79.2% to 43.5% (Broglio, Macciocchi, Stephen, & Ferrara, 2007). Combining neurocognitive testing, postural stability assessments and self-reported symptoms has been demonstrated to have greater sensitivity than individual components administered as a standalone evaluation with sensitivity increasing to 91.7% (Broglio, Macciocchi, Stephen, & Ferrara, 2007). Ideally any test battery being used should be conducted as a part of preseason evaluations to give clinicians a baseline to compare battery scores to in the event of injury (Broglio, Macciocchi, Stephen, & Ferrara, 2007). Advocates supporting clinical evaluation by licensed health care providers have also supported the multifaceted approach to concussion management (Mcrory P, 2013). While there is consensus regarding the use of test batteries to diagnose concussion post injury, studies showing the psychometric properties of each individual component are scarce in some cases and controversial in others. Psychometrically, any tool must be shown to be sensitive, reliable, and valid before becoming clinically relevant. (Schrout, P.E, 1979)

Postural stability has been identified as an objective measure when evaluating concussions up to 7 days post injury (Guskiewicz K. M., 2011) (Valovich Mcleod, Barr, Mcrea, & al., 2006). Postural stability can be measured during clinical evaluations using the Balance Error Scoring System (BESS) or by using force-plate technologies such as the Sensory Organization Test (SOT) performed on the NeuroCOM Smart Balance Master (NeuroCOM International Inc., Clackamas OR.) The BESS consists of three stances (single leg, dual and tandem stances) across two surfaces, stable and unstable. The surfaces typically used are floor (stable) and a medium density foam pad (unstable). Individuals are instructed to maintain position for 20 seconds as assessors count errors. The BESS has been shown in studies to have an intra-rater reliability range of .74 to .87 and an inter-rater reliability of .57 with improvements after serial administration. Test-retest reliability has been found to be .70 for total errors committed during test administration. (Valovich-Mcleod, et al., 2004) (Valovich-Mcleod, Barr, Mcrea, et al., 2006)

The Sensory Organization Test (SOT) consists of 18 trials across 6 conditions. The SOT's composite score has been shown to be moderately reliable with an intraclass correlation of .66. (Ross, et al., 2011) During the past decade portable computerized measures of postural stability have been introduced that are possibly more cost effective alternatives to the SOT system which retail for approximately $100,000, whereas the VSR system is listed at $15,000 and the BESS pad costs less than $70, on average. The VSR, which incorporates aspects of the BESS and SOT, offers an extremely mobile, cost efficient alternative to the SOT while providing objective information in the form of composite scores. The VSR Sport Sensory Evaluation Test (SET) is similar to the BESS in regard to the protocol consisting of six trials with each performed with eyes closed while maintaining varying stances. To date, no psychometric data exists supporting the SET as a reliable clinical measure.

1.1.1 Purpose

The purpose of the study was to evaluate the reliability of the SOT, VSR sport and BESS. Secondly, we sought to establish the concurrent validity of the VSR Sport and BESS compared to the SOT. While the SOT is widely accepted as the gold standard in evaluating and identifying postural control deficits, the BESS, and SET are two plausible alternative measures of postural assessment that could serve as cost and time effective alternatives to the SOT. (Broglio S. P., 2008)

1.2 Definition of Terms

1.2.1 Balance

The process of maintaining the center of gravity within the body's base of support.

1.2.2 Postural Control

Postural control describes the ability to maintain orientation and equilibrium in a gravitational setting. It involves processing information from somatosensory, vestibular, and visual inputs at the central nervous system to produce an appropriate response to maintain equilibrium. The vestibular system measures acceleration both linearly and angularly in relation to head movement. The somatosensory system provides proprioceptive inputs from joints, skin, and muscles. The visual inputs provide relative spatial location.

1.2.3 Postural Sway

Describes movement produced as the result of the interaction between forces acting on the body and the actions of the central nervous system to prevent loss of balance. During quiet standing postural sway is minimal in healthy subjects. However, in the presence of neurological deficits or dysfunctions postural sway characteristics are altered.

1.2.4 Computerized Dynamic Posturography (CDP)

Computerized Dynamic Posturography has gained popularity and acceptance as a measure of postural control. Most forms of CDP involve the use of dual platform force plates which are used to detect changes in center of gravity. The subjects' sensory systems (visual, vestibular, and proprioceptive) are isolated and evaluated to provide both a baseline as well as an indicator of functional performance. One such test is the Sensory Organization Test (SOT), which provides misleading sensory inputs and measures the individuals' ability to process misleading sensory information provided by the NeuroCOM and maintain balance by utilizing other sensory inputs.

1.2.5 Center of Gravity

Refers to the point of action for total gravitational force. In a standing individual the center of gravity is frequently located in the lower abdominal area of the trunk but it can be located internally or externally depending on action and position of the body. COG can also be defined as an imaginary point in space that encompasses measured forces and moments where the sum total of all the forces equal zero (Umphred, 2007).

1.2.6 Center Of Pressure

The point on any surface where the forces acting on it must be countered. This can be measured by using force plate technology to assess movement in anterior-posterior and medial-lateral directions. Center of Pressure is an indirect measure of sway and postural control. (Umphred, 2007)

1.2.7 Center of Mass

The point in an object where the sum of all torque is zero. (Umphred, 2007)

1.2.8 Objectivity

Objectivity or rater reliability is defined as the close agreement between scores assigned to each person by two or more judges. (Baumgartner et al 2007)

1.2.9 Reliability

A reliable measure is consistently unchanged over a short period of time. (Baumgartner et al 2007)

1.2.10 Stability / Test Retest Reliability

Is defined as a measures stability in scores across time (Baumgartner et al, 2006)

1.2.11 Validity

The degree to which interpretations of test scores or measures derived from a measuring instrument leads to correct conclusions. (Baumgartner et al, 2006)

1.2.12 Concurrent / Convergent Validity

In convergent validity we examine the degree of similarity between test batteries.

CHAPTER 2

LITERATURE REVIEW

2.1 Concussion Assessment

A concussion is defined as a complex pathophysiological process affecting the brain induced by traumatic biomechanical forces (Mcrory, et al., 2009). Concussion may occur as the result of a direct blow to the head or as an impulsive force transmitted from another impact point on the body. (Guskiewicz, et al., 2008) Concussions typically result in rapid onset of short-lived neurologic impairments to function that resolves spontaneously. (Guskiewicz, et al., 2004) Transient symptomology is associated with functional rather than structural disturbances. These disturbances can result in a wide variety of graded symptoms that may or may not include loss of consciousness. (Guskiewicz, et al., 2004) Symptoms typically resolve during a short period of time, 7 to 10 days) but may be prolonged (Guskiewicz K. M., e, 2001) (Guskiewicz et al 2003). Studies showing that athletes who receive three concussions are three times more likely to receive a subsequent injury in the same season. (Guskiewicz, et al., 2003)

In the pediatric population the accurate and timely diagnosis of concussion has become a prevalent topic in both public media and research. A multi-faceted approach has been suggested to diagnose and manage sport-related concussion (Guskiewicz, et al., 2004) (Harmon, et al.). This approach consists of self-reported symptoms, neurocognitive measures, postural stability and the physical/neurological examination. These tests are recommended to be administered by a clinician or trained technician in a clinical environment (i.e. quieted, isolated, and free from distractions). Neurocognitive assessments are used to identify deficiencies in certain parts of cognitive function such as long-term or short-term memory, reaction time, and impulse or reflex control (Echemendia, et al., 2013). These deficits are shown to resolve spontaneously within 7-10 days in adults and14 -21 days in young athletes following a concussion. (Covassin, Elbin, & Nakayama, 20 10) Neurocognitive testing may be performed using a computer-based format or by the use of a paper-and-pencil test.

Currently, serial assessment using computerized neurocognitive assessments such as ImPACT, obtaining a baseline to use as a control and then comparing post-injury scores to baselines, is a widely accepted protocol when looking for impairment post-concussion (Schatz & Sandel, 2012). While computerized neurocognitive testing is a common component of most concussion management paradigms, controversy regarding form equivalence, reliability, and validity still exists. (Broglio S. P., 2008). (Echemendia, et al., 2013)

The use of CDP to identify changes in postural control mechanisms post-concussion has been shown to be an effective tool as a part of a complete test battery. While there is consensus regarding the use of test batteries to baseline and diagnose concussions post injury, studies showing the psychometric properties of each individual component are scarce in some cases and controversial in others. Psychometrically, any tool must be shown to be objective, reliable and valid, in this order before becoming clinically relevant. The SOT and BESS each offer different indirect measures of balance. Both have been shown to be reliable and sensitive to changes in postural control and are therefore valid tools in the assessment of concussion. However, no data regarding the validity, reliability, or sensitivity of the VSR Sport Stability Evaluation Test has been published to date.

Reliability is the second psychometric consideration when evaluating which tools to use in the assessment of concussion. The Sensory Organization Test (SOT) possesses fair to good reliability with ICC of .67 for composite scores and a range of .35 to .93 for each of the six conditions. The Balance Error Scoring System (BESS) a second postural control assessment has been shown to have a fair to good test retest reliability as well with ICC reported at .70 for total errors counted. Neurocognitive assessments are used to identify deficiencies in certain parts of cognitive function such as long-term or short-term memory, reaction time, and impulse or reflex control. (Echemendia, et al., 2013) These deficits are shown to resolve spontaneously within 7-10 days in adults and14 -21 days in young athletes following a concussion. (Covassin, Elbin, & Nakayama, 20 10) Neurocognitive testing may be performed using a computer-based format or by the use of a paper-and-pencil test.

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The battery of tests suggested in the assessment of concussion vary but typically consists of an evaluation of neurocognitive function (ImPACT, ANAM, Cogstate), a self-reported symptom inventory, and a test of postural control (Sensory Organization Test (SOT), Balance Error Scoring System). When delivered as a battery, self-reported symptoms, a neurocognitive assessment, and a postural control assessment possess a sensitivity ranging from 89 to 90% when assessing concussed athletes. (Broglio, Macciocchi, & Ferrara, 2007) When delivered separately, HeadMinder CRI and ImPACT, two forms of computerized neurocognitive assessments were shown to be 78.6% sensitive and 79.2% sensitive to concussion when given within 24 hours of injury (Broglio, Macciocchi, & Ferrara, 2007). It is worth noting however that these ranges occurred only when individual component scores from each assessment were combined with each assessments symptom inventory. ImPACT's measures alone were only 62.5 % sensitive to concussion. Symptom inventories accounted for an additional 16.7%. The use of SOT as a postural control assessment alone proved to be 61.9 % sensitive. Self-reported symptoms scores alone proved to be 68 % sensitive to concussion (Broglio, Macciocchi, & Ferrara, 2007). Though this investigation focuses primarily on postural stability and its measurement, each component must be thoroughly addressed as components of a comprehensive concussion management protocol. Finally, a measurement requires validity. Validity describes the degree to which interpretations of test scores or measures derived from a measuring instrument lead to correct conclusions. In this study we determined convergent validity by examining the degree of similarity between test batteries on baseline.

