

CONCUSSION ASSESSMENT IN WHEELCHAIR USERS: QUANTIFYING SEATED
POSTURAL CONTROL

BY

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DISSERTATION

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Abstract

Introduction

Approximately 1.6-3.8 million traumatic brain injuries (TBI) occur each year in sport and recreational activity in the United States (Langlois, Rutland-Brown, & Wald, 2006). With concussions occurring in all aspects of sport, it is imperative for proper assessment and management to take place. The National Athletic Trainers' Association calls for evaluation of symptoms, cognition, and balance when a suspected concussion occurs (Guskiewicz et. al., 2004). Although current symptom scales and cognition measures can be utilized in wheelchair athletes all balance measures (e.g. the Balance Error Scoring System) are completed while standing and consequently not applicable to wheelchair athletes, therefore leaving a void in quantifying balance in this population. To properly detect concussions in this population, a seated postural control test was developed. It was the aim of this investigation to determine if this test was valid, reliable and sensitive to concussions in wheelchair athletes. .

Methods

Participants

Wheelchair athletes who were part of a collegiate wheelchair athletics program were recruited for participation. Participants were included if they were able to sit upright without support, had no recent surgeries, and had not reported a concussion within the past month.

Procedures

A seated postural control test, the Wheelchair Error Scoring System (WESS), was developed to quantify balance in wheelchair users. In order to determine if the WESS was appropriate, validity, reliability, and sensitivity had to be shown. To determine the validity of the WESS, seated postural control was indexed with a force platform. WESS scores were correlated to 95% confidence ellipse area, a force platform measure, to examine if the WESS measured postural control. Additionally, a dual-task condition was utilized to test cognitive and motor function simultaneously as sport is performed in this manner.

The WESS was completed twice, 45 days apart, to establish if there were any differences in testing sessions to determine test-retest reliability. Each participants' testing sessions were videotaped and examined by 4 certified athletic trainers. Scores were compared between the 4 athletic trainers to determine the intertester reliability of the WESS. Additionally, each athletic trainer watched and scored the videos 7 days from the original viewing to determine intratester reliability of the WESS.

Recent investigations have examined the use of dual-task testing to increase sensitivity of testing batteries to detecting concussions. This had been tested due to sport requiring both cognition and balance to occur simultaneously. For this reason, a cognitive task was added to the WESS to examine this dual-task paradigm. Three additional trials were added to the WESS to complete the Paced Auditory Serial Addition Task in each testing position. WESS scores and 95% confidence ellipse area were examined to discover the effect of adding a cognitive task to the WESS.

Five cases of concussion were examined to determine if the WESS is sensitive to changes in postural control after a concussion. Participants were baseline tested on a graded symptom scale, the standardized assessment of concussion, and the WESS. Post-injury scores were

compared to baseline values or a control in one case to determine if the WESS detected changes in postural control after concussion.

Results

Significant bivariate correlations were found between WESS error scores in specific positions and 95% confidence ellipse areas, showing validity of the WESS in measuring postural control. The WESS was found to have test-retest reliability as the scores between the 2 testing dates were not significantly different. The WESS also showed intertester and intratester reliability, thus making it usable between different administrators and across time. The addition of the cognitive task, the PASAT, improved balance performance in the wheelie position. In each of the case studies, WESS scores showed a decrease in postural control after concussion indicated by changes in WESS scores compared to baseline values.

Discussion

The WESS was developed to meet the void in balance measurement for concussion assessment in wheelchair athletes. The standard sideline balance assessment tool for concussions in ambulatory athletes is the BESS in which the WESS was modeled after. Both tests are quick, inexpensive, and easy to utilize on the sidelines of athletic events. Given the WESS is comparable and has similar testing instructions to the BESS, this allows clinicians already familiar with the BESS to easily implement the WESS in wheelchair sport and wheelchair users.

The addition of the cognitive task, the PASAT, increased postural control during the wheelie position. In theory, this could be due to the participant's focus being externally diverted to the cognitive task. This allows for less overcorrections to be made and for balance to occur as it normally occurs, subconsciously.

The WESS detected changes in postural control in each of the five cases of concussion in this investigation. With each case study showing increased WESS scores after concussive injury, this strongly suggests the WESS would be an appropriate test for quantifying seated postural control in wheelchair users during concussion assessment.

Conclusion

This investigation suggests the WESS is an appropriate test for quantifying seated postural control in wheelchair users. While a few documented concussions have shown the WESS is sensitive to detecting postural changes associated with concussion, further investigations are needed to examine this statistical relationship.

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Chapter 1: Introduction

In the United States, there are an estimated 1.5 million individuals who use manual wheelchairs (Kaye, 2000). This population is expected to increase due to the combination of the ongoing military conflicts, aging, our advanced medical care effects on survival rates (Kaye, 2000), and improvements in protective gear and vehicle armor for military use (Bass, 2011). With the expanding of the manual wheelchair user population, it is crucial to promote physical activity to this population. Physical activity in people with disabilities has been shown to improve well-being and helps prevent and delay chronic disease (Rimmer, 2004). Increased mood and self-image, decreased depression, anxiety, and stress, and better sleep patterns and health are all additional benefits to physical activity (Giacobbi, 2008). For people with physical disabilities, it aids in maintaining or increasing their level of function so they can stay independent in society. Previous research has shown that individuals with physical disabilities tend to report high levels of inactivity (Tolerico, 2007). Engaging in physical activity is a choice, but for people with physical disabilities there may be barriers that inhibit them from participating. Barriers are plentiful and can include anything from environmental to psychological barriers. By encouraging participation and societal awareness of disability sport, physical activity levels can be increased in those with physical disabilities thus increasing quality of life in those with physical disabilities.

There has been an increase in disability sport participation since the start of the Paralympic games in 1952 in Stoke Mandeville (Gold, 2007). The Paralympics were created to allow for competition for people with physical disabilities that is of equal caliber to the Olympics. It is called Paralympics because it is parallel to the Olympics. With an expected

increase in manual wheelchair users due to military conflicts and advanced medical care, it is expected that disability sport population will similarly increase. This increase in participation calls for the need of increased medical treatment, awareness, and research in disability sport; which has been limited. Studies have examined injuries occurring during disability sport while the majority of these studies focus only on injuries that occur during the two week period of the Paralympics. The Athletes with Disabilities Injury Registry provides information regarding injuries and their severity (Ferrara, 1996). An injury rate of 9.3/1000 athlete-exposures was found in athletes with disabilities. This is similar to a men's basketball rate of 7/1000 athletic-exposures, women's basketball rate of 7.3/1000 athletic-exposures, and a soccer rate of 9.8/1000 athletic-exposures. When looking at the severity of injuries to athletes with disabilities compared to able bodied athletes, severity of injury is quite similar. Athletes with disabilities suffered 52% minor injuries (7 days or less of competition lost), 29% moderate injuries (8-21 days of competition lost), and 19% major injuries (22 or more days of competition lost) compared to the able bodied counterparts who suffered 70% minor injuries, 20% moderate, and 10% major injuries. Through these studies it appears that athletes with disabilities face similar injury exposure rates as their able bodied counterparts, yet research in this area is limited. One aspect that has yet to be examined in disability sport is concussion. With increased societal interest to this injury, it is necessary to expand this attention to disability sport to ensure all aspects of concussion are considered.

