ASSESSING BALANCE IN HIGH SCHOOL ATHLETES AND ITS ROLE IN CONCUSSION MANAGEMENT

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Education with a major in Exercise Science.

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ABSTRACT

Technological advancements in electronics have provided access to quantitative methods of measuring balance or postural stability. In the past decade mobile devices have added built-in motion sensors called tri-axial accelerometers. Developers are accessing the accelerometer outputs while the device is against the body, and translating the values to postural sway and/or stability.

PURPOSE: The purpose of this study was to assess balance in high school athletes using a mobile device software application using accelerometric motion sensors in order to provide information for concussion management and return-to-play. **METHODS**: 121 healthy high school-aged athletes (62 male, 59 female; average age = 16.1 ± 1.3 yr) performed a series of balance tasks (bilateral, tandem, single leg) over multiple visits. Age, sex, orthopedic injuries post concussions, height, and weight were also recorded. **RESULTS**: Balance scores for concussed athletes did not show any significant difference between baseline and post-concussion test; however, there were three large effect size and one moderate effect size calculated. No significant differences were observed in balance scores between ages. **CONCLUSION**: Balance or postural sway is one of many important factors in providing vital information to help medical professionals determine proper management and return-to-play. Mobile devices with tri axis accelerometers is a new innovative and cost-effective method to measure human balance, however, more research needs to be completed to assess its effectiveness in identifying potential impairments resulting from sports concussions or mild traumatic brain injury.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Overview

Postural stability, or balance, is a non-simplistic process consisting of different components such as vision, motor, and vestibular (Guskiewicz & Perrin, 1996; Horak, 1997; Pollock, Durward, Rowe, & Paul, 2000; Shupert & Horak, 1999; Woollacott & ShumwayCook, 1996). Postural stability controls specific posture movements, such as standing or sitting; assisting in voluntary movement, such as different postural movements; and reaction to outside disturbances that affects control of balance such as a slip, trip, or push (Pollock et al., 2000). Improvements in balance have shown to assist in renewal, prevention of injury, and functional performance in all ages. Postural stability assessments have to be reproducible, valid, and reliable to provide the most accurate results. Several methods are used to assess balance, such as the one-legged balance test, Functional Independence Measures, Rhomberg Test, Forceplate Systems, Berg Balance Scale (BBS), Performance-Oriented Mobility Assessment (POMA), Dynamic Gait Index, and Postural Assessment Scale for Stroke Patients. These validated balance assessments are commonly used to assess postural stability in older adults and neurologically impaired (Bohannon & Leary, 1995; Goldie, Bach, & Evans, 1989; Hahn, Foldspang, Vestergaard, & Ingemann-Hansen, 1999; Pardasaney et al., 2012; Riemann, Guskiewicz, & Shields, 1999). Functional balance assessments have been developed to determine postural sway after balance perturbations occur (Bell, Guskiewicz, Clark, & Padua, 2011; Schneider, Emery, Kang, Schneider, & Meeuwisse, 2010). Balance is one symptom that is impaired after concussion. Injuries that can occur involving balance deficits could be concussions or mild traumatic brain injury (Harmon et al., 2013). Assessments such as the Sport Concussion Assessment Tool-

Version 2 (SCAT2) and The Balance Error Scoring System (BESS) are frequently used when assessing balance (Bell et al., 2011; Schneider et al., 2010). The BESS is considered a clinical evaluation tool that correlates with laboratory-based measures for criterion-related validity and construct validity (McCrea et al., 2013).

1.2 Statement of the Problem

Concussion is defined as a traumatically induced transient disturbance of brain function and involves a complex pathophysiological process (Harmon et al., 2013). It is estimated that as many as 3.8 million concussions occur in the United States each year during competitive/contact sports and recreational activities; however, as many as 50% of concussions may go unreported/undiagnosed (Harmon et al., 2013; Jinguji et al., 2012; Valovich McLeod, Bay, Lam, & Chhabra, 2012).

New methods and/or technologies are needed to aid in the diagnosis and management of mild traumatic brain injuries because too many balance assessments are subjective rather than objective. This study sought to answer the following questions:

1. Is there a difference between baseline balance scores and post-concussion balance scores?
2. Is there a difference in balance scores between ages?

The purpose of this study was to compare balance assessment scores of baseline and post-concussion tests using a mobile device application (iPod) utilizing accelerometric motion sensors. It was hypothesized that there would be a difference in balance scores between baseline and post-test for concussed athletes. Balance would be worse in the post-test. It was also hypothesized that balance scores would be higher in older athletes than younger athletes due to brain development.

1.3 Significance of the Study

Several balance assessments are used by different practitioners in all settings, but most assessments have been censured for determining subjective information instead of objective information. With the use of accelerometers in mobile devices used for this study, postural stability can be measured objectively. The information attained from this study will benefit athletic trainers, coaches, athletes, parents, and medical professionals. It will also provide better insight in return-to-play decisions for athletic trainers and medical professionals.

1.4 Limitations of the Study

Mobile devices that are affordable and reliable can provide precise, quantitative data on individuals' postural stability using accelerometers. The SWAY application would provide a convenient way to assess balance if an issue such as a sustained concussion, fall, or lower extremity injury were to occur. The first limitation is the social or cultural factors that may influence the knowledge or acceptance of technology and its use in health care. If the participant is unfamiliar or uncomfortable with the current technology used for this study (specifically the iPod), it may cause frustration or apprehension that could potentially affect the results of this study. It is important to note because the success of this study is dependent upon the acceptance and use of current technology. In order for the application to be widely utilized, the practitioner must have knowledge of the current technology and implement it into his or her repertoire.

Another limitation is the number of participants. Though 121 individuals participated in this study, several more participants could have been obtained in order to assess balance in athletes who could have potentially sustained a concussion.

Limitation 3 is measuring balance from above the human center of gravity. All previous balance studies have been completed by measuring balance from a platform.

1.5 Delimitations of the Study

Delimitations of the study are as follows:

1. This study is delimited to athletes at Wichita East High School at USD 259 district in Wichita, KS.
2. A delimitation of this study is the use of the Apple iPod instead of any other Smartphone device with built-in accelerometers.

1.6 Assumptions of the Study

Assumptions for this study are as follows:

1. It is assumed for this study that all participants are free of any recent injury or condition of the skeletal system, nervous system, or muscular system that would inhibit accurate assessment of balance scores.
2. It is assumed that all participants attempted each balance trial to the best of his/her knowledge, providing accurate results.

3. It was assumed that if 100-150 high school student athletes were assessed at baseline that 8-14 would have a concussion for follow up measures.
4. It is assumed that all tapes and braces of the lower extremity are removed before testing was started.

1.7 Definition of Terms

Accelerometer: a device that measures both static and dynamic acceleration that consists of a moveable bar suspended on micro-machined springs that provide resistance against acceleration (Culhane, O'Connor, Lyons, & Lyons, 2005).

Balance: the ability to maintain the center of body mass (COM) within limits of stability determined largely by the base of support whether the base is stationary or moving (Alexander, 1994; Davlin, 2004; Horak, 2006; Tyson & Connell, 2009; Woollacott & ShumwayCook, 1996). It is also a process involving coordination of multiple sensory, motor, and biomechanical components (Guskiewicz & Perrin, 1996; Horak, 1997).

Center of Mass (COM): center of gravity (Guskiewicz & Perrin, 1996).

Center of Pressure (COP): center of distribution of the total force applied to the supporting surface (Arnold & Schmitz, 1998; Guskiewicz & Perrin, 1996).

Concussion: a traumatically induced transient disturbance of brain function and is caused by a complex pathophysiological process. Also referred to a mild traumatic brain injury (MTBI) (Harmon et al., 2013).

Dynamic Stability: the ability to transfer the vertical projection of the COG around a stationary supporting base (Davlin, 2004; Guskiewicz & Perrin, 1996; Ruhe, Fejer, & Walker, 2010; Wolfson, Whipple, Derby, Amerman, & Nashner, 1994).

Force platform: a system that measures vertical forces at three or more points on the platform to determine parameters such as postural sway and center of pressure (Goldie et al., 1989; Riemann et al., 1999).

Golgi Tendon Organs (GTO): Located in the tendons near their junction with the muscles are responsible for sending information about tension in the muscle or rate of change of tension (Guskiewicz & Perrin, 1996).

Muscle Spindles: Stretch sensitive mechanoreceptors that provide the nervous system with information about the muscle's length and velocity of contraction (Guskiewicz & Perrin, 1996; Shaffer & Harrison, 2007).

Second Impact Syndrome: A syndrome that occurs when an athlete who sustains a head injury, often a concussion or worse injury, such as a cerebral contusion, sustains a second head injury before symptoms associated with the first have cleared (Cantu, 1998; P. McCrory, 2001).

Static Balance: Equilibrium is maintained for one stationary body position during continuous transfer of the center of gravity (Davlin, 2004; Ruhe et al., 2010).

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Balance

Balance is an important element from maintaining posture to completing complex sport skills and may be defined as the ability to maintain the center of body mass (COM) within limits of stability determined largely by the base of support (Alexander, 1994; Davlin, 2004; Horak, 2006; Pollock et al., 2000; Tyson & Connell, 2009; Woollacott & ShumwayCook, 1996). During simplistic tasks such as sitting or standing, the body continuously sways and to regulate this, the sensory systems continuously process information about the body's position in space (Horak, 2006; Mancini & Horak, 2010; Woollacott & ShumwayCook, 1996). It is a complex process involving coordination of multiple sensory, motor, and biomechanical components (Guskiewicz & Perrin, 1996). Fig 2.1 shows the conceptual model for the balance system theory, including the interacting systems contributing to balance and orientation (Mancini & Horak, 2010; Woollacott & ShumwayCook, 1996).