2.2 Balance

Balance is a complex physiological process involving reception and integration of sensory inputs and the planning and execution of movement. The process is used to achieve a movement goal requiring an upright posture (Umphred, 2007). Balance is defined as the process of maintaining the center of gravity (COG) within the body's base of support in a given sensory environment (Guskiewicz K.M., 2011). COG is defined as an imaginary point in space that encompasses measured forces and moments where the sum total of all the forces equal zero (Umphred, 2007). For most individuals, COG is located parallel to the 2nd sacral vertebrae in non-vertically challenged individuals. (Umphred, 2007) As movement occurs, the COG in space changes to accommodate shifts in position and weight distribution and is affected by the individual's base of support. In a complex balance activity, the shape of base of support will alter the distance the center of gravity can move and can make the balance task easier or more challenging to maintain (Umphred, 2007).

To maintain balance the body assimilates visual, somatosensory (proprioceptive) and vestibular inputs and provides feedback to the cerebellum for postural control. (Guskiewicz K. M., 2011) Visual inputs provide a twofold influence on balance. Central vision allows for environmental orientation and providing dynamic information on the perception of verticality and object motion as it relates to self (Umphred, 2007). Peripheral vision detects motion of one's self in relation to the environment including head movements and postural sways (Umphred, 2007). Vision is critical for feed forward postural control in changing environments (Umphred, 2007). Light travels into the eye itself through the pupil, an opening whose size is controlled by the basal tone of the iris muscles. Once through the pupil light passes through the lens. The lens is composed and supported by two transparent fluids, the aqueous and vitreous humor. These fluids give the lens its shape and help fix the lens in place. The lens fits visual information into a meaningful manner to the eye. Once through the lens photoreceptors absorb light and translate this into neural messages. This occurs at the retina via rods and cones, two receptors responsible for translation. This information travels from the retina to the visual cortex via the optic nerves to the optic chiasm where information is then carried to the visual cortex for processing.

The vestibular system's role in balance and postural control is twofold as well. It senses movement and maintains vision. Vestibular input is sensed directly as angular and linear acceleration in the semicircular canals and otolithic organs, which is then sent to the cerebellum and evaluated as to whether or not action is necessary (Guskiewicz K. M., 2011). The semicircular canals sense rotational movements, and the otolithic organs sense linear acceleration. These inputs are sent in two separate pathways via the vestibular nuclei. Input travels to the vestibular ocular reflex where it is used to maintain a stable field of vision by utilizing a reflex reaction that adjusts eye movement in response to head movements. Information from the vestibular nuclei also travels directly to the cerebellum, the spinal cord, and the thalamus. These various pathways allow for reflex reactions at the spinal level, as well as complex adjustments and fine-tuning of gross motor movement. These inputs provide constant feedback relative to movement and posture.

Somatosensory input involves receptors sense changes in tension, joint angle, pressure, length and send this information to the cerebellum for integration. (Guskiewicz K. M., 2011) Somatosensory pathways lead to the brain and spinal cord from muscle fibers joint capsules throughout the body. Reflex mediated responses are generated by a spinal nerve in some cases while others are processed in higher levels of the brain such as the motor cortex or basal ganglia. Mechanoreceptors in ligaments can sense changes in joint angle, fiber length or pressure and can communicate this information to the somatosensory cortex. Muscle and tendon mechanoreceptors such as the Golgi tendon apparatus, the nuclear bag, and nuclear chain fibers all sense muscle and tendon stretch. This information transmits via the dorsal columnal medial lemniscal pathway and the ascending sensory pathways to the cerebellum for processing. Mechanoreceptors are widespread across the body. In the case of maintaining balance these receptors identify a change in fiber tension or length. If the change is drastic a reflex response may occur locally to preserve fiber integrity or at the spinal column to provide a gross motor reflex response, such as shifting the hip back in response to a fall (Umphred 2007).

Falling is the result of a loss of balance or having to establish a new base of support with either reaching or stepping. This creates a perimeter that can be defined as a limit of stability (Umphred, 2007). Limit of stability influences how far an individual can move away from the center of gravity without altering the original base of support by either reaching, stepping, or falling (Umphred, 2007).

The sensory systems act to maintain the center of gravity over the base of support during a complex movement task (Umphred, 2007). The body also assimilates information from the visual, somatosensory and vestibular inputs to drive postural control during static and dynamic balance activities (Guskiewicz, K.M., 2011). The sensory environment can be external conditions present within the environment that affect how balance is achieved or perceived an example would be sand (Umphred 2007). Peripheral sensory systems such as mechanoreceptors in the ligaments and muscle fibers throughout the body, gather information relating body position and motion in relation to the self (Umphred 2007). Centrally the brainstem integrates sensory information for the cerebellum to process. The cerebellum coordinates movement, regulates posture and the cerebral cortex contributes higher level memory based responses and fine-tuning. These structures process the peripheral input to determine body orientation, position, and motion and then generate motor output in response to changes that will effect movement and postural control (Umphred, 2007). Gravity must be overcome and represents a constant conditional input to the postural control mechanism. Visual and surface inputs can vary significantly and can potentially produce a stabilizing or destabilizing effect on balance (Umphred, 2007). The more stable the environment such as a concrete floor, or stationary force plate, the lower demands on the individual for balance control compared to an unstable environment such as sand, gravel, or a medium density foam pad, requiring greater demands on the postural control systems (Umphred, 2007).

The term sensory organization describes the assimilation and integration of information obtained from the vestibular, somatosensory and visual inputs to determine the appropriate corrective movement to maintain upright posture. (Guskiewicz K. M., 2011) Dysfunctions in sensory organization have been shown to cause balance deficiencies as measured by increases in postural sway (Guskiewicz K. M, 2001). Somatosensory input is the preferred sense for balance control in healthy adults. (Guskiewicz K. M., 2011) However, in the presence of neurologic dysfunction following concussion, inter-sensory conflict can result in dependency on inappropriate inputs such as misleading visual or vestibular inputs including sway referencing. (Shumway-Cook, 1986) (Guskiewicz K. M. 2004) Increases in postural sway as a result of postural instability are shown to be present up to 72 hours post-concussion (Guskiewicz, Perrin, & Gansneder, 1996) and many, if not most, clinicians recommend the use of clinical balance testing to assess and track recovery.

Current clinical balance testing methods are derived from early research into static and dynamic balance testing. Static balance tests require participants to maintain COG over a fixed base. (Broglio, Sosnoff, Rosengren, & McShane, 2009) Variations in stance or visual input can increase or decrease sensory input relative to the condition. The Romberg test is one such examination. The Romberg test was developed in 1840 by Moritz Heinrich Romberg, as a method to evaluate proprioception. (Lee, 1998) The test consists of two trials; the subject assumes a neutral upright posture and stands for one full minute with eyes open and eyes closed. A positive test was determined if postural stability was unable to be maintained in either condition. This test was useful in eliminating suspected causes for postural instability such as vision related disorders. Simple in design, the Romberg Test was widely adapted by researchers to evaluate various postural stability pathologies. (Lee, 1998) While using the Romberg broadly as a gross measure of postural dysfunction, research into developing a refined, more objective balance assessment followed and in 1999 the Balance Error Scoring System (BESS) was introduced.

Dynamic balance testing incorporates a base that has some degree of compliance or tilting mechanism to reduce somatosensory feedback accuracy. The BESS is one example of this type of test. The BESS consists of three different stances (double leg, single leg, tandem) across two surfaces, the first being fixed (i.e. floor) and the second being a 45cm2 x 13cm thick, 60 kg/m2 medium density foam pad. Dynamic balance testing can also incorporate force plate technology. The incorporation of force plate technology to assess postural stability is known as Computerized Dynamic Posturography (CDP). CDP allows for the objective measurement of postural sway, and can potentially isolate and measure function in each sensory input (vestibular, somatosensory, and visual) while also measuring a given subjects preference in input for each task.

2.3 Balance Error Scoring System

The BESS is a non-computerized form of dynamic posturography. The test utilizes a 45cm2 x 13cm thick, 60-kg/m2 medium density foam pad and a firm surface (e.g. the floor). The test incorporates three stances, (dual leg, single leg, and tandem) performed in sequence on the firm surface and then on the foam pad for a total of six trials. In all stances participants are asked to stand with their hands on their iliac crests, with their feet in the appropriate position. Each trial lasts 20 seconds and errors are counted and then combined to give a score. Errors include lifting hands off the iliac crest, opening of eyes, stepping, stumbling or falling, moving the hip into 30 degrees of flexion or abduction and or lifting the forefoot or heel. Remaining out of testing position for longer than five seconds constitutes an error as well. The test is then scored by combining total errors committed by the athlete in each single trial together for a total error score. If a subject commits multiple errors at once only one error is recorded. Ideally the BESS is administered as a baseline prior to the start of an athlete's season. After concussive injury athletes are then reassessed and scores are then compared between baseline and time of injury.

Inter-rater reliability for each individual condition of the BESS has been found to range from .50 (poor to moderate reliability) to .88 (good reliability). While many experts suggest a reliability score > 90 it should be noted that the BESS has an overall Interater reliability of .50 (low reliability) However serial administrations has been shown to drastically improve efficacy and improve scoring via a reduction in error scores. The BESS was validated by comparing scores obtained with those obtained by using the SOT.