Concussion is defined as “a complex physiological process affecting the brain, induced by traumatic biomechanical forces” (McCroory et. al., 2013, p. 1). Concussions can result in cognitive and motor deficits that may have acute and/or chronic effects. Typically, concussions present with but are not limited to the following signs and symptoms: headache, confusion,

tinnitus, vertigo, sensitivity to light and/or noise, nausea, sleep disturbance, change in emotional state, difficulty with balance and coordination, and difficulty concentrating (Guskiewicz, 2004). Symptom duration and severity varies with each concussion. Full symptom resolution usually occurs within ten days (McCrorry et. al., 2013), however, some symptoms may resolve sooner. Balance deficits tend to dissipate within 3-5 days post-injury (McCrea, 2003). Neuropsychological deficits have a tendency to return to normal by day 5 (Macciocchi, 1996). Typically, symptoms will resolve and return to normal. If this progression does not occur, post-concussion syndrome is experienced. This syndrome is characterized by lack of complete resolution of concussive symptoms that can last anywhere from months to years. A typical course of action for post-concussion syndrome is rest and refraining from activities that worsen symptoms or make them reoccur. Some medications may be prescribed for lasting symptoms however there is no evidence based recommendations for this use (Jotwani, 2010).

While most deficits resolve within days, it is speculated that some lasting effects may be seen years later resulting in chronic traumatic encephalopathy (McKee, 2009). More recent research has shown lasting effects of multiple concussions in National Football League (NFL) players. In a study of retired professional football players, those with three or more concussions were twice as likely of receiving a physician diagnosis of mild cognitive impairment and significant memory problems (Guskiewicz, 2005). This study also showed repetitive concussions may initiate dementia-related syndromes and Alzheimer's disease (AD). In another study of NFL players, it was found multiple TBI is a risk factor for depression as those with three or more concussions had three-fold risk of depression while those with only concussion were not at risk (Guskiewicz, 2007). Another lasting effect shown in multiple athletes is chronic traumatic encephalopathy (CTE). This condition, also termed 'punch-drunk', commonly shows

a decline in cognitive function, memory, and concentration in later years of life (McKee, 2009). CTE may also present with disorientation, confusion, mood disturbances, headaches, dizziness, and gait abnormalities (McKee, 2009). Physical findings of CTE have been found to be Tau deposits, “reduction in brain weight, enlargement of the lateral and third ventricles, thinning of the corpus callosum, cavum septum pellucidum with fenestrations, and scarring and neuronal loss of the cerebellar tonsils” (McKee, 2009, pgs. 5-6). Those who have presented with CTE are athletes who have been involved in football and boxing and it appears the severity of CTE correlates with the length of time spent in the sport (McKee, 2009). Those who have been in the sport longer tend to have more severe cases of CTE and those who live longer experience greater symptoms of CTE as the condition progresses with time. These studies highlight the potential risks for sustaining multiple head injuries. With the potential of life long deficits resulting from concussion, it is vital to properly manage and assess this injury.

Since concussions are largely subjective, identification of them poses difficulties. Also, there are no biological markers of concussion and tests are not 100% sensitive to concussions thus making concussions harder to identify (McCrea, 2004). With the competitive nature of sports, some athletes may not want to verbalize their symptoms in fear of being withheld from their sport. Other athletes may not realize the danger of continuing to play with concussive symptoms. In order to assess a concussion, it is a common practice to use symptoms, cognition, and postural control to fully assess the effects of concussion. Broglio (Broglio, Macciocchi, & Ferrara, 2007) found that when these three assessments are used in the assessment procedure, they are sensitive to concussion 89-96% of the time. It is not enough to simply test these three measures after an injury occurs. With other orthopedic injuries, the uninjured limb or side of the body is used to assess normal values for each individual. However, with concussion you

obviously do not have this luxury (Oliaro, 2001). To distinguish normal, pre-injury values, it is imperative to baseline test at risk individuals to ensure proper assessment can occur. Baseline scores help distinguish individual differences so no assumptions have to be made. They are best completed before the season starts for the athlete. More recent research suggests the use of a dual-task paradigm which allows for cognitive and motor tasks to be completed concurrently. This is important given sport requires both cognition and balance to occur simultaneously, so return to play decisions would be more appropriately made when both are tested in similar manners.

Standard concussion assessment involves assessing cognition, balance, and symptoms (Guskiewicz, 2004). Measures of cognition and symptoms that are currently available to medical professionals can easily be used in the disability sport population. Balance assessments (Balance Error Scoring System, Sensory Organization Test, Romberg's Test), however, cannot be used as the measures commonly used all require a standing posture which may not be applicable to all athletes with disabilities. To date, there are no seated postural control assessments that are applicable to wheelchair athletes. With this void in assessment, it is crucial to develop an assessment for this purpose.

Chapter 2: Specific Aims and Hypothesis

Statement of Purpose and Hypotheses:

The purpose of this investigation is to develop a valid and reliable seated postural control assessment for individuals who utilize manual wheelchairs who are at risk of concussion.

Specific Aim 1: To develop a postural control assessment to be used in the assessment of concussion

Hypothesis 1: We hypothesize a seated modification of the Balance Error Scoring System will be an effective tool for measuring seated postural control.

Specific Aim 1.1: To determine the relationship between the Wheelchair Error Scoring System (WESS) and objective sway measures recorded on a force platform.

Hypothesis 1.1: We hypothesize that the WESS test and force platform measures will correlate strongly and positively.

Specific Aim 1.2: To determine the test-retest reliability of the WESS.

Hypothesis 1.2: We hypothesize the WESS will have similar test-retest reliability as the BESS. The scores from the original test date and the day 45 retest date will have a strong, positive correlation.

Specific Aim 1.3: To determine the intertester reliability of the WESS.

Hypothesis 1.3: We hypothesize the WESS will have strong/high intertester reliability.

Specific Aim 1.4: To determine the intratester reliability of the WESS.

Hypothesis 1.4: We hypothesize the WESS will have strong/high intratester reliability.

Specific Aim 2: To determine if the addition of a cognitive task influences WESS performance

Hypothesis 2: We hypothesize the addition of a cognitive task will increase balance performance.

Specific Aim 3: To determine if the WESS is sensitive and specific to concussions.

Hypothesis 3: We hypothesize the WESS will be sensitive to concussions by showing an increase in number of errors from baseline rates to post-injury errors.

Chapter 3: Literature Review

Concussion

Concussion Defined

When it comes to defining concussion, there is not one universal definition. However, numerous organizations have provided varying definitions. For this research project, a concussion will be defined as “a complex physiological process affecting the brain, induced by traumatic biomechanical forces (McCrory et al., 2013, pg. 1).” It is followed by a complex cascade of ionic, metabolic, and physiological events that can adversely affect cerebral function for several days to weeks (Giza & Hovda, 2001). Symptoms associated with concussion typically resolve spontaneously (Summary and agreement statement of the 1st international symposium on concussion in sport, Vienna 2001, 2002) and are a result of a functional disturbance rather than a structural injury (Guskiewicz et al., 2004). Symptom resolution occurs in a sequential manner, however, occasionally symptoms may persist resulting in post-concussion syndrome (McCrory et al., 2009). Concussion is categorized as a diffuse brain injury as it causes widespread neuronal dysfunction (Bailes & Hudson, 2001). No abnormalities are seen on structural imaging in the event of a concussion (McCrory et al., 2009). The Congress of Neurosurgeons provided the following definition of concussion in 1966: “Concussion is a clinical syndrome characterized by immediate and transient impairment of neural functions, such as alterations of consciousness, disturbance of vision, equilibrium, etc. due to mechanical forces (Guskiewicz, 2004, pg. 283)”. Regardless of the definition used, concussions are a common occurrence during sport and a better understanding of this injury is essential.