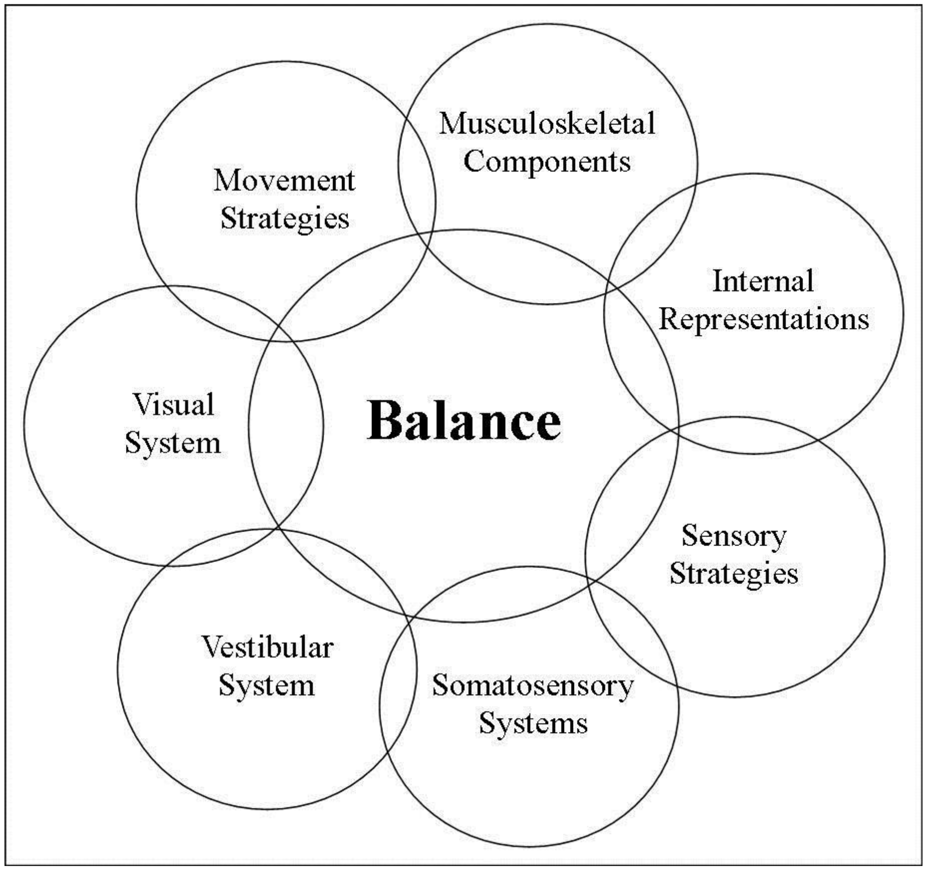

FIGURE 2.1

A CONCEPTUAL MODEL REPRESENTING THE INTERACTING SYSTEM CONTRIBUTING TO TASK SPECIFIC BALANCE AND ORIENTATION

Functional goals of the balance system include: 1) maintenance of a specified posture, such as sitting or standing; 2) voluntary movement, such as the movement between postures; and 3) the reaction to an external disturbance, such as a trip, slip, or push (Pollock et al., 2000). Three different postural responses that young and older adults can use when regaining stability are ankle strategy, hip strategy, and a stepping strategy (Alexander, 1994; Horak, 2006; Woollacott & ShumwayCook, 1996).

2.2 Types of Balance

Balance is achieved by the complex integration and coordination of multiple body systems including the vestibular, visual, auditory, motor, and higher level pre-motor systems (Mancini & Horak, 2010). Balance is categorized into two different types: static and dynamic. Static balance is when equilibrium is maintained for one stationary body position during continuous transfer of the center of gravity, whereas dynamic balance is the ability to transfer the vertical projection of the COG around a stationary supporting base (Davlin, 2004; Guskiewicz & Perrin, 1996; Ruhe et al., 2010; Wolfson et al., 1994). It uses sensory information which is processed by neural structures that produce an organized motor response that reflexively restores body alignment (Wolfson et al., 1994). Both balances entail integrating sensory information from the visual, vestibular, and somatosensory systems (Davlin, 2004). Feedback received from these systems relays commands to muscles of the extremities, which then generate an appropriate contraction to maintain postural stability (Jansen, Larson, & Olesen, 1982; Shumway-Cook & Horak, 1986).

2.3 Physiological Feedback Influencing Balance

Feedback sensors play an important role in maintaining balance. The vestibular apparatus can be used in three different ways: 1) the information used to control eye muscles so that when the head changes position, the eyes can stay fixed on one point; 2) information from the vestibular can be used to sustain upright posture; and 3) vestibular information use involves conscious awareness of the body's position and acceleration after information has been relayed to the cortex by the thalamus (Guskiewicz & Perrin, 1996).

Most individuals are dependent upon vision and somatosensory inputs when maintaining balance especially when perturbations are induced (Guskiewicz & Perrin, 1996). When the head is suddenly tilted, signals from the semicircular canals cause the eyes to rotate in an equal and opposite direction to the rotation of the head, which is a function of the vestibule-ocular reflex (Guskiewicz & Perrin, 1996). It contributes to posture by maintaining reflexes associated with keeping the head and neck in the vertical position (Guskiewicz & Perrin, 1996).

The proprioceptive system functions via the mechanoreceptive senses (Guskiewicz & Perrin, 1996). Sensory receptors, such as muscle spindles and golgi tendon organs, have an important role in the nervous system's control of posture (Guskiewicz & Perrin, 1996). Muscle spindles are stretch sensitive mechanoreceptors that provide the nervous system with information about the muscle's length and velocity of contraction (Guskiewicz & Perrin, 1996; Shaffer & Harrison, 2007). Muscle spindles provide afferent feedback that translates reflexive and voluntary movement. These fibers, from the muscle spindle, enter the central nervous system (CNS) and divide into branches that can take multiple paths (Guskiewicz & Perrin, 1996). One such path directly stimulates motor neurons going back to the muscle that was stretched, which in turn completes a reflex arc known as the stretch reflex (Guskiewicz & Perrin, 1996). Golgi tendon organs (GTO) are located in the tendons near their junction with the muscles and are responsible for sending information about tension in the muscle or rate of change of tension (Guskiewicz & Perrin, 1996). They are designed to protect a muscle by relaxing it when it is being overstretched (Guskiewicz & Perrin, 1996). GTOs are sensitive to extremely slight changes (Shaffer & Harrison, 2007).

2.4 Balance and Age

It has been suggested that younger athletes may be susceptible to more prolonged recovery and to concussions associated with catastrophic injury (Harmon et al., 2013). The developing brain differs physiologically from the adult brain when comparing the brain water content, degree of myelination, blood volume, blood-brain barrier, cerebral metabolic rate of glucose, blood flow, number of synapses and geometry and elasticity of the skulls sutures (Harmon et al., 2013). Developmentally, younger brains have less-established engrams which could explain the increase in time to recover from concussions in younger athletes than in older athletes (Harmon et al., 2013).

2.5 Methods of Assessment of Balance

Balance assessments are crucial for accurately determining an individual's postural stability. Assessments for evaluation of postural stability must be standard and reliable to provide valid and reproducible results.

Many assessments have been developed for measurements of standing balance. Standing balance is important in performance of sports activity and has been shown to be significant in predicting sports injury and in monitoring rehabilitative success (Hahn et al., 1999). One example of a uipedal static stance is the one-legged standing balance test. It is a reliable method and is well suited for population-based studies (Hahn et al., 1999). It is a time measured test where an individual stands on one leg with eyes closed, the other leg slightly flexed and each hand placed on the opposite shoulder (Hahn et al., 1999). During dynamic balance, a multiple direction stabilization test is administered (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012; Riemann et al., 1999). An example of a dynamic balance test is the Star Excursion Balance Test (SEBT) which is valid and reliable (Coughlan et al., 2012). This test involves having a participant maintain postural control with one leg while maximally reaching in eight different directions with the opposite leg (Coughlan et al., 2012). The Y Balance Test is another test that can assess dynamic balance. It involves the individual standing on an elevated central plastic footplate one inch off the ground and pushing a rectangular reach block in three different directions (Coughlan et al., 2012). Other tools have been used to assess dynamic balance such as foam and tilt boards which alter proprioceptive feedback (Riemann et al., 1999). Functional reach tests were developed to assess dynamic balance in children and older populations (Brauer, Burns, & Galley, 1999). An example is the Lateral Reach Test in which the participant standing on both feet, reaches as far as possible without taking a step towards an end distance marked by a yard stick (Brauer et al., 1999). Other functional tests are used to measure balance and posture in the elderly and neurologically impaired. These tests are the Berg Balance Test, Continuous-Scale Physical Functional Performance Test, and the Postural Assessment Scale for Stroke patients (Benaim, Perennou, Villy, Rousseaux, & Pelissier, 1999; Berg, Wooddauphinee, & Williams, 1995; Bohannon & Leary, 1995; Cress et al., 1996). The Berg Balance Test has fourteen categories in which the participant is tested on and scored, such as rising from a chair, to determine if the participant has enough stability to walk independently (Berg et al., 1995). The Continuous-Scale Physical Functional Performance Test measures tasks, similar to those required for independent living and are rated on scores from five domains: upper body strength, upper body flexibility, lower body strength, balance and coordination, and endurance (Cress et al., 1996). The Postural Assessment Scale for Stroke patients measures twelve, four-level items of varying difficulty for assessing the patient’s ability to maintain or change posture (Benaim et al., 1999). Other functional balance assessments have been developed to assess balance after injuries such as concussion or traumatic brain injury. The Sport Concussion Assessment Tool-version 2 (SCAT2) is a neurocognitive tool that was developed for patient education in addition to physician assessment in individuals who have sustained a sport related concussion (Jinguji et al., 2012; Schneider et al., 2010). It measures both subjective and objective information. The subjective portion consists of a 22-item post-concussion symptom score, which is graded 0-6 severity (Jinguji et al., 2012). The objective portion consists of physical signs, Glasgow coma scale, a balance examination, a coordination examination, and a cognitive assessment, which includes orientation, immediate memory, concentration, and delayed recall (Jinguji et al., 2012). A score is assigned for each section, with a total possible score of 100 (Jinguji et al., 2012). The Balance Error Scoring System (BESS) was developed as an objective sideline assessment tool for the evaluation of postural stability deficits after concussion (Susco, McLeod, Gansneder, & Shultz, 2004). It consists of six testing conditions that use three stances (double leg, single leg, tandem) and on two surfaces (firm, foam) (Susco et al., 2004). The double leg stance consists of hands on the hips and feet together; single leg stance consists of standing on the non-dominant leg with hands on hips; and tandem stance consists of non-dominant foot behind the dominant foot in a heel-to-toe fashion (Bell et al., 2011; Susco et al., 2004). The stances are performed with eyes-closed with errors counted during each 20-second trial (Bell et al., 2011; Susco et al., 2004). An error is defined as opening eyes, lifting hands off hips, stepping, stumbling or falling out of position, lifting the forefoot or heel, abducting the hip by more than 30 degrees or failing to return to the test position in more than five seconds (Bell et al., 2011; Susco et al., 2004). It has moderate to good reliability and moderate to high criterion-related validity (Bell et al., 2011). It has high content validity in identifying balance deficits in concussed and fatigued populations, functional ankle instability, ankle bracing, aging populations, and those completing neuromuscular training (Susco et al., 2004). It is a clinical evaluation that correlates with laboratory-based measures for criterion-related validity and construct validity (Bell et al., 2011). Several methods of balance assessment have been used in clinical settings; however, many have been criticized for offering only subjective information rather than objective information. Force platforms are a system that can provide an easily administered assessment of functional balance through analysis of postural sway (Guskiewicz & Perrin, 1996). Force platform systems measures the vertical ground reaction force and provide a means of computing the center of pressure (CP) by measuring force at three or more points on the platform or by measuring torque around the horizontal axes (Goldie et al., 1989). These systems measure four aspects of postural control: 1) steadiness (the ability to keep the body as motionless as possible); 2) symmetry (the ability to distribute weight evenly between the two feet in upright stance; 3) dynamic stability (the ability to transfer the vertical projection of the center of gravity (CG) around the supporting base; and 4) dynamic balance (the measurement of postural control responses to external perturbations from a platform moving in one of four directions: tilt toes up, tilting toes down, medial-lateral, and anterior-posterior) (Goldie et al., 1989; Stribley, Albers, Tourtellotte, & Cockrell, 1974).