2.4 The Sensory Organization Test (SOT)

A validated and acceptable form of CDP is the NeuroCOM Sensory Organization Test (SOT) which is assessed on the NeuroCOM Smart Balance Master (NeuroCOM International Inc., Clackamas, OR). The SOT consists of 18 trials, each lasting 20 seconds. The SOT also utilizes sway referencing. Sway referencing provides misleading visual or somatosensory information to the CNS. (NeuroCOM International Inc., 2001) The SOT tests six conditions with three trials performed for each condition. These conditions are 1) eyes open, 2) eyes closed, both with stable support. Condition three tests sway-referenced vision and stable support. Condition four tests eyes open and sway-referenced support. Condition five is eyes closed with sway-referenced support. Condition six uses sway-referenced vision and support. The SOT conditions are pictured in figure 1.This test uses visual and support sway-referencing in conjunction with eyes open and closed conditions to isolate and measure overall balance, the efficacy of each of the components (Visual, Vestibular, and Somatosensory), and interactions between them. (Broglio, Sosnoff, Rosengren, & McShane, 2009) (Guskiewicz K. M., Postural Stability Assessment Following Concussion: One piece of the Puzzle, 2001)

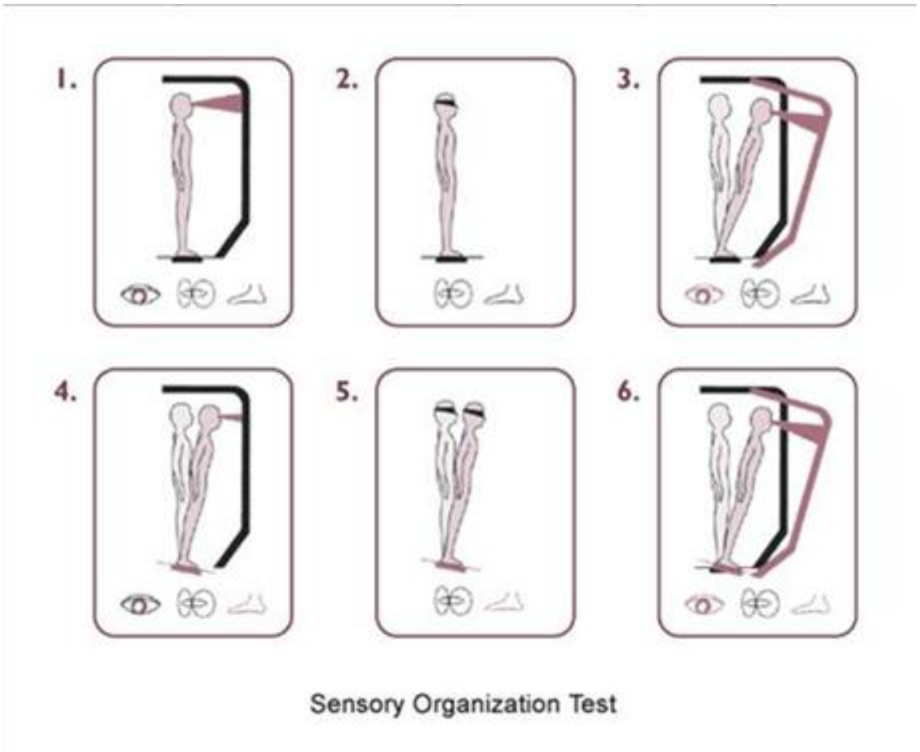

Figure 2.1. The six conditions of the Sensory Organization Test (NeuroCOM International Inc., 2001)

An equilibrium score for each trial completed is calculated by comparing the angular difference between the subjects calculated maximum anterior posterior center of gravity displacements to the theoretical maximum displacement. The result is displayed as an inverse percentage between 0 and 100

$$Equilibrium = \frac{12.5° - (\theta\, max - \theta \min\quad)}{12.5°} \times 100$$

Figure 2.2 Equilibrium Score Calculation

A composite score is generated by independently averaging equilibrium scores for conditions one and two, then adding these scores to the equilibrium scores from each trial of sensory conditions three, four, five, and six, then dividing the sum by total performed trials with each trial counting from conditions three, four, five, and six, plus two trials which account for all performed trials in conditions one and two. Ratios for each sensory component are calculated as follows. Vestibular ratio can be calculated by dividing the averages of condition five by the average equilibrium score for condition one. The visual ratio is calculated by again dividing the average for condition four over the average score on condition one. The somatosensory ratio is calculated by dividing the average score for condition two over the average for condition one. (Broglio, Sosnoff, Rosengren, & McShane, 2009) (Guskiewicz K. M., Postural Stability Assessment Following Concussion: One piece of the Puzzle, 2001) (NeuroCOM International Inc., 2001) As previously mentioned, postural stability is accepted as an indirect measure of balance. Increases in postural sway have been identified in concussed individuals suggesting the sensory organization test is sensitive to concussion when used within 72 hours of injury. In addition to testing acute balance disruptions in posture, the sensory organization test can be used to track recovery in subjects when compared with pre-obtained baseline data. (Guskiewicz K. M., Postural Stability Assessment Following Concussion: One piece of the Puzzle, 2001) (Broglio, Sosnoff, Rosengren, & McShane, 2009) (Broglio, Macciocchi, & Ferrara, 2007)

2.5 Stability Evaluation Test

The VSR Sport is another computerized dynamic posturography (CDP) testing platform. The Sensory Evaluation Test (SET) measures postural sway in subjects while they perform a series of three stances (double leg standing, single leg standing, and tandem) on two surface conditions, stable and unstable. Each trial lasts 20 seconds unless postural stability is overcome as the result of increased postural sway or an error is recorded such as eyes opening. As with the (SOT), somatosensory input is altered using a stable surface or the foam and subjects are instructed to keep eyes closed during all trials. The SET provides an average score for sway velocity measured in deg/sec.

The SET results are listed in graphical form upon completion of all six trials. The sway or unintentional movement is shown graphically, and length of time balance is maintained is represented numerically. Center of gravity traces are then shown for each condition and show the subjects trace patterns as well as normative values for sway excursion as shown by a red circle. Results are compared to the subject baseline data upon post injury evaluation. Scores are compared against normative data ranges or against baselines if they were previously collected. Currently no evidence of reliability or validity exists for the SET, as both the SOT and BESS are reliable, validated measures of balance concurrent validity can be examined by comparing the scores of the SET against the scores calculated by the BESS and the SOT.

CHAPTER 3

METHODS

3.1 Design

This study used a repeated-measures design. Participants completed four separate appointments arranged across a 50-day period.

3.2 Subjects

Our Sample size was N=38 (26 Females 12 Males) aged 20±1.62. All subjects were healthy and had no history of concussion within 6 months of evaluation. Participants were separated into 4 groups at random. Participants were recruited from undergraduate Kinesiology classes at the University of Texas at Arlington.

3.3 Experimental Protocol

Participants were scheduled across four separate time points Day 1, Day 2 (Baseline), Day 45 and Day 50. On Day 1 informed consent was obtained and subjects were screened for any exclusion criteria. Participants in this study could not have sustained a concussion for at least 6 months prior to participation in this study. Participants also had to be free from any vestibular or neurological disease pathologies that would otherwise compromise balance. Individuals who presented with any illness were rescheduled for a time after recovery. Subjects were asked to complete a health history and demographic questionnaire and were then oriented to each test. The orders of the tests were counterbalanced.

Orientation to each test consisted of reading each participant a scripted introduction to each test. For the Sensory Organization Test, Balance Error Scoring System and SET, each condition was then demonstrated. For the SOT, each participant was given one trial of each condition to familiarize him or herself. For the BESS, and SET each subject was given a trial run of each condition on the firm then foam surface. Upon completion of familiarization each subject was then asked to schedule an appointment for the next day. Total time for each session lasted approximately 40 minutes.

24-hours following familiarization each subject returned for baseline and again filled out the health history questionnaire and demographics sheet. Subjects were then given each balance assessment. Subjects returned approximately 45 days later to complete health questionnaires and retake all balance tests in the same order as previously administered. Finally, each participant returned for day 50 and completed all forms again and retook all tests in the appropriate order. The Institutional Review Board at the University of Texas at Arlington approved all procedures and all participants provided written informed consent.

3.4 Measures

3.4.1. Sensory Organization Test

This study utilized the Sensory Organization Test on the NeuroCOM International Smart Balance System (Clackamas, OR). The SOT tests the subject's ability to process inputs from the somatosensory, visual, and vestibular systems. The SOT consists of 18 trials each lasting 20 seconds in duration. These trials utilize six separate sensory conditions, eyes open with fixed support surface (Condition 1), eyes closed with fixed support surface (Condition 2), sway-referenced visual input with fixed support surface (Condition 3), normal vision with sway-referenced support surface (Condition 4), eyes closed and sway-referenced support surface (Condition 5), and sway-referenced vision and sway-referenced support surface (Condition 6). Sway-referenced conditions provide sensory inputs to the brain that are inconsistent with sensory input collected by other senses, forcing the subject to ignore the inaccurate input and rely on the accurate inputs from other senses to maintain postural control.

Subjects were instructed to remove shoes, as well as to empty their pockets to avoid any unnecessary distraction. Subjects were then instructed to stand with feet approximately shoulder width apart and arms rested comfortably at their side. Center of force is recorded by the machine relative to starting position. Each trial calculates equilibrium by measuring the distance traveled in the anterior-posterior directions. The greatest distanced traveled was compared to the theoretical limits of stability to create an equilibrium score for each trial. See Figure 1.

A mean stability score is calculated and ranges from 0 to 100, with 100 representing no movement from neutral, and a score of zero indicating a fall. This score is generated by independently averaging equilibrium scores for conditions 1 and 2, then adding these scores to the equilibrium scores from each trial of sensory conditions 3, 4, 5 and 6, then dividing the sum by total performed trials plus two trials which account for all performed trials in conditions one and two.

Composite Score = (AVG (SOT1)+AVG (SOT2) +Trial 1(SOT3) +Trial 2(SOT3) + Trial 3 + (SOT3) + Trial 1(SOT4) +Trial 2 (SOT4)+ Trial 3(SOT4) + Trial 1(SOT6) + Trial 2(SOT6) + Trial 3(SOT6))÷ (3 Trials (SOT3) + 3 Trials (SOT4) +3 Trials (SOT5) +3 Trials (SOT 6)+ 2 Trials (SOT1 and SOT2)

Figure 3.1: Composite

The SOT calculates deficits in integration by calculating scores for the somatosensory, visual, and vestibular inputs. The somatosensory score is calculated by dividing the average scores for condition 2 by the average scores for condition 1. The vestibular score can be calculated by dividing the average scores for condition 5 by the average scores for condition 1. The visual score can be calculated by dividing the average for condition 4 over the average score of condition 1. Adding conditions 3 and 6 and dividing by the sum of condition 2 and condition 5 calculate the Visual Preference score.