Neurometabolic Cascade Following Concussion

Impairment of cognitive and motor function follows a concussion injury due to a neurometabolic cascade that begins immediately following the initial injury. After the initial injury, there is an immediate discharge of neurotransmitters and an occurrence of ionic fluxes (Giza & Hovda, 2001). This ionic flux occurs from a shift in potassium and calcium which lead to cellular physiology changes. Due to these changes, the sodium-potassium pump has to work harder to try to restore the membrane potential which causes a demand for more energy to allow this process to occur. This causes an increase in glucose metabolism and causes a cellular energy crisis (Giza & Hovda, 2001). Concussion causes a decreased cerebral blood flow, possibly in upwards levels of 50%, which contributes to the energy crisis (Giza & Hovda, 2001). As potassium levels increase, excitatory amino acid glutamate gets further released and receptors for this open up even more which creates greater potassium flux. In order to properly function, the brain needs homeostasis so membrane pumps are activated. This process occurs best with the help of glycolysis (Giza & Hovda, 2001). Glycolysis is also increased by impairment of mitochondrial function which causes a decrease in adenosine triphosphate. However, increased glycolysis causes an increase in lactate production which could potentiate further injury (Giza & Hovda, 2001). Calcium accumulation in the brain also occurs after injury and can maintain that way for 2-4 days. This increase could be due to decreased levels of magnesium. Decreased levels of magnesium can slow protein synthesis, impair adenosine triphosphate production, and may lead to a flux in calcium levels. Decreased magnesium levels have been correlated to post-injury neurological deficits (Giza & Hovda, 2001).

Mechanism of Injury

It is often thought that concussions can only occur as a result of a direct blow to the head. However, concussions can also occur when there is impact to some part of the body with forces being transmitted to the head (Summary and agreement statement of the 1st international symposium on concussion in sport, vienna 2001.2002). This is termed an indirect impact as it puts the head into motion without direct head contact (Guskiewicz & Mihalik, 2011). These types of impacts commonly occur as a result of tackling or checking which abruptly stops the head from moving (Guskiewicz & Mihalik, 2011). Acceleration/deceleration is a common cause of concussion. When the head is free to move around, more injury is typically sustained than if the head is immobilized (McCrory, 2001). Acceleration can cause brain strain patterns which result in injury (Guskiewicz & Mihalik, 2011).

Loads applied to the head can be static or dynamic in nature. Static loads last longer than 200 milliseconds while dynamic loads are shorter than 200 milliseconds (McCrory, 2001). When the brain endures these impacts, three different types of stresses can occur: tensile, shearing, and compressive (Guskiewicz et al., 2004). Tensile stresses produce a stretching of tissue (Guskiewicz et al., 2004). Shearing stresses occur as a result of parallel movement across the tissue while compressive stresses occur as a result of a squashing force that does not allow the tissue to absorb additional loads (Guskiewicz et al., 2004). The brain handles brief compressive forces well but has more difficulties with tensile and shearing forces (Guskiewicz et al., 2004). Rotational impacts are believed to cause shearing and tensile strain as the cerebrum moves around the brain stem (Guskiewicz & Mihalik, 2011). As a result of impact, the brain may experience a coup or contrecoup injury. A coup injury results from a direct impact of the cerebral tissue with the inner surface of the cranium (Guskiewicz et al., 2004). The injured brain

tissue lies directly under where the trauma occurred. A contrecoup injury results when the cerebral tissue rebounds and contacts the opposite cranial surface (Guskiewicz et al., 2004). The brain shifts when the impact occurs and trauma occurs on the opposite side from where the impact was sustained. When a concussion occurs as part of sport, impacts that cause concussions could be intentional or unintentional. Intentional impacts come from the nature of the sport such as tackling in football. Unintentional impacts may occur from crashes with equipment, boundary obstructions, or another person (Powell, 2001). Concussion can result from various impacts and stresses and presents with a host of signs and symptoms.

Signs and Symptoms of a Concussion

When concussion occurs, a host of signs and symptoms may present. Not every concussion will present with the same signs and symptoms, however some combination of them could occur. The NATA position statement provides the following list of signs and symptoms that may occur following concussion:

headache, nausea, vomiting, dizziness, balance problems, feeling 'slowed down', fatigue, trouble falling asleep, drowsiness, sensitivity to light or noise, LOC, blurred vision, difficulty remembering or difficulty concentrating (Guskiewicz et al., 2004, pg. 283).

While this is an extensive list, concussion symptoms are not bound by this list. Other symptoms may include irritability, confusion, slow to answer questions, amnesia, poor concentration, vacant stare, glassy eyes, and personality changes (McCrorry et al., 2005). While symptoms may appear at the initial time of injury, some may be delayed by several hours (McCrorry et al., 2005).

Trademark signs appear to be confusion, amnesia (Guskiewicz, 2003), and decreased balance (Guskiewicz, Riemann, Perrin, & Nashner, 1997) with headache being the most commonly reported symptom (Guskiewicz, 2003). Headache is reported in upwards of 70% in athletes with concussions (Lovell, Collins, & Bradley, 2004). Another common symptom is fatigue which is commonly reported in the days after a concussion (Lovell et al., 2004).

When the impact of the concussion is sustained on the back of the head, visual disturbances (i.e. blurry vision, photosensitivity, etc.) and balance deficits are commonly reported. Balance deficits can be explained by sensory interaction deficits in which visual, vestibular, and somatosensory information fails to provide accurate information (Guskiewicz, Ross, & Marshall, 2001). In a study of 36 concussed individuals, postural control compared to baseline values was adversely affected following concussion, specifically the visual component as seen through decrements using the sensory organization test (Sosnoff, Broglio, & Ferrara, 2008). Additionally, in a study of concussed and non-concussed individuals, changes in postural control were seen using approximate entropy (ApEn) when clinical balance tests showed no balance deficits (Cavanaugh et al., 2005). The concussed individuals had a decline in the randomness of center of pressure oscillations compared to the uninjured group, thus indicating subtle postural control deficits are present in concussed individuals though they may not be visible. While the exact cause(s) of postural deficits following concussion are not known, there are speculations of inadequate sensory integration, disruption of axons, and a brain energy crisis causing these discrepancies.

Symptom duration and severity varies with each concussion. Full symptom resolution usually occurs within 5-7 days (McCrea et al., 2003), however, some symptoms may resolve sooner. Balance deficits tend to dissipate within 3-5 days post-injury (McCrea et al., 2003).

Neuropsychological deficits have a tendency to return to normal by day 5. Typically, symptoms will resolve and return to normal. If this progression does not occur, post-concussion syndrome is experienced.