Another method of assessing balance is computerized balance platforms, such as the BIODEX Balance System (BBS). It uses a circular platform that is free to move about the anterior-posterior (AP) and medial lateral (ML) axes simultaneously and measures stretch in multiple strain gauges to record movement (Arnold & Schmitz, 1998). Also, it is possible to vary the stability of the platform by varying the resistance force applied to the platform (Arnold & Schmitz, 1998). Rather than measuring the center of pressure during static conditions, the

BIODEX measures the degree of tilt about each axis during dynamic conditions (Arnold & Schmitz, 1998). From the degrees of tilt about the AP and ML axes, the BSS calculates the medial-lateral stability index (MLSI, the anterior-posterior stability index (APSI) and overall stability index (OSI) (Arnold & Schmitz, 1998).

2.6 Accelerometers

Technological advancements through accelerometers in mobile devices, specifically smartphones, have provided quantitative/objective methods of assessing static and dynamic stability. Accelerometers were first proposed in the 1950s, and were expensive, bulky, and unreliable (Culhane et al., 2005). The present technology readiness for accelerometer devices allows for the quantitative and portable assessment of human locomotion and movement disorder (Culhane et al., 2005; Lemoyne, Coroian, Mastroianni, & Grundfest, 2008). Accelerometers measure both static and dynamic acceleration and consist of a moveable bar suspended on micro-machined springs that provides resistance against acceleration (Culhane et al., 2005). Deflection of this bar is then converted into an acceleration reading (Culhane et al., 2005). Three accelerometers can be incorporated into a single device providing information on three-dimensional movement (tri-axial accelerometer) (Culhane et al., 2005). These devices have been increasingly integrated into the biomedical field (Lemoyne et al., 2008). They are an ideal choice for evaluating variability of movement and balance, providing a non-invasive, little setup time, and portable low-cost method of measurement that goes beyond the confines of a laboratory environment (Auvinet et al., 2002; Cho & Kamen, 1998; Culhane et al., 2005; Lemoyne et al., 2008; Menz, Lord, & Fitzpatrick, 2003). Balance assessments using accelerometers have been comparable with comprehensive clinical balance assessments, such as variants of the Rhomberg's test, functional reach test, and heel-toe straight line walking, in healthy older individuals and idiopathic fallers (Cho & Kamen, 1998; Culhane et al., 2005). Another study assessed gait in older subjects with and without balance issues and younger subjects (Yack & Berger, 1993). Comparisons were made between the two groups using trunk accelerometers (Yack & Berger, 1993). These two studies propose that accelerometers are useful in assessing balance and detect anomalies in the gait of fallers (Cho & Kamen, 1998; Yack & Berger, 1993). Accelerometers provide data over a long time and have successfully demonstrated to detect sensitive displacement (Auvinet et al., 2002; Lemoyne et al., 2008). Validity and reliability has been demonstrated in research environments (Cho & Kamen, 1998; Lemoyne et al., 2008).

2.7 Concussion

It is estimated that as many as 3.8 million concussions occur in the United States per year during competitive sports and recreational activities; however as many as 50% of concussions may go unreported (Broglio, Weimo, Sopiarz, & Youngsik, 2009; Guskiewicz & Mihalik, 2011; Harmon et al., 2013; Jinguji et al., 2012; Valovich McLeod et al., 2012). These injuries are now considered a major public health concern (De Beaumont et al., 2011) Concussion is defined as a traumatically induced transient disturbance of brain function and involves a complex pathophysiological process (Harmon et al., 2013). It is a subset of mild traumatic brain injury (MTBI) which is generally self-limited and at the less-severe end of the brain injury spectrum (Barlow, Schlabach, Peiffer, & Cook, 2011; Harmon et al., 2013). It is a frequent injury in contact and collision sports (e.g., football, hockey, and wrestling) at all levels of participation, including youth sports (Guskiewicz & Mihalik, 2011; McCrea et al., 2013). Sport-related concussion typically results from forces directly imparted to the head or indirectly through the neck, resulting in a combination of rapid acceleration and deceleration (Guskiewicz & Mihalik, 2011). Concussions typically occur when linear and/or rotational forces are transmitted to the brain (Guskiewicz & Mihalik, 2011; Harmon et al., 2013; Mulligan, Boland, & McIlhenny, 2013). When an athlete experiences a rotational mechanism, it is thought that rotation of the cerebrum about the brainstem produces shearing and tensile strains (Guskiewicz & Mihalik, 2011).

This injury remains a clinical diagnosis usually made by a healthcare provider familiar with the athlete and knowledge in the recognition and evaluation of concussion (Harmon et al., 2013). A multifaceted approach is recommended when evaluating concussive injuries because it provides the clinician unique information from a variety of domains (Broglio, Sosnoff, & Ferrara, 2009; T. C. V. McLeod, 2009; Valovich McLeod et al., 2012). This approach includes a symptoms checklist, cognitive evaluation (including orientation, past and immediate memory, new learning, and concentration), balance assessments, and further neurological physical examination (Barlow et al., 2011; Broglio et al., 2009; Guskiewicz, Ross, & Marshall, 2001; Harmon et al., 2013; Riemann & Guskiewicz, 1997; Ross et al., 2011; Valovich McLeod et al., 2012). Current literature suggests that this comprehensive battery has up to 90% sensitivity (Ross et al., 2011). Balance and postural stability are crucial components for controlling movement strategies involved in sport (Riemann & Guskiewicz, 1997; Ross et al., 2011). Balance disturbance, particularly, is a specific indicator of a concussion (Harmon et al., 2013). Over the past decade, the use of balance testing has become increasingly utilized in the diagnosis and management of sports-related concussions particularly on the sideline (Harmon et al., 2013).

Studies have identified temporal or permanent deficits in static and/or dynamic balance in individuals with mild-to-moderate traumatic brain injury (TBI) and similar balance deficits have been reported in sports-related concussions (Davis, Iverson, Guskiewicz, Ptito, & Johnston, 2009; Harmon et al., 2013). Functional recovery of postural control in the majority of athletes follows a close pattern as that of neurocognitive function, with postural control restoration ranging from 3 to 5 days (Broglio et al., 2009; De Beaumont et al., 2011; Harmon et al., 2013). Obtaining a preseason baseline score is recommended to have a standardized sideline assessment to determine an athlete's status at the time of injury (Broglio et al., 2009; Valovich McLeod et al., 2012). These baseline scores may be important in high-risk athletes with a prior history of concussions, with confounding conditions and sports with a higher incidence of concussions (Harmon et al., 2013).

Return-to-play is an extremely important concept that should not be taken lightly. It often creates a dilemma for athletic trainers and team physicians (Broglio et al., 2009; Guskiewicz, Perrin, & Gansneder, 1996). Return-to-play after a concussion should be individualized, gradual and progressive, and should consider factors that may affect individual risk and outcome (Harmon et al., 2013). Because of the potential complications and long-term consequences of returning to competition too early, sports medicine professionals are using more objective tools to assess athletes after a concussive injury (T. C. V. McLeod, Barr, McCrea, & Guskiewicz, 2006). The athlete should have a normal neurological exam including a normal cognitive and balance evaluation, ideally compared to a pre-injury baseline (Harmon et al., 2013). There are potential health risks of returning an athlete with persistent symptoms to play including the possibility of second impact syndrome or diffuse cerebral swelling, increased susceptibility to a recurred or more severe concussion and prolonged duration of symptoms

(Guskiewicz et al., 1996; Harmon et al., 2013; Mulligan et al., 2013). A history of concussions is associated with a higher risk of sustaining another concussion anywhere from 2-5.8 times higher (Harmon et al., 2013). Second impact syndrome involves fatal brain swelling following minor head trauma in individuals who still have symptoms from a prior head injury (Barlow et al., 2011; Riemann & Guskiewicz, 1997). The pathophysiology of SIS is thought to involve a loss of autoregulation of the brain's blood supply, leading to vascular engorgement, marked increase in intracranial pressure, brain herniation, and ultimately coma or death (Harmon et al., 2013; Riemann & Guskiewicz, 1997). The occurrence of second impact syndrome has been documented almost exclusively in immature brains, which suggests that young athletes are at the greatest risk (Barlow et al., 2011).