3.4.2. Stability Evaluation Test

This study also utilizes the Stability Evaluation Test (SET) on the VSR Sport Balance NeuroCOM International (Clackamas, OR). This tool measures postural sway in subjects while they perform a series of three stances (double leg standing, single leg standing, and tandem with non-dominant behind dominant) on two surface conditions, stable and unstable. The stable surface in this test is a force plate. The unstable surface is a 45cm2 x 13cm thick, 60 kg/m2 medium density foam pad. Subjects are asked to identify their nondominant leg by answering which leg they used to kick a ball with. This is considered the dominant leg. For testing, the non-dominant leg is used during the single leg condition as well as tandem. Each trial lasts 20 seconds or until a fall is recorded as the result of increased postural sway or an error is recorded such as eyes opening. Trial one places the subject on the force plate with feet together, eyes closed, and hands resting on the iliac crest. Trial two places subjects in a single leg stance on the force plate using only the nondominant leg, eyes closed and hands resting on the iliac crest. Trial three places the subject in the tandem stance with eyes closed on the force plate. Tandem stance requires the subject to place the nondominant foot behind the dominant foot toe to heel. The remaining three trials are performed on the medium density foam pad. Trial four has subjects stand feet together, eyes closed, and hands resting on the iliac crest. Trial five asks subjects to balance on the nondominant leg with eyes closed and hands resting on the iliac crest. Trial six places the subject in the tandem stance, with eyes closed, and hands resting on the iliac crest. The SET provides a graphical representation of the collected data as well as a composite score. The composite score is calculated by averaging individual condition scores together. Scores with lower values are interpreted as more stable than those higher than normative ranges for age and height.

3.4.3. Balance Error Scoring System

The final measure employed in this study is the Balance Error Scoring System (BESS). The BESS is performed using a 45cm2 x 13cm thick, 60 kg/m2 medium density foam pad and the floor. The test consists of six trials using three stances on two surfaces. The stances are feet together, single leg on non-dominant leg, and tandem with non-dominant behind dominant leg. Each trial lasts

20 seconds. Trial one places the subject on the floor with feet together, eyes closed, and hands resting on the iliac crest. Trial two places subjects in a single leg stance on the floor using only the nondominant leg, eyes closed and hands resting on the iliac crest. Trial three places the subject in the tandem stance with eyes closed on the floor. Tandem stance requires the subject to place the nondominant foot behind the dominant foot toe to heel. Subjects then stand on the medium density foam. The remaining three trials are performed on this medium density foam pad. Trial four has subjects stand feet together, eyes closed, and hands resting on the iliac crest. Trial five asks subjects to balance on the nondominant leg with eyes closed and hands resting on the iliac crest. Trial six places the subject in the tandem stance with eyes closed and hands resting on the iliac crest.

Errors are recorded for each section of the test. Errors are as follows: if the subject lifts a hand off their iliac crest, opens their eyes, takes a step, stumbles, hip flexion or abduction greater than 30 degrees, or remains out of testing position for more than five seconds, or if the subject lifts either the forefoot or heel. Each of the 20-second trials is scored by counting individual errors, with a maximum of 10 assigned for each condition. Scores are then totaled with a higher score indicating poor performance.

3.5 Statistical Analysis

All data was analyzed using IBM SPSS Statistics Version 19. Descriptive analyses were performed for all measures including demographics. Repeated measures analysis of variance (ANOVA) was used to determine significant differences across time for all balance test composite and individual condition scores. For violations of sphericity Greenhouse-Geisser corrections were employed. Post Hoc analysis was performed using paired t-tests.

To determine reliability, intraclass correlation coefficients (2,1) were calculated between each time point for each balance composite score. Inter-Rater reliability was calculated using Pearson correlation coefficients.

To determine concurrent validity Pearson correlation coefficients were calculated between measures at baseline. All analysis were performed with $\alpha \leq .05$.

CHAPTER 4

RESULTS

Preliminary analysis revealed no differences between groups, on age, height or across all composite scores. Our sample size was N=38 (22 Females 12 Males) aged 20±1.62. Repeated Measures ANOVA revealed significant differences on several scores across time, significant change occurred between baseline and day 45 SOT composite score (F(2,74)=8.552,p<.001,partial □2=.188) (t(37)=-2.186, p=.035), and baseline and day 50 (t(37)=-4.307, p<.001). See Table 4.1 for all SOT means and standard deviations. Significant differences were found between time points for SOT Somatosensory scores (F(2,74)=4.972,p=.015,partial □2=.118) post hoc t-tests revealed significant differences between baseline and day 50 (t(37)=-2.831, p=.007) as well as day 45 to day 50 (t(37)=2.657, p=.012). Significant differences were found for the SOT Vestibular Input score (F(2,74)=5.82, p=.005,partial □2=.136) post hoc paired t-tests revealed significant change between baseline and day 45 (t(37)=-2.195, p=.035) as well as baseline to day 50 (t(37)=-3.320, p=.002). Preliminary analyses also revealed differences in the BESS composite (F(2,74)=2.969,p=. 057,partial □2=.082) between baseline and day 50 (t(37)= 2.472, p=.018). See Table 4.2 for all BESS means and standard deviations. Analysis showed a significant change on condition 2 (F(2,74)=3.314,p=.042,partial □2=.082) between baseline and say 45 (t(37)= 2.472, p=.018), as well as between baseline and day 50 (t(37)=2.488, p=.017). Finally significant changes were found between baseline and day 45 for tandem firm condition F(2,74)=3.820p=.026,partial □2=.094) t(37)=2.144, p=.039), and between baseline and day 50 (t(37)= 2.078, p=.045) (Table 4.2)

Table 4.1: Sensory Organization Test Means and Standard Deviations by Time

Sensory Organization Test Scores *Means and (SD)* (*N =38*)					
	Composite Score	Somatosensory Input	Visual Input	Vestibular Input	Visual Conflict
Baseline	78.89	99.58	88.95	73.68	95.58
	(6.92)	(3.55)	(8.04)	(10.00)	(11.15)
Day 45	81†	98.87	89.42	77.32†	96.42
	(5.76)	(2.34)	(10.51)	(8.49)	(8.92)
Day 50	82.68†	97.71†‡	90.71	79.11†	97.21
	(6.25)	(6.25)	(7.34)	(9.99)	(7.01)

†= Significantly different from baseline values ($p \leq .05$) ‡=Significantly different from day 45 values ($p \leq .05$)

Table 4.2: Balance Error Scoring System Means and Standard Deviations By Time

Balance Error Scoring System *Means and (SD)* (N =*38*)							
	Composite Score	Cond 1	Cond 2	Cond 3	Cond 4	Cond 5	Cond 6
Baseline	12.76	0.00	2.29	1.11	0.08	5.55	3.82
	(7.23)	(0.00)	(1.99)	(1.93)	(0.36)	(2.71)	(2.64)
Day 45	10.97†	0.00	1.55†	0.55†	0.21	5.68	3.03
	(5.10)	(0.00)	(1.50)	(1.01)	(1.02)	(2.99)	(2.37)
Day 50	10.66†	0.00	1.55†	0.55†	0	4.71	3.61
	(6.95)	(0.00)	(2.14)	(1.01)	0	(2.64)	(3.17)

†= Significantly different from baseline values ($p \leq .05$)

Table 4.3: Sensory Organization Test Means and Standard Deviations by Time

Sensory Organization Test Scores *Means and (SD)* (*N =38*)					
	Composite Score	Somatosensory Input	Visual Input	Vestibular Input	Visual Conflict
Baseline	78.89	99.58	88.95	73.68	95.58
	(6.92)	(3.55)	(8.04)	(10.00)	(11.15)
Day 45	81†	98.87	89.42	77.32†	96.42
	(5.76)	(2.34)	(10.51)	(8.49)	(8.92)
Day 50	82.68†	97.71†‡	90.71	79.11†	97.21
	(6.25)	(6.25)	(7.34)	(9.99)	(7.01)

†= Significantly different from baseline values ($p \leq .05$) ‡=Significantly different from day 45 values ($p \leq .05$)

Prior to collecting test-retest reliability evidence, inter-rater reliability was determined to range from .94-.98 during BESS administration. To determine test retest reliability intraclass correlation coefficients (ICC) were calculated for each test across each time point. This study found the SET to have moderate reliability from baseline to day 45 and baseline to day 50. The SET showed strong reliability from day 45 to day 50. See table 4.4 for ICC SET Values. The BESS composite scores were moderately reliable from baseline to day 45 and day 45 to day 50, and showed strong reliability baseline to day 50. See Table 4.5 for BESS ICC values. The SOT composite scores showed moderate reliability from baseline to day 45 as well as from day 45 to day 50 with baseline to day 50 showing strong reliability. See Table 4.6 for ICC values.

Table 4.4: SET Test Retest Reliability

SET Test Re-Test Reliability (*N=38*)							
	SET Composite	Cond 1	Cond 2	Cond 3	Cond 4	Cond 5	Cond 6
Baseline-Day 45	0.74‡	0.33	0.54‡	0.35	0.66	0.34	0.58‡
Baseline-Day 50	0.73‡	0.01	0.17	0.56‡	-0.23	0.30	0.45‡
Day 45-Day 50	0.82†	0.65‡	0.43	0.29	0.42	0.54‡	0.62‡

†=ICC values show excellent reliability (ICC>0.75) ‡=Showed fair to moderate reliability (ICC >.45 but < 0.75)

Table 4.5: BESS Test Retest Reliability

Balance Error Scoring System Test Re-Test Reliability (N=*38*)							
	Composite	Cond 1	Cond 2	Cond 3	Cond 4	Cond 5	Cond 6
Baseline-Day 45	0.74‡	0	0.56‡	0.64‡	0.12	0.59‡	0.42
Baseline-Day 50	0.84†	0	0.76†	0.60‡	0	0.46‡	0.51‡
Day 45-Day 50	0.65‡	0	0.36	0.73‡	0	0.15	0.56‡

†=ICC values show excellent reliability (ICC>0.75) ‡=Showed fair to moderate reliability (ICC >.45 but < 0.75)

Table 4.6: SOT Test Retest Reliability

Sensory Organization Test Re-Test Reliability (N=38)					
	Composite	Somatosensory	Visual	Vestibular	Visual Conflict
Baseline-Day 45	0.72‡	0.11	0.62‡	0.57‡	0.57‡
Baseline-Day 50	0.80†	0.02	0.51‡	0.66‡	0.63‡
Day 45-Day 50	0.72‡	0.4	0.47‡	0.62‡	0.61‡

†=ICC values show excellent reliability (ICC>0.75) ‡=Showed fair to moderate reliability (ICC >.45 but < 0.75)

Pearson r correlation coefficients revealed a significant correlation between the SET and BESS (r=. 70) composite scores. No other significant correlations were observed.