Post-Concussion Syndrome

The World Health Organization says post-concussion syndrome (PCS) occurs after a head injury and presents with three or more the following concussive symptoms: headache, dizziness, fatigue, irritability, memory impairment, insomnia, difficulty concentrating, or reduced tolerance to stress, emotional excitement or alcohol (Jotwani & Harmon, 2010). The Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) provides a slightly varying definition. PCS occurs after a head injury with two of the following: loss of consciousness for five or more minutes, posttraumatic amnesia for 12 hours or more, or onset of seizures within six months. Also, difficulty concentrating and learning and three of the following symptoms must persist for three months: headache, sleep disturbance, irritability, easily fatigued, anxiety, depression, personality change, or apathy (Jotwani & Harmon, 2010). While these definitions are detailed, they may not be appropriate for sport concussion. Jotwani and Harmon (Jotwani & Harmon, 2010) suggest defining PCS as a persistence of concussive symptoms for a longer time frame than normally expected. A typical course of action for PCS is rest and refraining from activities that worsen symptoms or make them reoccur. Some medications may be prescribed for lasting symptoms however there is no evidence based recommendations for this use (Jotwani & Harmon, 2010). The first criterion for return to play is typically resolution of all symptoms. With symptoms lingering in PCS, return to play is more difficult to determine and may not ever be achieved if symptoms persist.

Second Impact Syndrome

It is a concern that if a concussed person sustains a second impact to the head before complete resolution of symptoms of the initial injury, second impact syndrome (SIS) may occur. The second impact causes cerebral vascular congestion which in return causes swelling with death typically following (McCrorry, 2001). This second impact may not be as severe as the initial impact or may not even occur to the head at all (Cantu, 1998). With SIS, there is a loss of autoregulation of the brain's blood supply which leads to cranial engorgement, increased intracranial pressure, then finally herniation of the temporal lobes through the foramen magnum (Cantu, 1998). This sequelae usually occurs 15 seconds to several minutes after the second impact. The individual may appear alert at first then quickly looks confused and will collapse to the ground. The pupils will rapidly dilate and the individual will have loss of eye movement (Cantu, 1998). This progression typically only takes minutes. Whether or not this syndrome actually exists has been debated. However, it does seem adolescents are the most at risk for this condition as it has only been found in this population. McCrorry et al. stated two groups seemed to be at risk of this condition; adolescents and boxers (McCrorry, Davis, & Makdissi, 2012). However, the boxers documented in these cases were still in their early twenties, thus still representing a young age. Conclusive evidence for either debating side has yet to be given.

Cumulative and Prolonged Effects of Concussion

While symptoms tend to resolve quickly with concussion, there may be lasting effects. Numerous studies have shown decreased cognitive performance when an individual has

sustained multiple concussions. Iverson et al. (Iverson, Gaetz, Lovell, & Collins, 2004) showed in a study of amateur athletes that signs and symptoms associated with concussion were worse in subsequent concussions and memory was decreased two days post-injury. They also found those with a previous history of concussion had lower preseason memory scores and were more likely to report post-concussion symptoms on a normal basis (Iverson et al., 2004). In a study of high school athletes, Moser et al. (Moser, Schatz, & Jordan, 2005) could not distinguish cognitive scores between a group of athletes who had previous history of concussion but did not display signs and symptoms of concussion and a group who had sustained a concussion within the previous week. Attention and cognitive flexibility were affected in both of these groups. The group with a history of previous concussions also had a lower grade point average. One thing that cannot be determined from this however, is a casual relationship. Do those with multiple concussions show decreases in cognitive performance; or perhaps are those with decreased cognitive performance more susceptible to concussion? Further evidence is need to dispute this either way.

Cognitive deficits may be seen after concussion; however, these deficits may not appear until later in life. While these deficits may not present immediately, it has been proposed that they may become more pronounced with aging (Pontifex, O'Connor, Broglio, & Hillman, 2009). Tests currently being conducted may not be sensitive to the subtle long term deficits or may not be observing the correct cognitive functions. Pontifex et al. (Pontifex et al., 2009) examined cognitive function of college-aged students who either had a history of concussion or were free from concussive injuries. They found those with a history of concussion had longer interference reaction times thus showing an inability to increase cognitive control to meet increased attentional needs of tasks with greater difficulty. Through this study they found that tests

designed to measure dramatic cognitive deficits (i.e. ImPACT) may not be applicable to measure lasting effects of concussion on cognitive control. Furthermore, in another study of college students using Concussion Resolution Index (CRI) and Immediate Post Concussion Assessment and Cognitive Testing (ImPACT), cognitive deficits were not present at baseline measure in a group of previously concussed individuals when compared to those with no previous concussions (Broglia, Ferrara, Piland, Anderson, & Collie, 2006). In another study of cognitive deficits, cognitive scores were not significantly different between individuals reporting a history of concussion and a group without a concussive history when using ImPACT during baseline testing (Iverson, Brooks, Lovell, & Collins, 2006). This shows that there could be no lasting cognitive deficits associated with concussion, or the current tests are not sensitive enough for subtle lasting deficits associated with concussion.

While postural control values are believed to return to baseline values approximately three days post-injury, postural control dynamics may still be altered (Sosnoff, Broglia, Shin, & Ferrara, 2011). To demonstrate this, an investigation was completed using 21 male and 6 female concussed athletes and 30 controls (15 male, 15 female nonathletes) (Cavanaugh et al., 2005). In this investigation, the concussed completed the sensory organization test (SOT) preseason and within 48 hours post-concussive injury. The concussed participants had no change in the center of pressure (COP) displacement measurements. However, instead they had a change in the COP oscillations. The concussed group had more random center of pressure displacements, however, instability was not present. This investigation shows that while noticeable balance deficits were not visible, subtle changes in balance were present in the form of random oscillations in center of pressure (Cavanaugh et al., 2005).

Given subtle postural control deficits may be present but not visible, it is imperative to detect these faint differences. SOT and other measures may not be capable of detecting these subtle deficits. SOT gives an equilibrium score. This value is calculated using only two data points, the minimum and the maximum, which only expresses the magnitude of variability (Cavanaugh et al., 2005). In response to this, approximate entropy (ApEn) was developed. ApEn is a statistic developed from nonlinear dynamics. It shows the randomness in center of pressure oscillations and determines the probability of sequences of data points repeating (Cavanaugh et al., 2005). Acute concussion has been associated with a decrease in the randomness of center of pressure measurements as injury constrains the postural control system. In another study of concussed athletes (19 male, 10 female), the SOT was completed preseason, within 48 hours of injury, and between 48-96 hours post-injury and an ApEn analysis was completed (Cavanaugh et al., 2005). While SOT equilibrium scores returned to normal within 3-4 days, ApEn values did not return to preseason values in the same time frame. The concussed individuals presented a constrained postural control system evident in the loss of randomness of the center of pressure. Optimal postural control is unconstrained and shows more irregular patterns of movement. This study shows the possible value of ApEn in the direction of subtle postural control changes following concussion.