2.8 Concussion and Balance

Areas of the brain disrupted as a result of concussion have been reported to be responsible for the maintenance of postural equilibrium (Guskiewicz et al., 1996; Guskiewicz et al., 2001). Balance is one of the main symptoms commonly reported following a concussion and balance testing has been used to document the presence of concussive brain injury and to track recovery (Davis et al., 2009; Kleffelgaard, Roe, Soberg, & Bergland, 2012). Balance deficits have been noted after concussion as individuals are often unable to interpret and integrate sensory information needed for appropriate motor responses to maintain postural control (Kleffelgaard et al., 2012; Mulligan et al., 2013; Ross et al., 2011). One postural control test developed with the explicit intent of concussion assessment is the Balance Error Scoring System (BESS). The BESS was created to provide objective postural control information to the clinician without the need for expensive equipment or extensive training (Broglio et al., 2009). Balance tests are sensitive to concussion's deleterious effects and add to the overall sensitivity of the assessment battery (Broglio et al., 2009). A memorandum, issued in 2010 by the National Collegiate Athletic Association (NCAA), indicates that baseline testing should be performed on athletes in most sports prior to preseason training to determine individual baseline scores (Mulligan et al., 2013). This in turn allows balance deficits after a concussion to be compared to baseline scores (Mulligan et al., 2013). Previous studies of clinical balance alone suggest that recovery is usually seen within 3-5 days after injury (Ross et al., 2011). However, not all scores for an individual with a concussion improve at a similar rate (Barlow et al., 2011).

2.9 Second Impact Syndrome

Several types of injuries can come about from participation in contact sports. Such injuries are: mild traumatic brain injury or concussion, subdural hematoma, epidural hematoma, intracerebral hemorrhage, and second impact syndrome. Contact sports in which participants can experience concussions which can lead to second impact syndrome are: football, boxing, ice hockey, judo, karate, tae kwon do, rugby, basketball, track, and soccer (Bailes & Hudson, 2001; McIntosh, 2003; Tommasone & Valovich McLeod, 2006). Other sports include: wrestling, field hockey, gymnastics, martial arts, equestrian sports, auto racing diving, bicycling, rodeo, and lacrosse (Harmon, 1999; Matser, Kessels, Lezak, Troost, & Jordan, 2000; Patel, Shivdasani, & Baker, 2005; Seward, 1997). However, a concussion and second impact syndrome, can be obtained in any sport, not just the following listed above. Most American reports of this condition are in football though because this sport has by far the greatest amount of players at risk, an estimated 1.5 million per year (Broglio, Vagnozzi, et al., 2010; Guskiewicz & Mihalik, 2011; Patel et al., 2005). Second impact syndrome or “recurrent traumatic brain injury” is a concern in all sports that involve head impact or any type of collision (Byard & Vink, 2009; Cantu, 1992b; Wetjen, Pichelmann, & Atkinson, 2010). It is an injury that is a resultant from the first concussion. Second impact syndrome research is a necessity if physicians, athletic trainers, parents, and athletes are to better understand this injury. Second impact syndrome was first described by Schneider in 1973 and later by Saunders and Harbaugh in 1984 as a syndrome that occurs when an athlete who sustains a head injury, often a concussion or worse injury, such as a cerebral contusion, sustains a second head injury before symptoms associated with the first have cleared (Cantu, 1992b, 1998; McCrory, 2001). Some suggest that neurotransmitter substances within the brain have not yet returned to normal following a prior injury (Cantu, 1992a; McCrory, Davis, & Makdissi, 2012). Usually the athlete suffers from post-concussion symptoms after the first head injury which may include visual, sensory, or motor changes and difficulty with memory and thought processes (Broglio, Schnebel, et al., 2010; Cantu, 1992b). Before the athlete is asymptomatic of these post-concussion symptoms (vomiting, confusion, headache, etc.), which may take days or weeks, the athlete returns to competition and receives a second blow to the head (Bey & Ostick, 2009; Hooker, 2001). This second blow does not always involve direct contact with the head. It can involve a blow to the side of the body, chest, or back that simply snaps the athlete’s head and indirectly imparts accelerative forces to the brain (Cantu & Voy, 1995; Jaworski, 2011). Athletes that experience repetitive concussions within a short period of time could suffer devastating or fatal reactions related to second impact syndrome (Byard & Vink, 2009; Cobb & Battin, 2004; Hodgson, 2011).

2.9.1 Pathophysiology

Second impact syndrome shares a common pathophysiology with “diffuse cerebral swelling” or “malignant brain edema” (Cantu, 2003; Jantzen, 2010). The pathophysiology of second impact syndrome is thought to involve a loss of autoregulation of the brain’s blood supply (Bey & Ostick, 2009; Cantu, 1997; Jordan, 2009; McCrory & Berkovic, 1998). This loss leads to vascular engorgement within the cranium, which in turn significantly increases intracranial pressure and leads to herniation either of the medial surface of the temporal lobe or lobes below the tentorium or of the cerebellar tonsils through the foramen magnum (Broglio & Dillon, 2005; Cantu, 1997; McCrory & Berkovic, 1998). The usual time from second impact to brainstem failure is rapid, taking around 2 to 5 minutes (Cantu, 1997). Once the brainstem herniation and brainstem compromise occur, coma, ocular involvement, and respiratory failure precipitously ensue (Cantu, 1997; Wetjen et al., 2010). An athlete with SIS typically appears stunned but remains conscious for a few seconds or minutes and is sometimes able to walk to the sideline before collapsing. The athlete then becomes semiconscious with rapidly dilating pupils, fixed eye movements, and experiences respiratory and brainstem failure (Cantu, 1997; Cobb & Battin, 2004).

2.9.2 Incidence

The incidence and danger of second impact syndrome is well documented in the literature and should be a concern of athletic trainers and team physicians faced with managing a concussion (Guskiewicz & Cantu, 2004). However, the exact frequency is unknown, but it is believed to be rare (Jordan, 2009). An estimated 300,000 sports-related concussions occur each year in the U.S. (Bailes & Cantu, 2001; Broglio & Dillon, 2005; M. McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004; McLain, 1998; Roberts, 1995; Sturmi, Smith, & Lombardo, 1998). This translates to one or two cases per year of second impact syndrome in football alone (Harmon, 1999). Any athlete that participates in a contact sport that is symptomatic has an increased risk for second impact syndrome (Bailes & Cantu, 2001; Corrigan, Selassie, & Orman, 2010; McLain, 1998). Once an athlete suffers a first concussion, he or she has been found to be at an increased risk for subsequent concussions and more likely to develop persistent concussion symptoms (Cantu, 2003; Liewen, 2011; Pellman, Viano, Tucker, Casson, & Waeckerle, 2003). After a concussion, the chance for a second concussion is found to increase to four to six times, increasing the chance of developing second impact syndrome if not properly managed (Cantu, 2001; Seward, 1997).

2.9.3 Prevention/Management

It is extremely important for the physician, athletic trainer, coaching staff, athlete and parents to understand how to prevent a catastrophic injury such as second impact syndrome. Second impact syndrome is approaching a mortality rate of 50% and morbidity rate nearing 100%, which suggests prevention is of extreme importance (Mueller, 2001). No two concussions are identical, and the resulting symptomatology can be very difficult depending on the force and location of the blow, the degree of metabolic dysfunction and tissue damage, the duration of time needed to recover, the number of previous concussions, and the time between injuries (Broglio & Dillon, 2005; Guskiewicz & Cantu, 2004; McCrea et al., 2004; Sturmi et al., 1998). A first step in appropriate management is providing proper evaluation of the first concussive blow (Bailes &

Hudson, 2001; Jordan, 2009). An athlete who is symptomatic from a head injury must not participate in contact or collision sports until all cerebral symptoms have dissipated and preferably not for at least 1 week thereafter (Cantu, 1997). Whether it takes days, weeks, or months to reach the asymptomatic state, the athlete must never be allowed to practice or compete while he or she has post-concussion symptoms (Cantu & Voy, 1995). To do so could end an athlete's life prematurely. In most cases, sport-related concussion will involve a grade 1 injury, with only 10% involving more serious grade 2 and 3 injuries. Mild cases are managed well by the athletic trainer or physician, however, management of moderate or severe injuries or recurrent injuries can be complicated and often involve persistent post-concussion symptoms (Bailes & Hudson, 2001; Cantu, 1998; Len & Neary, 2011). Any athlete suspected of experiencing second impact syndrome should be immediately transferred to a medical facility that is equipped with neuroradiological and neurosurgical services (Jordan, 2009; Logan, Bell, & Leonard, 2001; Matser et al., 2000).

2.9.4 Return-to-Play

Although second impact syndrome is rare, a premature return-to-play can place the athlete in danger for a catastrophic injury if he or she sustains a second concussive blow before the first concussion has resolved (Broglio, Macciocchi, & Ferrara, 2007; Guskiewicz et al., 2004; McCrory et al., 2012). After an injury, an athlete's speed of information processing and reaction times are slowed, this is important because if there is premature return-to-play, the athlete might not respond appropriately to a dangerous sporting situation (Logan et al., 2001; McCrory, 2001). If cognitive attributes remain impaired when the athlete returns to play, the athlete becomes susceptible to risk of injury (Broglio et al., 2007; Herring, 2011; Liewen, 2011; Powell, 2001). The most important guideline to remember is that no athlete under any circumstances should return to participation while still symptomatic at rest or following physical exertion (i.e., pushups, sit-ups, treadmill running) (Cantu, 2001; Crockett-Lohr, 2011; Guskiewicz et al., 2006; Mueller, 2001). This includes the presence of a headache related to a concussive episode (Guskiewicz & Cantu, 2004; Valovich McLeod & Register-Mihalik, 2011).

CHAPTER 3

METHODOLOGY

This chapter describes the methods and data used to address the research questions presented in this study. Discussion in this chapter includes: 1) restatement of the research questions answered by the study, 2) description of site and participant selection process, 3) explanation of the instruments and measures used for data collection, 4) discussion of the study procedures, 5) description of data analysis used, 6) assurances regarding the protection of human subjects.

3.1 Research Questions

Studies have shown that balance is a symptom following a concussion. Assessments used to test balance are criticized though for their lack of sensitivity and objectivity (Guskiewicz et al., 1996). Areas of the brain impacted as a result of concussion have been reported to be responsible for the maintenance of postural equilibrium (Guskiewicz et al., 2001). Because of this, postural stability measures have been proposed as a means by which concussion can be objectively assessed (Guskiewicz et al., 2001). Many balance assessment tools are being utilized, the most accessible and cost-efficient methods, though adequate, rely on subjective and qualitative measures that the test administrator observes and concludes based on opinion. This study sought to answer the following question:

1. Is there a difference between baseline balance scores and post-concussion balance scores?
2. Is there a difference in balance scores between ages?