Table4. 7: Correlations Between Composite Scores

Correlations Between Composite Scores (*N=37*)			
	SOT	BESS	SET
SOT	1	-0.04	-0.285
BESS	-	1	.700**
SET	-	-	1

†= Correlation is significant at the 0.01 level (2-tailed).

Table4. 7: Correlations Between Composite Scores

CHAPTER 5

DISCUSSION

The timely and accurate assessment of postural control has become an important concern in the management and diagnosis of concussion. Acutely, postural control deficits are shown up to 7 days post injury. Collecting baseline postural control scores prior to season has been advocated by both national and international medical communities (Harmon et al. 2013) (Guskiewicz et al 2013). To date the BESS and SOT accepted as reliable and valid measures of balance. Currently, the SOT is the gold standard in measuring postural control. (Guskiewicz, K.M 2011) (Broglio et al. 2007) The purpose of our study was to determine the test retest reliability of the SOT, SET, and VSR Sport using clinically relevant time points. We also sought to provide concurrent validity evidence for the SET by comparing it to scores obtained from both the BESS, and SOT.

To determine test retest reliability we compared each test's composite and individual component scores across three clinically relevant time points. We found each systems composite score to have fair to excellent reliability. The SET ICC values had the strongest reliability scores ranging from .73 to .82. The SOT's composite was found to have strong reliability with ICC's ranging from .72 to .80. The BESS composite score was found to have moderate to strong reliability with ICC values ranging from .65 to .84. These results are consistent with previously reported findings. (Wrisley et al. 2007) (Tsang et al. 2004) (Valovich- McLeod). While our findings show each test composite score having fair to excellent reliability, many individual component scores within each assessment often did not. The SOT components ICC scores ranged from .02 to .66, somatosensory input composites having the weakest reliability ICC values ranging of .02 to .4. The BESS condition scores ranged from .15 (Condition 5) to .76 (Condition 2) The SET conditions possessed weak to moderate reliability (.01 (condition 1) to .66 (Condition 4). Overall, each measure possessed adequate reliability. To determine concurrent validity we compared scores obtained from all three platforms on baseline. We observed weak correlations between SOT composite scores and those collected from both the BESS and SET. We did show a significant correlation between scores obtained by the SET and the BESS. This suggests that both tests may measure the same constructs of balance, while the SOT measures another.

Additionally, we found significant changes in scores in both the SOT and BESS between collection points. Composite scores obtained from the SOT increased significantly between the first and second administration, with no significant change between second and third administrations. Composite error scores obtained from the BESS show significant decreases in total errors made between baseline and retest. Interestingly, only two conditions showed significant change in scores between baseline, single leg and tandem on firm surface. In all three tests no significant changes in composite scores, and higher correlations were found between day 45 and day 50. This finding is potentially significant in the clinical applications for these tests. Our findings suggest that two administrations of each test to baseline may provide a better measure of true ability. These findings support those by Hinton-Bayre et al. suggesting two baseline sessions within a 1-2 week period interval. (Hinton-Bayre et al. 1999) Further studies identifying an ideal baseline test retest protocol are merited.

While the Sensory Organization Test is the current standard in postural assessment of concussion, budget and staffing constraints facing clinicians and administrators could render this test impractical for programs with smaller budgets. Accessibility and ease of administration are also key concerns in the selection process for individual concussion management. Ideally clinicians such as athletic trainers, or other trained technicians should administer all of these tests.

The NeuroCOM Smart Balance Master offers technicians and clinicians a 2-day clinical integration seminar to familiarize and train each clinician on administering and interpreting results in addition to a user manual with further guidance. (NeuroCOM 2001) The VSR Sport and BESS can be taught using an online format utilizing video based examples and manuals for each system. (NeuroCOM 2011) While cost of transportation and training may vary for the SOT, the use of an internet-based training platform further highlights the accessible nature of both the BESS and SET platforms. The average time to administer the SOT is approximately 20 minutes for each complete evaluation. While single test administration time may not preclude using this tool for smaller groups, considerations for groups with larger populations (High-School and Collegiate sports programs) must be made. Alternatively the BESS and SET take approximately 5 minutes to introduce and administer. Both the BESS and SOT are also considerably more budget friendly, portable and both reduce testing time exponentially making either more efficient in larger samples

In sum, in addition to supporting previous research regarding the reliability of both the SOT and BESS, this study finds that the SET is also a reliable measure of balance. This study also found strong evidence showing the SET to be a valid measurement of balance.

CHAPTER 6

6.1 Manuscript 1

Title: Test Re-Test Reliability of the SOT, BESS and SET

Running Title:

Authors: William Shane Warren, Jake E. Resch

Corresponding Author

Work Performed at the University of Texas at Arlington

Key Words Postural Control, Balance, BESS, SOT, VSR SPORT, SET Computerized Dynamic Posturography.

Financial Support:

6.1.1 Abstract

Test Re-Test Reliability of Three forms of Postural Control

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Context: In the United States an estimated 1.6 to 3.8 million sports related mild traumatic brain injuries occur annually (Broglio, 2008). The accurate and timely diagnosis of concussion using a comprehensive test battery that includes symptom inventories, postural control screening, a physical and neurological screen and a neurocognitive assessment has been recommended. Postural control assessments vary in type, and have a range of reported sensitivities. The Sensory Organization Test (SOT), the Balance Error Scoring System (BESS), and the Stability Evaluation Test (SET). Objective: To determine the test-retest reliability of three postural control assessments. The SOT, BESS and SET. Design: Repeated Measures Setting: Research Laboratory Patients or other Participants: Participants consisted of N=38 (22 Females 12 Males) aged 20±1.62 years Interventions: Participants were scheduled across 4 separate time points. Familiarization, Baseline, Day 45 and Day 50. Subjects completed all tests during each appointment following familiarization Main Outcome Measurements: The Sensory Organization Test calculates five composite score: Composite Balance, Somatosensory Input, Vestibular Input, Visual Input and Visual Conflict. The Balance Error Scoring System provides a composite error score. The Stability Evaluation Test provides a composite sway score in degrees per second. Participants were grouped at random and received each test during each assessment period in the order dictated by group assignment. Intraclass correlations were calculated for each test comparing scores across each time period. Results: Preliminary analysis revealed no differences between groups, on age, height or across all composite scores. Repeated Measures ANOVA revealed significant differences on several scores

across time, Significant change occurred between baseline and day 45 SOT composite score (F(2,74)=8.552,p<.001,partial □2=.188) (t(37)=-2.186, p=.035), and baseline and day 50 (t(37)=-4.307, p<.001). Significant differences were found between time points for SOT Somatosensory scores (F(2,74)=4.972,p=.015,partial □2=.118) post hoc t-tests revealed significant differences between baseline and day 50 (t(37)=-2.831, p=.007) as well as day 45 to day 50 (t(37)=2.657, p=.012). Significant differences were found for the SOT Vestibular Input score (F(2,74)=5.82, p=.005,partial □2=.136) post hoc paired t-tests revealed significant change between baseline and day 45 (t(37)=-2.195, p=.035) as well as baseline to day 50 (t(37)=-3.320, p=.002) Preliminary analyses also revealed differences in the BESS composite (F(2,74)=2.969,p=.057,partial □2=.082) between baseline and day 50 (t(37)= 2.472, p=.018), Analysis showed a significant change on condition 2 (F(2,74)=3.314,p=.042,partial □2=.082) between baseline and say 45 (t(37)= 2.472, p=.018), as well as between baseline and day 50 (t(37)=2.488, p=.017). Finally significant changes were found between baseline and day 45 for tandem firm condition F(2,74)=3.820p=.026,partial □2=.094) t(37)=2.144, p=.039), and between baseline and day 50 (t(37)= 2.078, p=.045) Conclusions: We found each systems composite score to have fair to excellent reliability. The SET ICC values had the strongest reliability scores ranging from .73 to .82, The SOT's composite was found to have fair to excellent reliability with ICC's ranging from .72 to .80. Finally the BESS composite score was found to have fair to excellent reliability with ICC values ranging from .65 to .84

4.1.2 Manuscript 1

Context

Rapid assessment and interventions are vital in accurately identifying and treating incidences of mild sports-related traumatic brain injury. While on-site certified athletic trainers trained in how to assess concussions are rapidly becoming commonplace in many schools, the incidence of undiagnosed concussions is estimated to be as high as 50% (Covassin, Elbin, & Nakayama, 2010). Rapid clinical assessment and accurate clinical diagnosis of concussion are key issues facing clinicians and coaches. Ideally any test battery being used should be conducted as a part of preseason evaluations to give clinicians a baseline to compare battery scores to in the event of injury (Broglio, Macciocchi, Stephen, & Ferrara, 2007). Advocates supporting clinical evaluation by licensed health care providers have also supported the multifaceted approach to concussion management (Mcrory P, 2013). While there is consensus regarding the use of test batteries to diagnose concussion post injury, studies showing the psychometric properties of each individual component are scarce in some cases and controversial in others. Psychometrically, any tool must be shown to be sensitive, reliable, and valid before becoming clinically relevant. (Schrout, P.E, 1979)

Postural stability has been identified as an objective measure when evaluating concussions up to 7 days post injury (Guskiewicz K. M., 2011) (Valovich Mcleod, Barr, Mcrea, & al., 2006). Postural stability can be measured during clinical evaluations using the Balance Error Scoring System (BESS) or by using force-plate technologies such as the Sensory Organization Test (SOT) performed on the NeuroCOM Smart Balance Master (NeuroCOM International Inc., Clackamas OR.) The BESS consists of three stances (single leg, dual and tandem stances) across two surfaces, stable and unstable. The surfaces typically used are floor (stable) and a medium density foam pad (unstable). Individuals are instructed to maintain position for 20 seconds as assessors count errors. The BESS has been shown in studies to have an intra-rater reliability range of .74 to .87 and an inter-rater reliability of .57 with improvements after serial administration. Test-retest reliability has been found to be .70 for total errors committed during test administration. (Valovich-Mcleod, et al., 2004) (Valovich-McLeod, Barr, Mcrea, et al., 2006)

The Sensory Organization Test (SOT) consists of 18 trials across 6 conditions. The SOT's composite score has been shown to be moderately reliable with an intraclass correlation of .66. (Ross, et al., 2011) During the past decade portable computerized measures of postural stability have been introduced that are possibly more cost effective alternatives to the SOT system which retail for approximately $100,000, whereas the VSR system is listed at $15,000 and the BESS pad costs less than $70, on average. The VSR, which incorporates aspects of the BESS and SOT offers an extremely mobile, cost efficient alternative to the SOT while providing objective information in the form of composite scores. The VSR Sport Sensory Evaluation Test (SET) is similar to the BESS in regard to the protocol consisting of six trials with each performed with eyes closed while maintaining varying stances. To date, no psychometric data exists supporting the SET as a reliable clinical measure.