To further these researches, individuals with and without a previous concussion history were examined using the SOT and ApEn. While the two groups did not significantly differ on balance scores, they differed on postural strategies during anteroposterior (AP) and mediolateral (ML) tasks, thus showing task-dependent alterations in postural control (Sosnoff et al., 2011). Those with a concussion history showed an increase in time-dependent structure of the AP sway with increased AP task difficulty and a decrease in time-dependent structure of the ML sway

with increased ML task difficulty while those with no concussion history had inverse results. While prolonged postural control alterations may not be immediately evident following concussion, those with a history of concussion show altered postural control strategies.

Once a concussion has been suffered, the person is more likely to sustain subsequent concussions compared to those who have never suffered this injury. In a study of football players, those with three previous concussions were three folds more likely to sustain another concussion than those who had never experienced one before (Guskiewicz, 2003). Those with a concussive history also had longer symptom recovery on further concussions compared to those who had encountered a concussion for the first time. After a concussion has been endured, there is a 7-10 day window of vulnerability (McCrea et al., 2009). In a study of 635 concussed individuals, 80% of the individuals who experienced repeat concussions did so within this window of vulnerability (McCrea et al., 2009). Additionally, the risk of developing neurodegenerative disease later in life increases with repetitive brain trauma even when the initial trauma was not severe enough to cause long-lasting disability (Laurer et al., 2001). In a study of mice who were introduced to two concussive injuries in a 24 hour period, they experienced prolonged functional neurological deficits and histopathological damage. It is also led to significant impairment in neurological function tests up to eight weeks post-injury when compared to mice who only endured one concussive episode in 24 hours (Laurer et al., 2001). This evidence supports the notion that multiple concussions sustained in a short period before recovery from the initial injury has occurred could cause even further cognitive deficits. Also, it suggests the brain has increased vulnerability after a concussion (Laurer et al., 2001).

More recent research has shown lasting effects of multiple concussions in National Football League (NFL) players. In a study of retired professional football players, those with

three or more concussions were twice as likely of receiving a physician diagnosis of mild cognitive impairment and significant memory problems (Guskiewicz et al., 2005). This study also showed repetitive concussions may initiate dementia-related syndromes and Alzheimer's disease (AD). In another study of NFL players, it was found multiple TBI is a risk factor for depression as those with three or more concussions had three-fold risk of depression while those with only concussion were not at risk (Guskiewicz et al., 2007). Another lasting effect shown in multiple athletes is chronic traumatic encephalopathy (CTE). This condition, also termed 'punch-drunk', commonly shows a decline in cognitive function, memory, and concentration in later years of life (McKee et al., 2009). CTE may also present with disorientation, confusion, mood disturbances, headaches, dizziness, and gait abnormalities (McKee et al., 2009). Physical findings of CTE have been found to be "reduction in brain weight, enlargement of the lateral and third ventricles, thinning of the corpus callosum, cavum septum pellucidum with fenestrations, and scarring and neuronal loss of the cerebellar tonsils (McKee et al., 2009, pgs. 5-6)." Those who have presented with CTE are athletes who have been involved in football and boxing and it appears the severity of CTE correlates with the length of time spent in the sport (McKee et al., 2009). Those who have been in the sport longer tend to have more severe cases of CTE and those who live longer experience greater symptoms of CTE as the condition progresses with time. These studies highlight the potential risks for sustaining multiple head injuries.

Gender Differences

Whether or not there are gender differences in concussion recognition, severity, and outcome have been recently studied. While there are no evident conclusions of this research, few findings have emerged. It appears females suffer from a greater incidence of concussions

compared to males (Dick, 2009). Females also tend to have a longer recovery from concussion (Covassin, 2011) and are at higher risk for poor outcome compared to males (Bazarian, Blyth, Mookerjee, He, & McDermott, 2010). The reason(s) that females are at a greater risk for concussion is currently unknown. It has been speculated that female's smaller stature and proportionally weaker neck musculature places them at greater risk for concussion (Covassin, Swanikt, & Sachs, 2003). It has also been speculated that females have a tendency to be more honest in injury reporting, while males are culturally encouraged to continue engaging in activity as to not be removed from play (Dick, 2009). Therefore, incident rates may be similar for each gender; however males' head injuries are going unreported. Further work is needed to determine what factors contribute to the gender discrepancy in concussion incidence.

Incidence Rates

It is estimated that 1.6-3.8 million traumatic brain injuries (TBI) occur each year in sport and recreational activity in the United States (Langlois, Rutland-Brown, & Wald, 2006). A number of studies examining concussion incidence rates in varying able-bodied sports have been reported. The incidence rate varies according to the nature of the sport with greater incidence in contact sports. Incident rates range from 2.6% in women's gymnastics (Marshall, Covassin, Dick, Nassar, & Agel, 2007) to 21.6% in women's hockey (Agel, Dick, Nelson, Marshall, & Dompier, 2007). Females also tend to have a greater concussion incidence than males. For instance, in able-bodied basketball the concussion incident rates are 3.6% in men's basketball (Dick, Hertel, Agel, Grossman, & Marshall, 2007) and 6.5% in women's basketball (Agel et al., 2007). Additionally, concussion incidence in able bodied basketball as well as hockey is

approximately twice as great in females than in males (Agel et al., 2007; Agel et al., 2007; Dick et al., 2007).

Unreported Concussions

While there are varying beliefs of the incident rates of concussion in sport, it is a common belief that underreporting of concussion occurs, thus making actual concussion rates higher than published. McCrea et al. (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004) examined unreported concussions in high school football players and found concussions were only reported 47.3% of the time. This rate is alarming given the seriousness of the injury and potential for catastrophic results if not managed properly. Reasons for not reporting the concussion were as follows: did not want to leave the game, did not know it was a concussion, did not want to let teammates down, with the most commonly reported reason being not thinking the concussion was serious enough (McCrea et al., 2004). This study shows the need for education of those involved with sport to the consequences associated with continued activity after concussion.

Grading Concussion Severity

Just as the definition of concussion is not universal, neither are the grading scales used. Grading scales are used to rate the severity of concussions. They have evolved over time; however, grading scales have been abandoned following the most recent concussion consensus statement (McCrory et al., 2009). Numerous older grading scales focused on amnesia and loss of consciousness as the two main markers for injury severity {Tables 3.1-3.9}. In some older

views, if loss of consciousness and amnesia were not present then it was not considered a concussion (McCrea, 2001). However, evidence for using loss of consciousness and amnesia as markers of severity is scarce (Guskiewicz et al., 2004). Guskiewicz et al. (Guskiewicz, Weaver, Padua, & Garrett, 2000) found that loss of consciousness was only reported in 9% of their cases while amnesia was only reported 27% of the time. These two symptoms may not always be present when grading concussions, thus making it difficult to grade solely on the presence of these two symptoms. Now, it is commonly held that there may be subtle cognitive deficits with concussion that may not be as obvious as loss of consciousness (McCrea, 2001). The NATA position statement on concussion (Guskiewicz et al., 2004) gives 3 possible approaches to grading concussions. One could grade the concussion at the initial time of injury using the American Academy of Neurology Concussion Scale {Table 3.8}. Another approach is not grading the concussion until all symptoms have resolved and then using the Cantu Evidence-Based Grading Scale {Table 3.7}. The final given approach is to not focus on grading concussions, rather, focus on being asymptomatic and then progress from there. The grade of the concussion for this approach is not of importance, rather ensuring the person is returned to activity at the proper time. Return to play decisions can be made with the use of varying assessment protocols.