3.2 Site and Participation Selection

This study was conducted at Wichita East High School in Wichita, KS. Baseline measures were assessed in the athletic training room and all balance assessments were conducted within the same training room. The selection site was chosen for two reasons: 1) time constraints regarding room availability and 2) convenience of the location for participant use. The location for this study had to be a familiar, convenient location for all participants in order to prevent location from being a limiting factor.

3.2.1 Participants

The participants of this study were high school athletes from USD 259 school district at Wichita East High School. 121 participants (59 female, 62 male), age ranging from 14 to 18 years (16.14 ± 1.28 yrs) were recruited from Wichita East High School. Each participant, or legal guardian, gave written and verbal consent before participation in the study.

3.3 Instruments and Measures

Discussion of the instrument and measure used during this study include the SWAY Smartphone Application. All device configurations, settings, and usage were in accordance with each device's manufacturer instructions for proper set up, use, and care of the equipment.

3.3.1 SWAY Smartphone Application

The SWAY Smartphone Application was developed by Capacity Sports (Tulsa, OK) and is designed as a tool to measure balance or postural stability. It can be used in athletic, clinical, or everyday settings with the objective of providing quantitative and accurate information about the individual, to help assess balance and to help determine return-to-play decisions for athletes diagnosed with concussion. This application takes advantage of the accelerometers found in mobile devices, such as apple iPods and iPhones. Accelerometers, which consist of a moveable bar suspended on micro-machined springs that provide resistance against acceleration, measure dynamic and static acceleration (Culhane et al., 2005). An acceleration reading is assessed from deflection of that bar (Culhane et al., 2005). Information measured through accelerometers is anterior/posterior and medial/lateral stability. Three accelerometers can be integrated into a single device providing information on three-dimensional movement (tri-axial accelerometer) (Culhane et al., 2005; Lemoyne et al., 2008). A low-cost, portable system of measurement, accelerometers are an ideal choice for measuring sway variation (Auvinet et al., 2002; Cho & Kamen, 1998; Lemoyne et al., 2008).

3.4 Procedures

Upon enrollment into the study, participants completed the Informed consent form detailing the outline of the study's trials. Following completion of the Informed consent, Participants' height, weight, age, gender, and dominant foot were recorded. Injuries were also recorded per Wichita East High's athletic trainer. After personal data were collected, each participant was familiarized with the technology and instructed on proper technique for each trial.

3.4.1 iPod Trials for Assessing Balance in Athletes

Participants used the SWAY Smartphone Application, developed by Capacity Sports, completing three balance assessments two times each. Participants were familiarized with the SWAY Smartphone application. The SWAY application conducts three, ten second tests before collecting data. The application consists of an “Okay Let’s Go” button and a “Begin Test” button. Once “Begin Test” is pressed, the participant has three seconds to assume the proper position before the test begins. SWAY application has an audible count-down tone to inform the participant when the test begins and ends. Once the test ends, the participant presses the “Proceed” button to move onto the next test. The participant then presses “Begin Test,” and again has a three second count-down to assume proper position in which the ten second test begins. Three assessments were conducted (bilateral, tandem, and single leg stance). For the bilateral stance, the feet were just placed together side by side. For the tandem stance the dominant foot was placed in front on the non-dominant foot and for the single leg stance the non-dominant foot was stood on while the dominant foot was lifted up. The assessments began with the bilateral stance, followed by tandem stance and single leg stance. Proper posture was required for every test, which involved keeping the shoulders back and standing in an upright position, with both hands holding the mobile device, along with the device pressed firmly against the center of the chest and with eyes closed. Anterior/posterior and medial/lateral stability were recorded and was termed Actual Stability Score.

3.5 Statistical Analysis

Statistical analyses for this study were completed with the use of Statistical Packages for the Social Sciences (SPSS) version 21.0. Descriptive statistics were computed on all data. For the data, paired samples t-test, independent samples t-test, and one way ANOVA were computed. Due to 20 paired samples t-test being run, $p<0.05$ and $p<0.01$, were not appropriate significant levels to use. A more conservative p value is needed because so many paired sample t-tests are being run which could increase type 1 error. A calculated p value for 20 paired t-test would be $P=0.0025$.

3.6 Protection of Human Subjects

Approval from the Wichita State University Institutional Review Board (IRB) for Research involving Human Subjects was obtained for the study design and consent form prior to the initiation of participation recruitment and data collection. Informed consent was explained verbally and in writing for all study participants and parents/legal guardians. Informed consent was obtained from all study participants and assurances were provided by the researcher that their responses or data would be reported as a group, or a representative or group data, and not identified by, or identifiable as pertaining to, a specific individual.

CHAPTER 4

RESULTS

4.1 Restatement of the Study Hypothesis

Concussion is defined as a traumatically induced transient disturbance of brain function and involves a complex pathophysiological process (Harmon et al., 2013). It is estimated that as many as 3.8 million concussions occur in the United States each year during competitive/contact sports and recreational activities; however, as many as 50% of concussions may go unreported/undiagnosed (Harmon et al., 2013; Jinguji et al., 2012; Valovich McLeod et al., 2012).

New methods and/or technologies are needed to aid in the diagnosis and management of mild traumatic brain injuries. This study sought to answer the following question:

1. Is there a difference between baseline balance scores and post-concussion balance scores?
2. Is there a difference in balance scores between ages?

The purpose of this study was to compare balance assessment scores of baseline and post-concussion tests using a mobile device application (iPod) utilizing accelerometric motion sensors. It was hypothesized that there would be a difference in balance scores before pre and post-test for concussed athletes. Balance would be worse in the post-test. It was also hypothesized that balance scores would be higher in older athletes than younger athletes due to brain development. SPSS version 21.0 was used to assess the descriptive statistical information for all participants. However, not all participants' balance scores or demographic information was collected due to insufficient syncing of the iPods and athletes not always being available for testing. Table 4.1 displays the descriptive statistics for height, weight and age for those demographics collected.

TABLE 4.1

BASELINE SUBJECT CHARACTERISTICS

Descriptive Statistics							
	N	**Range**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
height (in)	69	18.50	59.50	78.00	68.0725	4.00760	16.061
weight (lbs)	69	137.00	103.00	240.00	155.9159	28.57105	816.305
age (years)	118	4.00	14.00	18.00	16.1356	1.28046	1.640

4.2 iPod Comparisons of Concussed Athletes

The present study recruited 121 participants. 16 participants' data were not fully included in this study because their balance scores did not sync properly; this included both healthy and concussed athletes. Participant compliance with procedures posed a problem with data collection. If the participant moved or looked at the screen of the iPod before the test was over, the movement of the device could affect the data. Also, if the participant made an error on the beginning position (center of balance), then all other positions would be effected because the test did not start at a perfectly balanced state. Participants were explained the procedures at the beginning of the study and throughout all tests. It was hypothesized that there would be a difference between baseline balance scores and post-concussion balance scores. A total of 13 athletes experienced a concussion throughout this study; however, six participants were either completely or partially omitted due to insufficient data from syncing issues. The number of concussed athletes vs. healthy athletes is seen in Figure 4.1

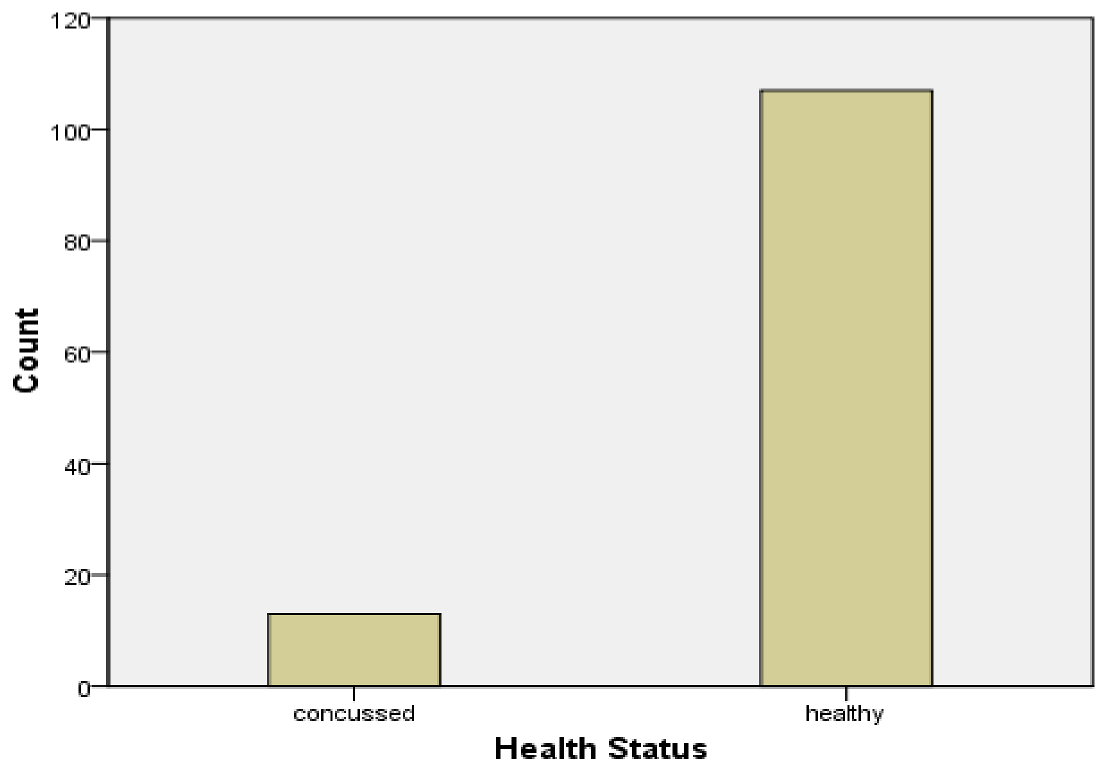

FIGURE 4.1

NUMBER OF CONCUSSED ATHLETES VS. HEALTHY ATHLETES

A paired samples t-test was used to determine differences in balance scores between baseline and post-test of concussed athletes. The paired samples t-test looked at both Single Leg Stance and Tandem Stance. Each of these tests consisted of multiple data points for both baseline test and post-concussion test. Single leg stance consisted of: avg. for anterior/posterior movement during single leg stance for test1 & avg. for anterior/posterior movement during single leg stance for test2, std. deviation for anterior/posterior movement during single leg stance for test1 & std.