Methods

Participants: Participants consisted of thirty-eight healthy college students (16 male and 22 female) 20 ± 1.6 years of age.

Procedures: Participants were scheduled across four separate time points Day 1, Day 2(Baseline), Day 45 and Day 50. Health and Demographic information was collected at each appointment. At each subject initial appointment informed consent was obtained, subjects were also briefly familiarized with each test. Approximately 24 hours following the initial appointment each subject returned and was base lined across each of the three balance assessments. Health and Demographic information was collected at each appointment. Approximately 45 days following baseline subjects return and complete the assessment battery again. Approximately 5 days after retest they return for a final assessment battery. The battery consisted of the NeuroCOM Sensory

Organization Test (SOT) the Balance Error Scoring System (BESS) and the Stability Evaluation Test (SET).

Main Outcome Measurements: The SOT calculates five composite score: Composite Balance, Somatosensory Input, Vestibular Input, Visual Input and Visual Conflict. The BESS provides a composite error score. The SET provides a composite sway score in degrees per second. Participants were grouped randomly into four groups and given each test in a different order. Repeated Measures ANOVA's were run for each test composite score and condition between each testing period. Post-hoc paired t-tests were used to determine change between time periods. Intraclass correlations were calculated for each test to determine test-retest reliability by comparing scores across each time period.

Design**:** This study used a repeated measures design.

Results

Preliminary analysis revealed no differences between groups, on age, height or across all composite scores. Our sample size was N=38 (22 Females 12 Males) aged 20±1.62. Repeated Measures ANOVA revealed significant differences on several scores across time, Significant change occurred between baseline and day 45 SOT composite score (F(2,74)=8.552,p<.001,partial □2=.188) (t(37)=-2.186, p=.035), and baseline and day 50 (t(37)=-4.307, p<.001). See Table 4.3 for all SOT means and standard deviations. Significant differences were found between time points for SOT Somatosensory scores (F(2,74)=4.972,p=.015,partial □2=.118) post hoc t-tests revealed significant differences between baseline and day 50 (t(37)=-2.831, p=.007) as well as day 45 to day 50 (t(37)=2.657, p=.012). Significant differences were found for the SOT Vestibular Input score (F(2,74)=5.82, p=.005,partial □2=.136) post hoc paired t-tests revealed significant change between baseline and day 45 (t(37)=-2.195, p=.035) as well as baseline to day 50 (t(37)=-3.320, p=.002).

Preliminary analyses also revealed differences in the BESS composite (F(2,74)=2.969,p=.057,partial □2=.082) between baseline and day 50 (t(37)= 2.472, p=.018). See Table 4.2 for all BESS means and standard deviations. Analysis showed a significant change on condition 2 (F(2,74)=3.314,p=.042,partial □2=.082) between baseline and say 45 (t(37)= 2.472, p=.018), as well as between baseline and day 50 (t(37)=2.488, p=.017). Finally significant changes were found between baseline and day 45 for tandem firm condition F(2,74)=3.820p=.026,partial □2=.094) t(37)=2.144, p=.039), and between baseline and day 50 (t(37)= 2.078, p=.045) (Table 4.2)

Stability Evaluation Test
Means and (SD)
(N =*38*)

	Composite Score	Cond 1	Cond 2	Cond 3	Cond 4	Cond 5	Cond 6
Baseline	2.85	0.74	2.44	1.99	4.85	5.05	4.85
	(0.90)	(0.45)	(1.76)	(1.71)	(3.06)	(1.71)	(3.06)
Day 45	2.88	0.73	2.74	1.89	1.75	5.34	5.03
	(0.96)	(0.34)	(1.62)	(1.58)	(0.51)	(1.65)	(3.30)
Day 50	2.84	0.77	2.57	2.01	1.71	4.54	2.84
	(0.99)	(0.22)	(1.93)	(1.67)	(0.80)	(1.86)	(0.99)

Table 2: Balance Error Scoring System Means and Standard Deviations By Time

Balance Error Scoring System *Means and (SD)* (N =*38*)							
	Composite Score	Cond 1	Cond 2	Cond 3	Cond 4	Cond 5	Cond 6
Baseline	12.76	0.00	2.29	1.11	0.08	5.55	3.82
	(7.23)	(0.00)	(1.99)	(1.93)	(0.36)	(2.71)	(2.64)
Day 45	10.97†	0.00	1.55†	0.55†	0.21	5.68	3.03
	(5.10)	(0.00)	(1.50)	(1.01)	(1.02)	(2.99)	(2.37)
Day 50	10.66†	0.00	1.55†	0.55†	0	4.71	3.61
	(6.95)	(0.00)	(2.14)	(1.01)	0	(2.64)	(3.17)

†= Significantly different from baseline values ($p \leq .05$)

Table 3: Sensory Organization Test Means and Standard Deviations by Time

Sensory Organization Test Scores *Means and (SD)* (*N =38*)					
	Composite Score	Somatosensory Input	Visual Input	Vestibular Input	Visual Conflict
Baseline	78.89	99.58	88.95	73.68	95.58
	(6.92)	(3.55)	(8.04)	(10.00)	(11.15)
Day 45	81†	98.87	89.42	77.32†	96.42
	(5.76)	(2.34)	(10.51)	(8.49)	(8.92)
Day 50	82.68†	97.71†‡	90.71	79.11†	97.21
	(6.25)	(6.25)	(7.34)	(9.99)	(7.01)

†= Significantly different from baseline values ($p \leq .05$) ‡=Significantly different from day 45 values ($p \leq .05$)

Prior to collecting test-retest reliability evidence, inter-rater reliability was determined to range from .94-.98 during BESS administration. This study found the SET to have moderate reliability from baseline to day 45 and baseline to day 50. The SET showed strong reliability from day 45 to day 50. See table 6.4 for ICC SET Values. The BESS composite scores were moderately reliable from baseline to day 45 and day 45 to day 50, and showed strong reliability baseline to day 50. See Table 6.5 for BESS ICC values. The SOT composite scores showed moderate reliability from baseline to day 45 as well as from day 45 to day 50 with baseline to day 50 showing strong reliability. See Table 6.6 for ICC values.

Table 6.4: SET Test Retest Reliability

SET Test Re-Test Reliability (*N=38*)							
	SET Composite	Cond 1	Cond 2	Cond 3	Cond 4	Cond 5	Cond 6
Baseline-Day 45	0.74‡	0.33	0.54‡	0.35	0.66	0.34	0.58‡
Baseline-Day 50	0.73‡	0.01	0.17	0.56‡	-0.23	0.30	0.45‡
Day 45-Day 50	0.82†	0.65‡	0.43	0.29	0.42	0.54‡	0.62‡

†=ICC values show excellent reliability (ICC>0.75) ‡=Showed fair to moderate reliability (ICC >.45 but < 0.75)

Table 6.5: BESS Test Retest Reliability

Balance Error Scoring System Test Re-Test Reliability (N=*38*)							
	Composite	Cond 1	Cond 2	Cond 3	Cond 4	Cond 5	Cond 6
Baseline-Day 45	0.74‡	0	0.56‡	0.64‡	0.12	0.59‡	0.42
Baseline-Day 50	0.84†	0	0.76†	0.60‡	0	0.46‡	0.51‡
Day 45-Day 50	0.65‡	0	0.36	0.73‡	0	0.15	0.56‡

†=ICC values show excellent reliability (ICC>0.75) ‡=Showed fair to moderate reliability (ICC >.45 but < 0.75)

Table 6.6: SOT Test Retest Reliability

Sensory Organization Test Re-Test Reliability (N=*38*)					
	Composite	Somatosensory	Visual	Vestibular	Visual Conflict
Baseline-Day 45	0.72‡	0.11	0.62‡	0.57‡	0.57‡
Baseline-Day 50	0.80†	0.02	0.51‡	0.66‡	0.63‡
Day 45-Day 50	0.72‡	0.4	0.47‡	0.62‡	0.61‡

†=ICC values show excellent reliability (ICC>0.75) ‡=Showed fair to moderate reliability (ICC >.45 but < 0.75)

Discussion

The timely and accurate assessment of postural control has become an important concern in the management and diagnosis of concussion. Acutely, postural control deficits are shown up to 7 days post injury. Obtaining baseline postural control scores prior to participation in sporting events has been advocated by both national and international medical communities (Harmon et al. 2013) (Guskiewicz et al 2013). To date the BESS and SOT accepted as reliable and valid measures of balance. Currently, the SOT is the gold standard in measuring postural control. (Guskiewicz, K.M 2011)(Broglio et al. 2007) Our studies primary aim was to determine concurrent validity and test retest reliability of the SET by comparing it to scores obtained from both the BESS, and SOT.

To determine test retest reliability we compared each test's composite and individual component scores across three clinically relevant time points. We found each systems composite score to have fair to excellent reliability. The SET possessed the highest ICC values (.73 to .82), The SOT's composite was found to have moderate to strong reliability with ICC's ranging from .72 to .80. Finally the BESS composite score was found to have fair to excellent reliability with ICC values ranging from .65 to .84. These results concur with previous findings on the BESS and SOT by

Wrisley (2007), Tsang (2004), and Valovich McLeod (2006). While our findings show each test composite score having fair to excellent reliability, many individual component scores within each assessment often did not. The SOT components ICC scores ranged from .02 to .66, somatosensory input composites having the weakest reliability ICC values ranging of .02 to .4. The BESS component scores ranged from .15 to .76, with condition 5 having the weakest reliability score of .15. The SET component scores reliability ranged from .01 to .66 with condition 1 having the weakest reliability scores. We found significant changes in scores in both the SOT and BESS between collection points. Composite scores obtained from the SOT increased significantly between the first and second administration, with no significant change between second and third administrations. Composite error scores obtained from the BESS show significant decreases in total errors made between baseline and retest. Interestingly, only two conditions showed significant change in scores between baseline, single leg and tandem on firm surface. In all three tests no significant changes in composite scores, and higher correlations were found between day 45 and day 50. This finding is potentially significant in the clinical applications for these tests. Our findings suggest that two administrations of each test to baseline may provide a better measure of true ability. Further studies identifying an ideal baseline test retest protocol are merited. The SOT and BESS have been previously reported as reliable by researchers, and our findings further support those findings.