Assessment Battery

Since concussions are largely subjective, identification of them poses difficulties. Also, there are no biological markers of concussion and tests are not 100% sensitive to concussions thus making concussions harder to identify (McCrea et al., 2004). With the competitive nature of sports, some athletes may not want to verbalize their symptoms in fear of being withheld from

their sport. Other athletes may not realize the danger of continuing to play with concussive symptoms. In order to assess a concussion, it is a common practice to use symptoms, cognition, and postural control to fully assess the effects of concussion. Broglio (Broglio, Macciocchi, & Ferrara, 2007) found that when these three assessments are used in the assessment procedure, they are sensitive to concussion 89-96% of the time. It is not enough to simply test these three measures after an injury occurs. With other orthopedic injuries, the uninjured limb or side of the body is used to assess normal values for each individual. However, with concussion you obviously do not have this luxury (Oliaro, Anderson, & Hooker, 2001). To distinguish normal, pre-injury values, it is imperative to baseline test at risk individuals to ensure proper assessment can occur. Baseline scores help distinguish individual differences so no assumptions have to be made. They are best completed before the season starts for the athlete. It is also imperative to baseline test the athlete not only when it is convenient for the test giver, but also for the athlete. Often, baseline testing occurs when it is convenient for the test giver which may be when the athlete is fatigued or injured from practice or perhaps when the athlete is ill. Those who are sick or injured tend to report higher baseline symptoms (Piland, Ferrara, Macciocchi, Broglio, & Gould, 2010), thus not truly being indicative of normal values.

Self-reported Symptoms

Graded symptoms scales are often used to evaluate symptoms associated with concussion. In a study of certified athletic trainers (ATCs), 85% of the ATCs used a symptom checklist during their concussion assessment (Notebaert & Guskiewicz, 2005). These scales focus on symptoms related to cognition, information processing, balance, and memory (Piland et al., 2010). It is imperative to measure not only the presence of these symptoms, but also the

severity (Piland et al., 2010). Assessing the severity of each symptom allows you to mark progress or digression post-injury. Measuring severity can be done using a Likert-type scale. As symptoms individually vary on a normal basis, it is also important to complete this measure during baseline testing. This helps ensure post-injury recovery can be properly managed and restored to baseline levels. The National Athletic Trainers' Association recommends the use of the Graded Symptom Check List to measure self-reported symptoms (Guskiewicz et al., 2004). Using a symptom check list is a quick and cost efficient way to obtain this information (Elleberg, Henry, Macciocchi, Guskiewicz, & Broglio, 2009). However, this check list has a down fall in that it is self-reported and the individual may not be willing to accurately report their symptoms due to peer pressure and not wanting to cease current activity (Elleberg et al., 2009). While the self-reported symptom scale is important to use, the results must be cautiously interpreted.

Neuropsychology

Another important aspect of concussion assessment is assessing cognitive function via neuropsychological testing. Neuropsychological testing is best utilized when baseline assessments are taken before an injury has occurred. This is essential so you do not have to compare post-morbid scores to normal values which may not account for individual differences such as previous head injury, learning disability, attention deficit disorder, test anxiety, psychiatric problems, or educational background (Grindel, Lovell, & Collins, 2001). Various areas of the brain can be affected with each concussion. For this reason, it is imperative to test a variety of brain functions (i.e. Information processing, motor dexterity, verbal memory, visual memory, executive function, and concentration) to ensure a complete assessment can be made

(Grindel et al., 2001). One negative aspect of neuropsychological testing is the chance for practice effects. Practice effects can occur when an individual repetitively completes testing and obtains better scores due to practice alone. Practice effects can be minimized by reducing retesting and using equivalent variations of the tests (Grindel et al., 2001).

Pencil and Paper Testing

The traditional method of this testing was completed using pencil and paper tests. The advantage of this type of test is the tests are usually freely available online to use (Collie, Darby, & Maruff, 2001). However, the time needed to complete a battery of paper and pencil tests is consuming and may not be applicable to teams with large numbers. To properly assess the results of these tests, it may take a trained neuropsychologist which is not always available and not cost efficient (Elleberg et al., 2009). {Table 3.10}

Computer Testing

With the advancement of technology, many have turned to using computerized assessments of cognition. The use of computers has helped reduce some of the problems associated with pencil and paper testing. Computerized testing allows for a standard administration technique across users and can be used to test groups at a time as long as computer resources are available (Collie et al., 2001). It also helps reduce any practice effects by having numerous forms of the tests readily available for use (Collie et al., 2001). Another advantage is the location of data. Data can be quickly stored in a central location either in an online data base or locally on a computer. This allows for quick access of the data and

possibilities of sending the test to a neuropsychologist to be examined. However, computerized assessments are not free from drawbacks. If the location of test administration does not have multiple computers available, testing can be time consuming. It can also be expensive to complete these tests. The software can be expensive and some of the programs require additional hardware to complete the assessment thus adding further expenses (Collie et al., 2001). Poorly designed computer interfaces may also increase testing anxiety in users who could already be cognitively impaired (Schatz & Zillmer, 2003). Furthermore, these tests are not typically accessible on the sideline where medical professionals may need them for quick assessment of concussion to determine whether or not the individual may resume activity. There are four computerized tests commonly used for the assessment of concussions: Immediate Post Concussion Assessment and Cognitive Testing (ImPACT), Axon, Concussion Resolution Index (CRI), Automated Neuropsychological Assessment Metrics (ANAM) and CNS vital signs.

Immediate Post Concussion Assessment and Cognitive Testing(ImPACT)

This computerized test comprises six neurocognitive subtests: word memory, design memory, X's and O's, symbol match, color match, and three letters. These subtests give five composite scores in the following areas: verbal memory, visual memory, visual motor speed, reaction time, and impulse control. The ImPACT also includes a self-report symptom scale and a concussion history form. The test requires approximately 25 minutes to complete. Schatz et al. (Schatz, Pardini, Lovell, Collins, & Podell, 2006) showed ImPACT is sensitive and specific to the neurocognitive and neurobehavioral effects of concussion. During their study, 85% of concussions were correctly identified using this software.

Axon

Axon is a computerized test measuring reaction time, attention, short term memory and new learning, incidental memory, adaptive problem solving, continuous performance, and spatial abilities (Schatz & Browndyke, 2002). The test takes approximately 20 minutes to complete and requires the results be sent to Axon for analysis in which they will analyze the results at a cost of \$50.

Concussion Resolution Index (CRI)

This test is provided by HeadMinder Inc. and is available online. This test measures reaction time and speed decision making and is sensitive to post-concussion symptoms. This also includes a Sideline Assistant which is a PDA tool that gives health and contact information for your roster of athletes and has the Standard Assessment of Concussion electronically available. Results of the test are stored on HeadMinder's server. The CRI has strong concurrent validation with the following pencil and paper tests: Trail Making Test, Grooved Pegboard, Symbol Digit Modalities Test, and the WAIS Digit Symbol and Symbol Search (Schatz & Zillmer, 2003). The CRI has an approximate 25 minute completion time.