deviation for anterior/posterior movement during single leg stance for test2, avg. for medial/lateral movement during single leg stance for test1 & avg. for medial/lateral movement during single leg stance for test2, std. deviation for medial/lateral movement during single leg stance for test1 & std. deviation for medial/lateral movement during single leg stance for test2, variance of X coordinate during single leg stance for test1 & variance of X coordinate during single leg stance for test2, variance of Y coordinate during single leg stance for test1 & variance of Y coordinate during single leg stance for test2, std. deviation of X coordinate during single leg stance for test1 & std. deviation of X coordinate during single leg stance for test2, std. deviation of Y coordinate during single leg stance for test1 & std. deviation for Y coordinate during single leg stance for test2, range of X coordinate during single leg stance for test1 & range of X coordinate during single leg stance for test2, and range of Y coordinate during single leg stance for test1 & range of Y coordinate during single leg stance for test 2. Tandem stance consisted of: avg. for anterior/posterior movement during tandem stance for test1 & avg. for anterior/posterior movement during tandem stance for test2, std. deviation for anterior/posterior movement during tandem stance for test1 & std. deviation for anterior/posterior movement during tandem stance for test2, avg. for medial/lateral movement during tandem stance for test1 & avg. for medial/lateral movement during tandem stance for test2, std. deviation for medial/lateral movement during tandem stance for test1 & std. deviation for medial/lateral movement during tandem stance for test2, variance of X coordinate during tandem stance for test1 & variance of X coordinate during tandem stance for test2, variance of Y coordinate during tandem stance for test1 & variance of Y coordinate during tandem stance for test2, std. deviation of X coordinate during tandem stance for test1 & std. deviation of X coordinate during tandem stance for test2, std. deviation of Y coordinate during tandem stance for test1 & std. deviation of Y coordinate during tandem stance for test2, range of X coordinate during tandem stance for test1 & range of X coordinate during tandem stance for test2, and range of Y coordinate during tandem stance for test1 & range of Y coordinate during tandem stance for test2. With the new calculated p value, none of the sampled t-tests were significant. Four paired samples t-test were close to significance. Those were std. deviation for medial/lateral movement during single leg stance for test1 & std. deviation for medial/lateral movement during single leg stance for test2 (P=0.047), std. deviation of Y coordinate during single leg stance for test1 & std. deviation for Y coordinate during single leg stance for test2 (P=0.089), range of X coordinate during single leg stance for test1 & range of X coordinate during single leg stance for test2 (P=0.054), and range of Y coordinate during single leg stance for test1 & range of Y coordinate during single leg stance for test 2 (P=0.090). Because these variables did not reach the calculated P value, Cohen's D Effect Size was calculated for each one. Table 4.2 displays concussed athletes in both single leg stance and tandem stance for baseline test and post-concussion test. Figure 4.2 displays Cohen's D effect size for four paired samples t-tests. Concussed athletes are displayed in Table 4.2 and the calculated effect sizes are displayed in Figure 4.2.

TABLE 4.2

CONCUSSED ATHLETES

Paired Samples Test Concussed Athletes		
		Sig. (2 tailed)
Pair 1	Avg. for anterior/posterior movement during single leg stance for test1 & Avg. for anterior/posterior movement during single leg stance for test2	0.132
Pair 2	Std. deviation for anterior/posterior movement during single leg stance for test1 & Std. deviation for anterior/posterior movement during single leg stance for test2	0.12

TABLE 4.2 (continued)

Pair 3	Avg. for medial/lateral movement during single leg stance for test1 & Avg. for medial/lateral movement during single leg stance for test2	0.101
Pair 4	Std. deviation for medial/lateral movement during single leg stance for test1 & Std. deviation for medial/lateral movement during single leg stance for test2	**0.047**
Pair 5	Variance of X coordinate during single leg stance for test1 & Variance of X coordinate during single leg stance for test2	0.194
Pair 6	Variance of Y coordinate during single leg stance for test1 & Variance of Y coordinate during single leg stance for test2	0.101
Pair 7	Std. deviation of X coordinate during single leg stance for test1 & Std. deviation of X coordinate during single leg stance for test2	0.165
Pair 8	Std. deviation of Y coordinate during single leg stance for test1 & Std. deviation for Y coordinate during single leg stance for test2	**0.089**
Pair 9	Range of X coordinate during single leg stance for test1 & Range of X coordinate during single leg stance for test2	**0.054**
Pair 10	Range of Y coordinate during single leg stance for test1 & Range of Y coordinate during single leg stance for test 2	**0.09**

TABLE 4.2 (continued)

Pair 11	Avg. for anterior/posterior movement during tandem stance for test1 & Avg. for anterior/posterior movement during tandem stance for test2	0.95
Pair 12	Std. deviation for anterior/posterior movement during tandem stance for test1 & Std. deviation for anterior/posterior movement during tandem stance for test2	0.795
Pair 13	Avg. for medial/lateral movement during tandem stance for test1 & Avg. for medial/lateral movement during tandem stance for test2	0.618
Pair 14	Std. deviation for medial/lateral movement during tandem stance for test1 & Std. deviation for medial/lateral movement during tandem stance for test2	0.832
Pair 15	Variance of X coordinate during tandem stance for test1 & Variance of X coordinate during tandem stance for test2	0.497
Pair 16	Variance of Y coordinate during tandem stance for test1 & Variance of Y coordinate during tandem stance for test2	0.494
Pair 17	Std. deviation of X coordinate during tandem stance for test1 & Std. deviation of X coordinate during tandem stance for test2	0.821
Pair 18	Std. deviation of Y coordinate during tandem stance for test1 & Std. deviation of Y coordinate during tandem stance for test2	0.607

TABLE 4.2 (continued)

Pair 19	Range of X coordinate during tandem stance for test1 & Range of X coordinate during tandem stance for test2,	0.8
Pair 20	Range of Y coordinate during tandem stance for test1 & Range of Y coordinate during tandem stance for test2	0.688

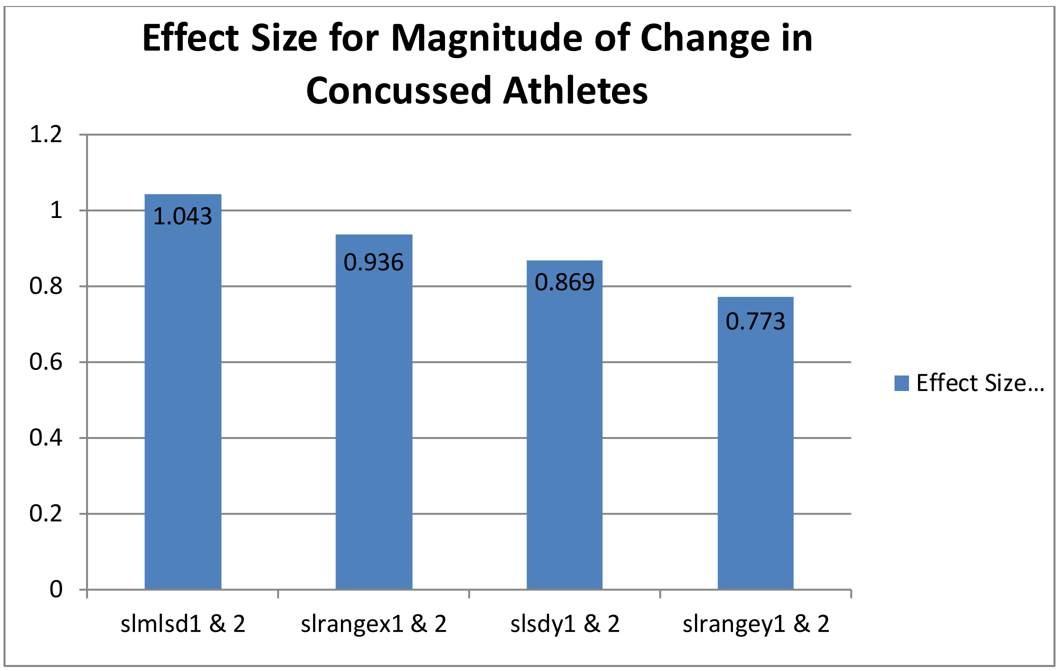

FIGURE 4.2

EFFECT SIZE OF CONCUSSED ATHLETES

Effect sized calculated for std. deviation for medial/lateral movement during single leg stance for test1 & std. deviation for medial/lateral movement during single leg stance for test2 (1.043), range of X coordinate during single leg stance for test1 & range of X coordinate during single leg stance for test2 (0.936), std. deviation of Y coordinate during single leg stance for test1 & std. deviation for Y coordinate during single leg stance for test2 (0.869) were all large effect sizes. Range of Y coordinate during single leg stance for test1 & range of Y coordinate during single leg stance for test 2 (0.773) was a moderate effect size.

4.3 Balance and Age

It was hypothesized that differences would be seen in balance scores between ages. Statistical analysis was computed from 102 participants. A One Way ANOVA test was completed to determine any significant differences between athletes ages 14-18. Age groups were 14, 15, 16, 17, and 18. There were no significant differences found between groups of ages for Test 1. Between age groups are displayed in Table 4.3.