While the Sensory Organization Test is the current standard in postural assessment of concussion, budget and staffing constraints facing clinicians and administrators could render this test impractical for programs with smaller budgets. Accessibility and ease of administration are also key concerns in the selection process for individual concussion management programs. Ideally clinicians such as athletic trainers, or other trained technicians should administer all of these tests. The NeuroCOM Smart Balance Master offers technicians and clinicians a 2-day training seminar to familiarize and train each clinician on administering and interpreting results in addition to a user manual with further guidance. The VSR Sport and BESS can be taught using an online format utilizing video based examples and manuals for each system. While cost of transportation and training may vary for the SOT, the use of an internet-based training platform further highlights the accessible nature of both the BESS and SET platforms. The average time to administer the SOT is approximately 20 minutes for each complete evaluation. While single test administration time may not preclude using this tool for smaller groups, considerations for groups with larger populations (High-School and Collegiate sports programs) must be made. Alternatively the BESS and SET take approximately 5 minutes to introduce and administer. Both the BESS and SOT are also considerably more budget friendly, portable and both reduce testing time exponentially making either more efficient in larger samples

In sum, in addition to supporting previous research regarding the reliability of both the SOT and BESS, this study finds that the SET is also a reliable measure of balance.

6.2 Manuscript 2

Title: Concurrent Validity of the Stability Evaluation Test

Running title:

Authors: William Shane Warren, Jake E. Resch

Corresponding Author

Work performed at the University of Texas at Arlington

Key words: Postural Control, Balance, BESS, SOT, VSR SPORT, Computerized Dynamic Posturography.

Financial Support:

Concurrent Validity of the Stability Evaluation Test

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The University of Texas at Arlington, Arlington

Context: Postural control assessments utilizing computerized dynamic posturography are a vital tool in the assessment of sports related concussion. Many of these measurements are costly and require lab space, can take up to 20 minutes to administer. Advances in technology have made these measures portable and more cost effective to implement. One such technology is the VSR Sport. Objective: To determine concurrent validity between the Stability Evaluation Test and the Sensory Organization Test and BESS utilizing baselines. Design: Cross Sectional Setting: Research Laboratory Participants: Participants consisted of thirty-eight healthy college students (16 male and 22 female) 20 ± 1.6 years of age. Interventions: Participants were scheduled for two appointments spaced 24 apart. Upon arrival for the first appointment informed consent was obtained and a health history questionnaire was administered to screen for any exclusion criteria. Health and Demographic information was collected upon arrival to each appointment. Subjects were then familiarized with each measure of balance and asked to schedule an appointment the following day. The next appointment was scheduled 24 hours after the initial assessment and each subject was then administered a battery of three balance assessments in the order dictated by random group assignment. The battery consisted of the NeuroCOM Sensory Organization Test (SOT) the Balance Error Scoring System (BESS) and the Stability Evaluation Test (SET). Main Outcome Measurements: The Sensory Organization Test calculates five composite scores: Composite Balance, Somatosensory Input, Vestibular Input, Visual Input and Visual Conflict. The Balance Error Scoring System provides a composite error score. The Stability Evaluation Test provides a composite sway score in degrees per second. Participants were grouped at random and received each test during each assessment period in the order dictated by group assignment. Pearson r correlations' were calculated between each condition and test. For this study each composite score was compared to another using Pearson r correlation coefficients. Results: Pearson r correlation coefficients revealed a significant correlation between the SET and BESS (r=. 70) composite scores at the time of baseline. No other significant correlations were observed. Conclusion: Our findings show a strong correlation between SET and BESS composite scores, but no correlation was shown between both measures and the SOT.

Introduction

In pediatric age groups across the United States an estimated 136,000 concussions occur in high schools each academic year of play (Broglio, Macciocchi, & Ferrara, 2007). Rapid assessment and interventions are vital in accurately identifying and treating incidences of mild sports-related traumatic brain injury. Rapid clinical assessment and accurate clinical diagnosis of concussion are key issues facing clinicians and coaches. Ideally any test battery being used should be conducted as a part of preseason evaluations to give clinicians a baseline to compare battery scores to in the event of injury (Broglio, Macciocchi, Stephen, & Ferrara, 2007). Advocates supporting clinical evaluation by licensed health care providers have also supported the multifaceted approach to concussion management (Mcrory P, 2013). While there is consensus regarding the use of test batteries to diagnose concussion post injury, studies showing the psychometric properties of each individual component are scarce in some cases and controversial in others. Psychometrically, any tool must be shown to be sensitive, reliable, and valid before becoming clinically relevant. (Schrout, P.E, 1979)

Postural stability has been identified as an objective measure when evaluating concussions up to 7 days post injury (Guskiewicz K. M., 2011) (Valovich Mcleod, Barr, Mcrea, & al., 2006). Postural stability can be measured during clinical evaluations using the Balance Error Scoring System (BESS) or by using force-plate technologies such as the Sensory Organization Test (SOT) performed on the NeuroCOM Smart Balance Master (NeuroCOM International Inc., Clackamas OR.) The BESS consists of three stances (single leg, dual and tandem stances) across two surfaces, stable and unstable. The surfaces typically used are floor (stable) and a medium density foam pad (unstable). Individuals are instructed to maintain position for 20 seconds as assessors count errors. The BESS has been shown in studies to have an intra-rater reliability range of .74 to .87 and an inter-rater reliability of .57 with improvements after serial administration. Test-retest reliability has been found to be .70 for total errors committed during test administration. (Valovich-Mcleod, et al., 2004) (Valovich-Mcleod, Barr, Mcrea, et al., 2006)

The Sensory Organization Test (SOT) consists of 18 trials across 6 conditions. The SOT's composite score has been shown to be moderately reliable with an intraclass correlation of .66. (Ross, et al., 2011) During the past decade portable computerized measures of postural stability have been introduced that are possibly more cost effective alternatives to the SOT system which retail for approximately $100,000, whereas the VSR system is listed at $15,000 and the BESS pad costs less than $70, on average. The VSR, which incorporates aspects of the BESS and SOT, offers an extremely mobile, cost efficient alternative to the SOT while providing objective information in the form of composite scores. The VSR Sport Sensory Evaluation Test (SET) is similar to the BESS in regard to the protocol consisting of six trials with each performed with eyes closed while maintaining varying stances. Additionally the SOT assessment takes about 20 minutes to administer, the BESS and SET take approximately 5 minutes to complete respectively. To date, no psychometric data exists supporting the SET as a valid clinical measure.

Methods

Participants: Participants consisted of thirty-eight healthy college students (16 male and 22 female) 20 ± 1.6 years of age.

Procedures: Participants completed two separate time points Day 1, and Day 2. Health and Demographic information was collected at both appointments. At each initial appointment informed consent was obtained, all forms were filled and then subjects were briefly familiarized with each test. Approximately 24 hours following the initial appointment each subject returned and was base lined across each of the three balance assessments. Health and Demographic information was collected at each appointment. The battery consisted of the NeuroCOM Sensory Organization Test (SOT) the Balance Error Scoring System (BESS) and the Stability Evaluation Test (SET) and each subject received the tests in a random order determined by group number.

Main Outcome Measurements: The SOT calculates five composite score: Composite Balance, Somatosensory Input, Vestibular Input, Visual Input and Visual Conflict. The BESS provides a composite error score. The SET provides a composite sway score in degrees per second. Participants were grouped randomly into four groups and given each test in a different order. Means and standard deviations are shown in Table 1

Results: Pearson r correlation coefficients revealed a significant correlation between the SET and BESS (r=. 70) composite scores at the time of baseline. No other significant correlations were observed

Table 1: Composite Score Means and Standard Deviations by Test

Composite and Individual Trial Scores
Means and (SD)
(N =*38*)

	Composite	Cond 1	Cond 2	Cond 3	Cond 4	Cond 5	Cond 6
SET	2.85	0.74	2.44	1.99	4.85	5.05	4.85
	(0.9)	(0.45)	(1.76)	(1.71)	(3.06)	(1.71)	(3.06)
BESS	12.76	0	2.29	1.11	0.08	5.55	3.82
	(7.23)	(0)	(1.99)	(1.93)	(0.36)	(2.71)	(2.64)
	Composite	Somatosensory	Vestibular	Visual	Visual Preference		
SOT	78.89	99.58	88.95	73.68	95.58		
	6.92	3.55	8.04	10	11.15		

Table 2: Correlations Between Composite Scores

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Correlations Between Composite Scores (*N=37*)			
	SOT	BESS	SET
SOT	1	-0.04	-0.285
BESS	-	1	.700**
SET	-	-	1

†= Correlation is significant at the 0.01 level (2-tailed).

Discussion:

The timely and accurate assessment of postural control has become an important concern in the management and diagnosis of concussion. Acutely, postural control deficits are shown up to 7 days post injury. Obtaining baseline postural control scores prior to participation in sporting events has been advocated by both national and international medical communities (Harmon et al. 2013) (Guskiewicz et al 2013). To date the BESS and SOT accepted as reliable and valid measures of balance. Currently, the SOT is the gold standard in measuring postural control. (Guskiewicz, K.M 2011)(Broglio et al. 2007) Our studies primary aim was to determine concurrent validity of the SET by comparing it to scores obtained from both the BESS, and SOT.

To determine concurrent validity we compared scores obtained from all three platforms on baseline. Our findings show little correlation between composite scores obtained by the SOT, and those collected from both the BESS and SET. We did show a significant correlation between scores obtained by the SET and the BESS. This suggests that both tests may measure the same constructs of balance, while the SOT measures another. In conclusion we found the SET to be a valid measure of balance. While the Sensory Organization Test is the current standard in postural assessment of concussion, budget and staffing constraints facing clinicians and administrators could render this test impractical for programs with smaller budgets.

Accessibility and ease of administration are also key concerns in the selection process for individual concussion management programs. Ideally clinicians such as athletic trainers, or other trained technicians should administer all of these tests. The NeuroCOM Smart Balance Master offers technicians and clinicians a 2-day training seminar to familiarize and train each clinician on administering and interpreting results in addition to a user manual with further guidance. The VSR Sport and BESS can be taught using an online format utilizing video based examples and manuals for each system. While cost of transportation and training may vary for the SOT, the use of an internet-based training platform further highlights the accessible nature of both the BESS and SET platforms.