Automated Neuropsychological Assessment Metrics (ANAM)

This computerized assessment encompasses 6 subtests in the assessment of concussion. These areas of subtest include simple reaction time, matching to sample, continuous performance

test, math processing, spatial processing, and Sternberg memory. The total time required is approximately 20 minutes.

CNS Vital Signs

CNS Vital Signs is a computerized assessment composed of seven tests testing the following areas: verbal memory, visual memory, psychomotor speed, information processing speed, cognitive flexibility, and complex attention (Gualtieri & Johnson, 2006). The testing battery takes approximately 30 minutes, can be used by anyone with a fourth grade reading level, and has been shown to be sensitive to mild cognitive deficits (Gualtieri & Johnson, 2006)

Standardized Assessment of Concussion (SAC)

When computerized assessments are not readily available, perhaps a more convenient tool such as the SAC could be used. The SAC is a measure of orientation, immediate memory, concentration, and delayed recall that takes approximately five minutes to complete. A summation score from the aforementioned areas provides a quick reference of cognitive function with a maximum score of 30. The SAC was designed to be used by non-neuropsychologists with no prior expertise in psychometric testing (McCrea, 2001). It is imperative to have a baseline measure to be able to compare the post-morbid score to normal values for each individual. The SAC is most useful when used immediately following concussion as it is a reliable measure of cognitive status (Guskiewicz et al., 2004). It can then be used again during subsequent time points to measure recovery up to 48 hours in which sensitivity decreases (McCrea, 2001).

The SAC was shown to be sensitive and specific in a study by McCrea et al. (McCrea, 2001). In this study, concussed individuals had a four point drop during the SAC assessment compared to unconcussed individuals who had an average increase of less than one point. In this study, a drop of one point post-injury was 95% sensitive and 76% specific in identifying concussions. The SAC has been shown to have no practice effects as well which makes it ideal for repeat administrations (Valovich, Perrin, & Gansneder, 2003).

Postural Control Assessment

Romberg

Balance assessment associated with disease dates back as far as 1800s under the research of Romberg. He discovered that those with tabes dorsalis could not maintain upright posture if they closed their eyes (Rogers, 1980). His clinical test of balance has since been described in the literature as standing with the feet together and hands to the side or on the hips (Rogers, 1980). When the person is standing with their eyes open, they will have no difficulties with this position. However, when the eyes are closed swaying will increase to the point of falling over when dorsal column disease is present (Rogers, 1980). This is called a positive Romberg's Test. When the test was first developed it was not believed to indicate any cerebellar or vestibular disease (Rogers, 1980). Since the development of the initial Romberg test, variations have been made. One variation has the person standing in the initial Romberg position and closes their eyes. Once the eyes are closed, then the individual shakes their head in the "no" gesture four times. A positive test for this modified version is if the person takes a step or opens their eyes. Other modified versions have changed the position of the feet (tandem or one leg) in order to

assess balance. However, some have argued that the Romberg is too subjective to identify subtle balance deficits after concussion (Guskiewicz et al., 2001).

Sensory Organization Test (SOT)

The SOT measures the ability to maintain balance. The testing consists of eighteen 20 second trials using three visual conditions (open, closed, sway-referenced) and two surface conditions (fixed, sway-referenced). The sway reference conditions have either the platform or the wall move as the center of gravity moves so the person doing the test cannot recognize that they are not in equilibrium (Guskiewicz et al., 1997). A composite score at the end of testing is compiled of averages of all the testing conditions. The test gives equilibrium scores for conditions 3-6. This equilibrium score is a percentage comparing peak anterior-posterior sway to anterior-posterior limit of stability. Additionally, ratios are given as well for vestibular (comparing condition 5 to 1), visual (comparing 4 to 1), and somatosensory (comparing 2 to 1). Ratios are used to identify where the deficit in the balance system may be (Guskiewicz, 2001). While this test proves to be capable of measuring balance, it is not practical to use for quick concussion assessment as the equipment is expensive and testing cannot be done on the sideline.

Balance Error Scoring System (BESS)

The BESS is a balance assessment tool commonly used following sport concussion. It is an objective way to measure balance and is inexpensive and requires no extensive training (Riemann, 1999), thus making it an ideal assessment tool following sport concussion. The test administrator records the number of balance errors a person commits while standing in three

positions on two surfaces. The test positions are double leg stance, single leg stance, and tandem stance (Riemann, Guskiewicz, & Shields, 1999). During the double leg stance the person stands with their feet side by side, hands on their hips, and eyes closed. For the single leg stance, the person stands on their non-dominant foot with their hip flexed to approximately 30 degrees and their knee flexed to 45 degrees, hands on their hip, and eyes closed. Non-dominance can be established by asking the person which foot they kick a ball with and having them stand on the opposite foot. For the tandem stance, the person stands heel to toe with the non-dominant foot in the back, hands on their hips, and eyes closed. Each of these test conditions is completed while standing on firm ground and while on a foam surface. The foam creates an unstable surface, thus challenging balance. Each trial is timed for 20 seconds while the test administrator records errors. Errors are noted if during the timed trials, the person either removes their hands from their hips, opens their eyes, steps, stumbles, falls, lifts their forefoot or heel, moves hip into greater than 30 degrees of abduction, or remains out of the test position for more than five seconds. Only one point is given if the person commits more than one error at a time. If the person cannot maintain the test position for five seconds, a maximum score of ten is given. One point is given for each error, therefore the higher the score, the less postural control. The maximum number of errors given in any test condition is ten (Riemann et al., 1999). The BESS is best utilized when given as a baseline test so post-injury scores can be compared to normal scores. The same tester should give serial tests and should be trained on how to complete the BESS to best ensure reliability (Bell, Guskiewicz, Clark, & Padua, 2011). The average number of errors during baseline testing is 10 and after concussion is 17 (Bell et al., 2011; Bell et al., 2011). The BESS has demonstrated high content validity in identifying balance problems in concussed or fatigued people (Bell et al., 2011).

As with other tests, learning effects are of concern with the BESS. Broglio et al. (Broglio et al., 2009) completed a study in which they showed learning effects associated with multiple exposures to the BESS. In order to cancel out these effects, the BESS should be completed three times during a single occasion and the scores should be averaged. Another option is completing the test on two different days. If completed in the manner, the test is only needed to be administered twice on each day and the scores averaged together. Using either of these methods has been shown to account for learning effects (Broglio et al., 2009).