TABLE 4.3

BETWEEN AGE GROUPS

ANOVA AGE		
	F	**Sig.**
Avg. for anterior/posterior movement during single leg stance for test2	0.59	0.671
Std. deviation for anterior/posterior movement during single leg stance for test2	1.194	0.325
Avg. for medial/lateral movement during single leg stance for test2	0.416	0.796
Std. deviation for medial/lateral movement during single leg stance for test2	0.211	0.931
Variance of X coordinate during single leg stance for test2	0.328	0.743
Variance of Y coordinate during single leg stance for test2	0.312	0.753

TABLE 4.3 (continued)

Std. deviation of X coordinate during single leg stance for test2	0.258	0.788
Std. deviation for Y coordinate during single leg stance for test2	0.275	0.777
Range of X coordinate during single leg stance for test2	0.241	0.8
Range of Y coordinate during single leg stance for test 2	0.351	0.73
Avg. for anterior/posterior movement during tandem stance for test2	0.362	0.835
Std. deviation for anterior/posterior movement during tandem stance for test2	0.844	0.5
Avg. for medial/lateral movement during tandem stance for test2	0.363	0.834
Std. deviation for medial/lateral movement during tandem stance for test2	0.962	0.432
Variance of X coordinate during tandem stance for test2	1.837	0.239
Variance of Y coordinate during tandem stance for test2	1.46	0.304
Std. deviation of X coordinate during tandem stance for test2	1.954	0.222
Std. deviation of Y coordinate during tandem stance for test2	1.516	0.293
Range of X coordinate during tandem stance for test2,	2.268	0.185
Range of Y coordinate during tandem stance for test2	0.394	0.691

4.4 Other Results Worth Noting

Other tests analyzed were if there were any significant differences in balance between the familiarization test and test 1 in healthy subjects, any difference between males and females, and any differences between single-sport athletes and multi-sports athletes. A paired samples t-test was used to analyze data between the familiarization test and test1 in healthy participants. The P value was set at P<0.01. No significant differences were found. The significant differences are seen in Table 4.4.

TABLE 4.4

FAMILIARIZATION VS. TEST1

Paired Samples T-Test Familiarization and Test 1	
Healthy	**Sig. (2-tailed)**
Avg. for anterior/posterior movement during single leg stance for test1 & Avg. for anterior/posterior movement during single leg stance for test2	0.123
Std. deviation for anterior/posterior movement during single leg stance for test1 & Std. deviation for anterior/posterior movement during single leg stance for test2	0.25
Avg. for medial/lateral movement during single leg stance for test1 & Avg. for medial/lateral movement during single leg stance for test2	0.158
Std. deviation for medial/lateral movement during single leg stance for test1 & Std. deviation for medial/lateral movement during single leg stance for test2	0.311
Avg. for anterior/posterior movement during tandem stance for test1 & Avg. for anterior/posterior movement during tandem stance for test2	0.097
Std. deviation for anterior/posterior movement during tandem stance for test1 & Std. deviation for anterior/posterior movement during tandem stance for test2	0.389
Avg. for medial/lateral movement during tandem stance for test1 & Avg. for medial/lateral movement during tandem stance for test2	**0.036**

TABLE 4.4 (continued)

Std. deviation for medial/lateral movement during tandem stance for test1 & Std. deviation for medial/lateral movement during tandem stance for test2	0.37

Though 121 subjects participated in this study, statistical analysis was only computed for 97 participants due to insufficient data. An independent samples t-test was used to analyze balance scores between males and females for Test1. The P value was set at P<0.01. No significant difference was found between male and female for Test1. Male VS. Female variables are displayed in Table 4.5.

TABLE 4.5

MALE VS. FEMALE

Independent Samples T-Test Female VS. Male		
		Sig. (2-tailed)
Avg. for anterior/posterior movement during single leg stance for test2	Equal Variances Assumed	0.534
	Equal Variances Not Assumed	0.432
Std. deviation for anterior/posterior movement during single leg stance for test2	Equal Variances Assumed	0.519
	Equal Variances Not Assumed	0.336
Avg. for medial/lateral movement during single leg stance for test2	Equal Variances Assumed	0.961
	Equal Variances Not Assumed	0.947
Std. deviation for medial/lateral movement during single leg stance for test2	Equal Variances Assumed	0.962

TABLE 4.5 (continued)

	Equal Variances Not Assumed	0.951
Avg. for anterior/posterior movement during tandem stance for test2	Equal Variances Assumed	0.525
	Equal Variances Not Assumed	0.526
Std. deviation for anterior/posterior movement during tandem stance for test2	Equal Variances Assumed	0.619
	Equal Variances Not Assumed	0.614
Avg. for medial/lateral movement during tandem stance for test2	Equal Variances Assumed	0.205
	Equal Variances Not Assumed	0.21
Std. deviation for medial/lateral movement during tandem stance for test2	Equal Variances Assumed	0.309
	Equal Variances Not Assumed	0.337

An independent samples t-test was used to analyze balance scores between 85 single-sport athletes and 35 multi-sport athletes. The P value was set at P<0.01. A significant difference was found in slapsd2 when equal variances were not assumed (P=0.014). Single VS. Multi-Sport athletes are displayed in Table 4.6 and the mean and standard deviation for both single-sport and multi-sport athletes are displayed in Figure 4.3.

TABLE 4.6

SINGLE VS. MULTI-SPORT ATHLETES

	Independent Samples T-Test	
		Sig. (2-tailed)
Avg. for anterior/posterior movement during single leg stance for test2	Equal Variances Assumed	0.174
	Equal Variances Not Assumed	0.076
Std. deviation for anterior/posterior movement during single leg stance for test2	Equal Variances Assumed	0.113
	Equal Variances Not Assumed	**0.014**
Avg. for medial/lateral movement during single leg stance for test2	Equal Variances Assumed	0.63
	Equal Variances Not Assumed	0.587
Std. deviation for medial/lateral movement during single leg stance for test2	Equal Variances Assumed	0.167
	Equal Variances Not Assumed	0.062
Avg. for anterior/posterior movement during tandem stance for test2	Equal Variances Assumed	0.646
	Equal Variances Not Assumed	0.61
Std. deviation for anterior/posterior movement during tandem stance for test2	Equal Variances Assumed	0.705
	Equal Variances Not Assumed	0.686
Avg. for medial/lateral movement during tandem stance for test2	Equal Variances Assumed	0.802
	Equal Variances Not Assumed	0.797

TABLE 4.6 (continued)

Std. deviation for medial/lateral movement during tandem stance for test2	Equal Variances Assumed	0.559
	Equal Variances Not Assumed	0.388

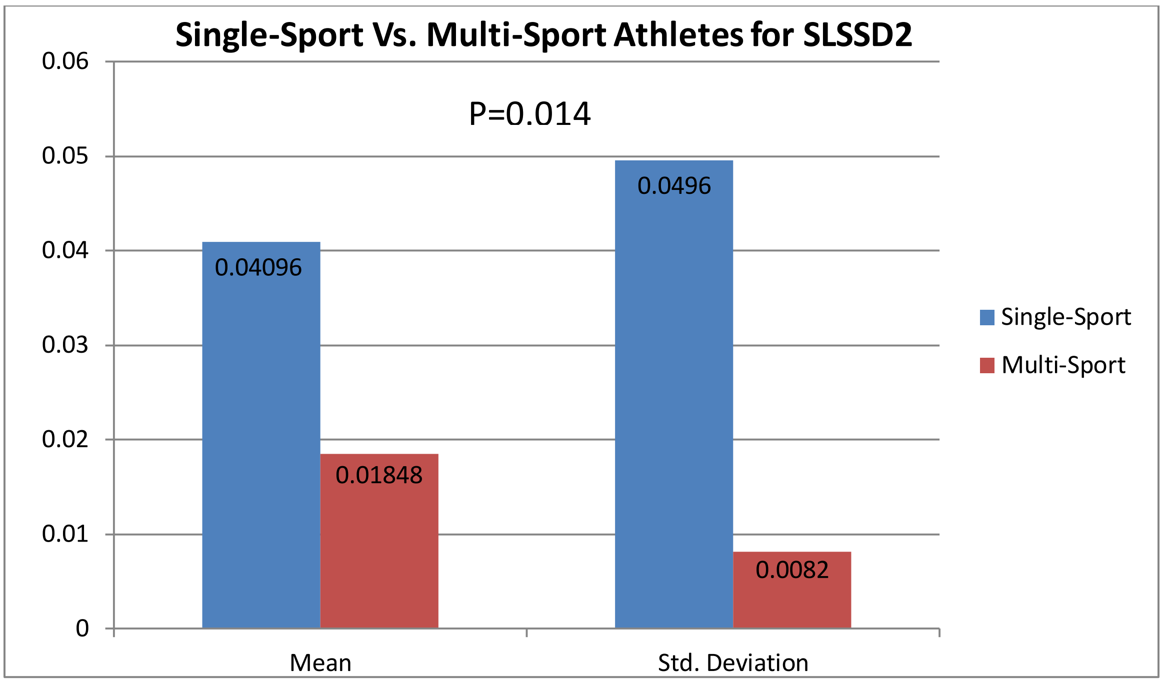

FIGURE 4.3

MEAN AND STD. DEVIATION SINGLE VS. MULTI-SPORT ATHLETES

CHAPTER 5

DISCUSSION

5.1 Overview

The purpose of this study was to assess balance scores in high school athletes using accelerometers in mobile devices, comparing scores between athletes' ages and comparing scores between concussed and healthy athletes. A search through Web of Science showed that there are 255,439 previous studies assessing balance. Of those 255,439 balance studies, 340 discussed balance as a symptom following a head injury, while 153 discussed balance as a symptom following a concussion. Several populations have been studied when assessing balance, especially older adults. The present investigation studied adolescent athletes ages 14-18. Of the 153 studies discussing balance following a concussion, 27 used athletes as their population while one study used high school athletes as its population.

This discussion will look at the hypotheses formed. Fourteen studies were reviewed, and table 5.1 summarizes the methods and results of each study.