The average time to administer the SOT is approximately 20 minutes for each complete evaluation. While single test administration time may not preclude using this tool for smaller groups, considerations for groups with larger populations (High-School and Collegiate sports programs) must be made. Alternatively the BESS and SET take approximately 5 minutes to introduce and administer. Both the BESS and SOT are also considerably more budget friendly, portable and both reduce testing time exponentially making either more efficient in larger samples.

APPENDIX A

Forms and Scripts Used

Scripts

First Identify the Dominant Leg by asking them which leg they would kick a ball with. The foot that kicks the ball is the dominant leg. If they kick with the right foot the left is the non dominant leg, if they kick with the left foot they use the right foot during the balance testing. Please circle this on the BESS SHEET

During Each instance of Balance testing

"I am now going to test your balance. Please take your shoes off, roll up your pant legs above ankle . 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. Falling is not failing, please when you move out of position reset as quickly as you can and then close 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." Falling is not failing, please when you move out of position reset as quickly as you can and then close 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." Falling is not failing, please when you move out of position reset as quickly as you can and then close your eyes.

Prior to the SOT please read the following script to each participant :

You are about to undergo the Sensory Organization Test which is a computerized measure of balance. During this test you will complete a series of 18 trials consisting of 6 different conditions. Each trial lasts approximately 20 seconds and the total duration of the test is approximately 20 minutes. During each condition one of four things will happen, 1.) Neither the floor or wall will move. 2.) The floor will move but the walls will not. 3.) The walls will move but the floor will not. Or 4.) Both the floor and the walls will move. During each trial you will be asked to either keep your eyes open or closed. Try to pick a focus point straight ahead and at about your eye level . Use this when your eyes are opened and when closed. During testing you must keep your eyes focused straight ahead (even when c losed) and your arms should rest at your side (not gripping your shorts or in your pockets.) Between each trial you will have a brief resting period to adjust yourself as needed, you may scratch your nose bend your knees, but please do not move your feet from the set position. The keys to success on this test are to 1.) not anticipate each condition. 2.) the machine responds to your motion. The more you move the more the machine will move as well. If you feel you are unbalanced correct yourself by shifting forward or backward. If you feel you are going to fall , I will be behind to spot you.

APPENDIX B

Forms and Scripts Used

Appendix B

IRB Consent Forms

PRINCIPAL INVESTIGATOR

Mr. William Shane Warren

FACULTY ADVISOR

Jake Resch Ph.D., ATC

TITLE OF PROJECT

Concurrent Validity and Test-Retest Reliability of the VSR Sport Stability Evaluation Test

INTRODUCTION

You are being asked to participate in the research study titled, "Concurrent Validity and Test-Retest Reliability of the VSR Sport Stability Evaluation Test," which is being conducted by William S. Warren (817-272-7102) of the Department of Kinesiology at the University of Texas at Arlington. Participation is completely voluntary. You can refuse to participate or withdraw your consent at any time without penalty or loss of benefits to which you are otherwise entitled. At this time you may have the results of the participation, to the extent that it can be identified as yours, returned to you, removed from the research records and destroyed.

PURPOSE

The purpose of this study is to verify the test-retest reliability and concurrent validity of four commercially available tests of balance.

DURATION

You will be asked to report to the Brain Injury Laboratory on 4 separate occasions. Your first appointment will be familiarization and screening. This will be followed by your baseline test which will be 24 hours after screening. Your third appointment will be 43-47 days after your baseline. The fourth and final test will be 5 days after your third appointment for a total of four sessions lasting approximately 1 hour each.

NUMBER OF PARTICIPANTS

We expect 200 participants to enroll in this study.

PROCEDURES

The procedures are as follows. You will receive a detailed explanation of the study, the benefits and risks of participation and then sign the informed consent. You will be asked to fill out a health questionnaire and a self-reported symptoms inventory. The health questionnaire addresses demographic information (provide examples) and prior concussion history.

Next you will be asked to practice 4 measures of balance including the Sensory Organization Test (SOT), Balance Error Scoring System (BESS), VSR Sport, and Bertec Sports Advantage.

The SOT will take approximately 20 minutes to complete. It consists of 18 twenty second trials in which your postural control will be measured as it responds to various challenges. These challenges fall under 6 separate conditions. In some conditions the platform will be fixed and stable. In others the platform will move in response to shifts in center of gravity. In some conditions the surroundings will move, and in some they will not. In some trials your eyes will be open and in others they will be asked to be closed. You will have a safety spotter behind you at all times during the evaluation.

The Balance Error Scoring System (BESS) will take approximately 5 minutes to complete. It consists of 6 trials. Three stances are used on two separate surfaces. The stances are single leg, dual leg and tandem postures. This means you will either stand on one leg, both legs in tandem or normal stance. The surfaces are either fixed (the ground) or unstable (foam pad). You will be asked to close your eyes during the trials. This trial will be recorded to ensure accuracy of score.

The VSR Sport and Betrec Sports Advantage both mimic the BESS. The key difference being the use of a forceplate to measure sway and center of gravity. They both have 6 trials and use the same stances mentioned above and use the same foam pad as well These trials also only take 5 minutes in length for each protocol.

Each session will last approximately 1 hour. The following day you will be asked to return to complete the health questionnaire and the symptoms inventory followed by all 4 balance measures. Approximately 45 days later you will be asked to return and complete both the health questionnaire and the symptom inventory, and again take all 4 measures of balance. 5 days after your third appointment you will be asked to return for a final collection of health questionnaire, symptom inventories, and your final testing on all 4 balance measures.

Exclusion Criteria

If you are not between the ages of 18 and 24 you will be ineligible to participate in this study. Furthermore any diagnosed concussions that have occurred within 6 months of your first appointment will render you ineligible as well. Any clinically diagnosed ADD/ADHD, vestibular disorder or neurological condition that would affect your ability to maintain postural stability will render you ineligible for participation.

VIDEO RECORDING OF BALANCE ERROR SCORING SYSTEM: The Balance Error Scoring System tests will be video recorded. Recordings will film participants, the camera will be positioned directly in front of the participants. The camera area will include all of the participants from the crown of the head to the base of the foam pad, or floor. After the examination, the tape will be watched, to ensure that any and all errors were accurately recorded. Videos will be archived for review on an ecrypted flash drive stored in a locked filing cabinet in room 154 of the Maverick Activities Center at the University of Texas at Arlington.

POSSIBLE BENEFITS

The benefits that you may expect from this research are to better understand your postural stability and contribute to the expanding body of knowledge regarding mild traumatic brain injuries.

POSSIBLE RISKS/DISCOMFORTS

There is minimal risk of injury from your participation in this project. Potential injuries may occur from a fall during the balance testing. To reduce the risk of falling a trained spotter will be present for each testing session.

COMPENSATION

No Compensation for participation will be offered during this study.

ALTERNATIVE PROCEDURES

There are no alternative procedures offered for this study. However, you can elect not to participate in the study or quit at any time at no consequence.

VOLUNTARY PARTICIPATION

Participation in this research study is voluntary. You have the right to decline participation in any or all study procedures or quit at any time at no consequence.

CONFIDENTIALITY

Every attempt will be made to see that your study results are kept confidential. A copy of this signed consent form and all data collected [including transcriptions/tapes if applicable] from this study will be stored in [MAC room 154] for at least three (3) years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a participant. Additional research studies could evolve from the information you have provided, but your information will not be linked to you in anyway; it will be anonymous. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, the UTA Institutional Review Board (IRB), and personnel particular to this research have access to the study records. Your records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above. The IRB at UTA has reviewed and approved this study and the information within this consent form. If in the unlikely event it becomes necessary for the Institutional Review Board to review your research records, the University of Texas at Arlington will protect the confidentiality of those records to the extent permitted by law.

CONTACT FOR QUESTIONS

Questions about this research study may be directed to William Warren (wwarren@mavs.uta.edu, Office Phone 817-272-7102 or Dr. Jake E. Resch at (Resch@uta.edu) Office Phone 817-272-1402 . Any questions you may have about your rights as a research participant or a research-related injury may be directed to the Office of Research Administration; Regulatory Services at 817-272-2105 or regulatoryservices@uta.edu.

As a representative of this study, I have explained the purpose, the procedures, the benefits, and the risks that are involved in this research study:

____

Signature and printed name of principal investigator or person obtaining consent Date

CONSENT

Instructions: If the subject is 18 years of age or older and capable of consenting on their own behalf this paragraph should be used.

By signing below, you confirm that you are 18 years of age or older and have read or had this document read to you. You have been informed about this study's purpose, procedures, possible benefits and risks, and you have received a copy of this form. You have been given the opportunity to ask questions before you sign, and you have been told that you can ask other questions at any time.

You voluntarily agree to participate in this study. By signing this form, you are not waiving any of your legal rights. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits, to which you are otherwise entitled.

____

SIGNATURE OF VOLUNTEER DATE

APPENDIX C

Health History Form

Appendix C

Health Questionnaire

Please answer the following questions as accurately and as thoroughly as you can.

NAME: Last:_________________________ Middle Initial:_____ First:_________________

Home Address: ____

Telephone number (Home) ____________________(Work)________________________

What is your birth date? Month: ________________ Day: ________ Year:19_____

What is your current age? __________ Circle your sex: male female

Have you ever torn your ACL? YES NO If so, when? (year) _________________

What is your RACE/ETHNICITY?

(Check one)

White (not of Hispanic origin) Black (not of Hispanic origin)

Hispanic Asian or Pacific Islander

American Indian or Alaskan Native Other

3. Have you ever had a concussion? (CIRCLE ONE) YES NO

4. How many times have you had a concussion?

(CIRCLE ONE) 0 1 2 3 4 4+

5. What is the year of your most recent concussion? Year: ____________________

(Skip if not applicable)

6. Are you physically sick (cold, flu, allergies) today? (CIRCLE ONE) YES NO

7. Are you currently receiving treatments for any type of injury?

(Example: ankle sprain, bruise, pulled muscle) (CIRCLE ONE) YES NO

8. Are you tired from any physical activities you have participated in today?

(CIRCLE ONE) YES NO NOT APPLICABLE

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BIOGRAPHICAL INFORMATION

William Shane Warren was born in the spring of 1982, in Peru Indiana. On his third birthday he was relocated to Ramstein Air Force Base Germany. He grew up and traveled in Europe extensively. He pursued his Bachelors of Science in Exercise Science, and relocated to Dallas. His area of interests includes concussion research, current practices and management in concussion, adapted athletics, and finally rehabilitative concerns in athletes with disabilities.