TABLE 5.1

BALANCE AND CONCUSSION IN ATHLETES LITERATURE REVIEW

Year	Journal	Author	Population	Measures	Results
2012	Disability and Rehabilitation	Kleffelgaard	52 subjects with MTBI	Good Balance Metitur (GBM) w/ Force Platform	No significant changes in self-reported balance problems or post-concussion system severity from 1 to 4 years
2009	British Journal of Sports Medicine	Davis	N/A	Looked at BESS and SOT	N/A

TABLE 5.1 (continued)

2011	The International Journal of Sports Physical Therapy	Barlow	106 patients	Post-Concussion Symptom Scale (PCSS); BESS; Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)	Mild correlation between BESS and ImPACT (r=-0.31; P=0.002)
2009	Journal of Athletic Training	Broglio	48 participants free from injury	BESS	Time main effect was significant (p<0.01)
2011	Journal of Athletic Training	Beaumont	21 college football players with previous concussion and 15 non-concussed football players	Force platform used to assess center of pressure (COP) displacement and COP oscillation regularity as measures of postural stability	Previously concussed athletes showed persistently lower COP oscillation randomness, normal performance of a rapid alternating movement task, and more primary motor cortex inhibition that was related to the number of previous concussions
2010	Scandinavian Journal of Medicine and Science in Sports	Schneiders	90 healthy and physically active males and females aged 18-32 years	BESS after exertion	Static balance decreased after exertion and balance errors in static balance increased in BESS

TABLE 5.1 (continued)

2013	Sports Health: A Multidisciplinary Approach	Mulligan	84 participants age 18-26 years	BESS (randomly placed in 1 of 3 groups)	No significant difference among the three groups in baseline BESS scores; No significant difference between the three groups for week 4 BESS scores (P=0.29)
2013	Journal of Sport Rehabilitation	Cripps	1-18 & 19-25 year old concussed athletes	SOT and BESS	Significant declines in balance in days immediately after a concussion when compared with both control group and baseline data
1997	Journal of Sport Rehabilitation	Riemann	20 year old college football player with 3 concussions	SOT and NeuroCom EquiTest System	After receiving a third concussion, the athletes balance scores were well below normal; Lower than what was recorded from first injury
2011	Journal of Sport Rehabilitation	Valovich McLeod	14 year old female soccer player	BESS	BESS score of 18 one week after concussion
2013	Journal of the International Neuropsychological society	McCrea	570 high school and collegiate athletes during 10 year period; control group of 166 athletes	BESS	60.5% (High school) and 39.5% (Collegiate); Despite report of symptoms 45-90 days post-injury in prolonged recovery group, no significant deficits in postural stability

TABLE 5.1 (continued)

2012	The American Journal of Sports Medicine	Valovich McLeod	1134 high school athletes (872 males and 262 females)	SCAT2 (BESS)	Male athletes scored lower on SCAT2 and BESS score than females; 10^{th}, 11^{th}, and 12^{th} graders scored higher (P=0.002) than 9^{th} graders
2012	British Journal of Sports Medicine	Jinguji	214 participants age 13-19 years (59 female, 155 male)	SCAT2 (BESS)	Females scored significantly better in balance (P=0.01) then males; Discrepancy between males and females with age. Female age 13-15 years had total balance score of 27.41 compared to with males 25.25, while females 16-19 years scored 26.38 and males 25.65
2009	Clinical Journal of Sports Medicine	Broglio	32 Concussed collegiate-level athletes	SOT	Significant Spearman Correlations noted between reports of "dizziness" and SOT composite balance (r_s=-0.55) and vestibular ratio (r_s=-0.50)

5.2 Balance Assessments in Concussed Athletes

This study focused on balance as an important symptom following concussion and the need to have an objective form of measurement to assess balance deficits. Sport-related concussion is a substantial problem in all levels of athletic participation (Tommasone & Valovich McLeod, 2006). Balance deficits, both static and dynamic, are one of the most commonly reported physical symptoms following concussion (Davis et al., 2009; Kleffelgaard et al., 2012). The use of postural stability testing for the management of sport-related concussion is gradually becoming more commonplace among sports medicine clinicians (Guskiewicz et al., 2001). Balance assessments are used to document the presence of a concussive brain injury and to help track recovery of the injury (Davis et al., 2009). This is due to potential complications and long-term consequences of returning athletes to competition too early (Tommasone & Valovich McLeod, 2006). Disrupted areas of the brain as a result from a concussive injury have been known to be responsible for the maintenance of postural equilibrium (Guskiewicz et al., 1996; Guskiewicz et al., 2001). The overall postural stability deficit can be explained by a sensory interaction problem that prevents concussed athletes from accurately using and exchanging sensory information from the visual, vestibular, and somatosensory systems (Guskiewicz et al., 2001). The integration of vestibular and visual information is essential for the maintenance of equilibrium under certain altered conditions similar to those performed during SOT (Guskiewicz et al., 2001). It is now being suggested that assessments be measured objectively rather than subjectively.

Traditionally, clinicians have used the Rhomberg test for assessing disequilibrium in head-injured athletes, but only recently has computerized posturography been available to offer a more objective, challenging, and quantifiable assessment (Guskiewicz et al., 2001). The SCAT2 is a multifaceted assessment administered by athletic trainers in the high school level. It consists of both subjective and objective information. SCAT2 assesses concussion-related signs and symptoms, level of consciousness, cognition, balance, and coordination (Valovich McLeod et al., 2012). It is composed of a 22-item graded symptom scale (22 points); a 2-item sign score determining loss of consciousness and balance difficulties (2 points); the Glasgow Coma Scale (GCS) evaluating eye response, verbal response, and motor response (15 points); the SAC for orientation, immediate memory, concentration, and delayed recall (30 points); the modified BESS (30 points); a coordination examination (1 point); and Maddocks questions for sideline assessment (not included in the SCAT2 summary score and only used for sideline diagnosis of concussion) (Valovich McLeod et al., 2012). It is measured on a 100 point scale. SCAT2 is a good multifaceted approach to measuring concussions; however, its main focus is mostly on signs and symptoms reported by the athlete which is subjectively measured. Balance, as an objective measure, needs to be more of a priority when assessing a concussed athlete. It needs to be a primary measurement tool for monitoring recovery and for making return-to-play decisions because progress can be measured daily or weekly (Cripps & Livingston, 2013).

Though the results didn't demonstrate any significant differences between baseline and post-tests for concussed athletes, it is believed this was due to too small of a sample size. Results most likely would have been significant if more concussed athletes would have been in this study. Though no differences were observed, there have been several studies that have shown significant differences between baseline and post-concussion scores. Studies by Beaumont, Cripps, Guskiewicz, Riemann, and Valovich McLeod are among the few that have shown significant differences.

To the author's knowledge, the current study was the only study to assess balance in high school athletes utilizing smartphone accelerometers.

5.3 Balance Assessments and Age

It has been suggested that younger athletes may be susceptible to more prolonged recovery and to concussions associated with catastrophic injury (Harmon et al., 2013). The developing brain differs physiologically from the adult brain when comparing the brain water content, degree of myelination, blood volume, blood-brain barrier, cerebral metabolic rate of glucose, blood flow, number of synapses and geometry and elasticity of the skulls sutures (Harmon et al., 2013). Developmentally, younger brains have less-established engrams which could explain the increase in time to recover from concussions seen in younger athletes then in older athletes (Harmon et al., 2013).

When using baseline assessments, it is often a question by many clinicians as to how frequently baseline testing should be completed, especially in younger athletes (Valovich McLeod et al., 2012). In the study conducted, no significant differences were found between age using the SWAY application using a mobile device; however, in another study, with respect to the baseline SCAT2 score and grade level, total scores for 9th graders compared with 11th and 12 graders were significantly lower. The component scores for the SAC and BESS were also significantly lower in the 9th graders compared with 10th, 11th, and 12th graders (Valovich McLeod et al., 2012).

5.4 Limitations

This study is not without limitations. One limitation present in this study was social or cultural factors that may influence the knowledge or acceptance of technology and its use in health care. If the participant and/or test administrator is unfamiliar or uncomfortable with the current technology used for this study (specifically the iPod), it may cause frustration or apprehension that could potentially affect the results of this study. The success of this study is dependent upon the acceptance and use of current technology.

Another limitation is the number of participants. Though 121 individuals participated in this study, several more participants could have been obtained for this study in order to asses balance in athletes who could have potentially sustained a concussion. Also more participants could have been recruited in order to have more comparisons of younger athletes versus older athletes and females versus males.

Limitation 3 is measuring balance from above the human center of gravity. All previous balance studies have been completed by measuring balance from a platform.

Limitation 4 is the error of the participant while using the device. If the participant moves or looks at the screen of the iPod before the test ends, the movement of the device can affect the data. Furthermore, if the participant makes an error on the first position (center of balance), then all the subsequent positions will be effected because the test did not start at a perfectly balanced state.

Limitation 5 was the participant’s technique. Many of the participants had to be corrected during the trials because they failed to adhere to the protocol of the test. The device is to be placed directly on the chest, while simultaneously holding it with both hands. Many participants held the device with both hands, but didn’t press if directly on his/her chest and instead holding if 1 to 2 inches off of the chest. The results may be inconsistent or inaccurate because the device is recording movements of the hands and arms, rather than the movements of the center of mass.

Limitation 6 was correct syncing of the iPods and being able to connect to wifi. Several participants balance scores were not used due to the iPod not syncing correctly. Also wifi was very difficult to attain due to using iPod touches and not iPhones. This created difficulty when more profiles needed to be added while testing.

5.5 Practical Implications

Assessing balance from a mobile device is practical because the device measures the stability index from center of mass (sternum level of the chest), where the device is held during the test. This may suggest an advantage of measuring human balance because the device gives a balance score without any subjective error scoring system being utilized such as the BESS test.

5.6 Future Research

Baseline balance scores and balance deficits after concussions occur need to be further researched. A baseline can provide values for comparison in order to help determine return-to-play for all athletes. Other research needs to be conducted on balance assessments of adolescents because research has suggested there is a comparative difference between younger athletes and older athletes due to the development of the brain. Research needs to be conducted on why some athletes experience balance problems after a concussive blow, while others experience no balance problems. This could be due the specific parts of the brain affected by the concussion, but further research needs to be done to understand this phenomena. Future research needs to be conducted on female athletes with concussion versus male athletes with concussions. Recent data suggest that in sports with similar rules female athletes sustain more concussions than their male counterparts (Harmon et al., 2013). Female athletes experience a longer duration of recover than males do which could be due to a decreased head-neck segment mass in females compared to male athletes which could contribute to greater angular acceleration of the head after a concussive blow (Harmon et al., 2013). Further research needs to be conducted on this phenomenon.

5.7 Conclusions

At the conclusion of this study, the researcher has developed the following conclusions:

1. Balance scores in concussed athletes did not show any significant difference between baseline and post-concussion tests. However, there were three large effect sizes and one moderate effect size calculated.
2. No significant differences were found between balance scores and age of the athlete.
3. At least 1500 athletes need to be recruited for participation in a study in order to have adequate amounts of concussed athletes

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