Return To Play Following Concussion

With every concussion being individually different, it is nearly impossible to set return of play guidelines to be used for every concussion. With each concussion being unique, it is important to assess each individually and make return to play decisions based on signs and symptoms being presented. However, there are return to play guidelines available for use as just that, guidelines. When a concussion is first sustained, there are varying views as to how soon the individual may resume with physical activity. It was once supported that if the individual is asymptomatic within 20 minutes and symptoms do not resurface with activity, then they were allowed to resume activity. However, this guideline has diminished as more recent studies have shown that all signs and symptoms may not be present immediately (McCrory et al., 2005). Guskiewicz (Guskiewicz et al., 2003) found when athletes returned to activity on the same day, 33% of them showed delayed symptoms (3 hours later). Additionally, Lovell (Lovell et al., 2004) found athletes whose symptoms resolved within 15 minutes still had memory deficits 36 hours after the initial injury. This shows the brain is still experiencing difficulties and further injury during this crucial period could have further detrimental effects. Furthermore, the

Concussion and Team Physician consensus statement ([Anon], 2006) states it is safest to have the individual refrain from further activity on the same day. Before deciding when to return an athlete to activity, there are some factors that should be taken into consideration. It is imperative to examine the individual's prior concussive history (Oliaro et al., 2001). Some studies suggest a history of concussion shows prolonged recovery on subsequent concussions (Guskiewicz et al., 2003). If the current injury is not the first concussion experienced by the individual, the time between injuries is also imperative to determine (Guskiewicz et al., 2004; Lovell et al., 2004). One thing that is consistent among research is activity should not resume until all symptoms have resolved (Guskiewicz et al., 2004). At this time, it is strongly recommended that the individual refrain from activity until asymptomatic then begin a return to play protocol (McCrory et al., 2009). {Table 2.11} It should also be taken in to consideration whether or not the person is taking medications that may mask his signs and symptoms. The person should be free from medications that may hide these signs when they declare they are asymptomatic (P. McCrory et al., 2005). This should allow adequate time for the brain to recover. Exertional activity should then be tested to see if symptoms return. If symptoms do not resume, the individual should begin a progression of activities starting with sport-specific drills. Any drills that may place the individual at risk of another head injury should be avoided (Guskiewicz et al., 2004). If still asymptomatic, the individual can progress back into their sport. Throughout this duration, the person should be monitored for returning signs and symptoms of a concussion.

To safely participate in sport, it requires the use of cognition and dynamic balance simultaneously, each system requiring attention. When both tasks are completed at the same time, attention must be divided and allocated appropriately to each function. Attention is comprised of three parts; the alerting, the orienting, and the executive function components

(Ross et al., 2011). The alerting component is responsible for arousal and sustaining effort throughout the given task. The orienting component calls for the most appropriate systems to be efficient and provides direction for the task. The executive function component focuses the system and allows for adaptability to switch attention between tasks (Ross et al., 2011). Mild traumatic brain injury (mTBI) reduces the processing speed and capacity of the executive function component making it more difficult to switch attention between tasks (Van Donkelaar, Osternig, & Chou, 2006). mTBI also affects the orienting component of attention while leaving the alerting component relatively unaffected (Van Donkelaar et al., 2006). The orienting component requires an estimated week to recover from mTBI while the executive function component has been shown to be deficient one month post-injury. Given two of the components of attention are affected after mTBI, thus reducing attention capacity, completing multiple tasks succumbs the capacity of attention itself. To task these systems, tasks should be completed in tandem. Dual-tasks are when a primary task and a secondary task are concurrently completed.

To test the effects of dual tasks on healthy people, 23 healthy participants completed the SOT and stroop test concurrently twice, 14 days apart (Teel, Register-Mihalik, Troy Blackburn, & Guskiewicz, 2013). Slower reaction times were present during the dual-task. This indicates during times of divided attention there is a cost to cognitive function. However, there were significant improvements in balance in SOT condition four with the cognitive task. This could be because an increase in external focus could force the person to leave balance to be controlled automatically (Teel et al., 2013). Another investigation examined the effects of cognition and balance completed concurrently using the SOT and a cognitive task (S. P. Broglio, Tomporowski, & Ferrara, 2005).

However, varying views of the effects of cognition on balance have been expressed. An investigation examined 24 participants completing the stroop test on the force control platform utilizing different stances (Dault, Geurts, Mulder, & Duysens, 2001). In shoulder-width stance, the cognitive task did not disrupt postural control due to the belief it is a well-known task. When a seesaw was added to stand on, the participants became stiffer. When they were asked to stand tandem on the seesaw, they had decreased postural control, most likely due to capacity interference (Dault et al., 2001). If the difficulty of one task increases, the performance on the other may decrease as attention becomes divided.

An explanation for this difference in views may be found in a study examining the effects of focus on 18 participants on a stabilometer (Wulf, Weigelt, Poulter, & McNevin, 2003). Half of the participants were told to focus on keeping a ball in the middle of a tube they were holding while standing on the stabilometer (external focus). The other half was told to focus on maintaining their hands parallel to the ground while holding the tube with the ball in it (internal focus). Those who were told to use an external focus resulted in better performance in both balance and the suprapostural task. It seems having an external focus enhances motor performance. This is consistent with the constrained-action hypothesis which states internal focus intervenes with the automatic processes of balance, thus disrupting them (Ross et al., 2011). It constrains degrees of freedom of the motor system which results in lower frequency of movement. Therefore, if the person concentrates on the external task of cognition and leaves balance aside, then balance performance increases with the addition of a cognitive task. However, if the person does not allocate their attention to the cognitive task and rather focuses on balance, both performances suffer.

In view of the fact that sport participation requires concurrently utilizing both cognitive and postural control systems, it is imperative to determine return to play status tasking both of these systems simultaneously. Dual-tasks more directly mimic everyday life and sport participation, thus making them more useful in determining full recovery. To examine the potential use of dual-tasks with concussion assessment, 30 healthy participants were examined using the SOT, BESS, procedural auditory task, and procedural reaction time task during two testing sessions (Ross et al., 2011). Significant balance deficits were not present when a cognitive task was introduced. There was an overall improvement in the SOT when cognitive tasks were introduced. This was expected as healthy people can divide their attention to both tasks when a simple cognitive task is used and externally focuses their attention. However, there was no significant difference with the BESS which could be due to the BESS being a more difficult task and previous research has shown the influences of tasks on each other is related to the difficulty of each task (Ross et al., 2011).

Postural Control

Postural control is the ability to maintain the body in equilibrium. Equilibrium during posture requires controlling the center of mass over the limits of stability (Jacobs & Burleigh-Jacobs, 2000). The limits of stability are boundaries in which the body can maintain its position (Shumway-Cook & Woollacott, 2001). Postural control requires generation and scaling of muscular forces to coordinate the center of mass (Montgomery & Connolly, 2003). The two main goals for this system are stability and orientation (Shumway-Cook & Woollacott, 2001). The postural control system is comprised of three subsystems; the sensory system, the central nervous system, and the musculo-skeletal system (Winter, Patla, & Frank, 1990). Postural

control is dependent on accurate information from the sensory systems in which the central nervous system must be capable of integrating that information to choose the appropriate response from the musculo-skeletal system to maintain balance (Winter et al., 1990). The sensory system is comprised of the vestibular, visual, and somatosensory systems. The redundancy of the sensory system allows for compensation of deficits in other systems and allows for comparison to the signals to each other to make sure they are relaying accurate information. Coordination of the head, trunk, and appendages is important for postural control due to the head housing the vestibular and visual sensors (Jacobs & Burleigh-Jacobs, 2000).

Visual Control of Posture

Visual information signals movement of the body relative to the environment (Winter et al., 1990). It signals either self-motion or motion of the environment. Information from the eyes is sent to the roof of the midbrain, the colliculi, where it senses movement and decides one's relationship to that movement (Human Movement 2010). Information from the colliculi is then sent along one of three tracts: tectopontine tract where head control is processed, the brainstem region where eye movement is controlled, or the tectospinal tract where neck and head movement is controlled (Human Movement 2010).

Numerous studies have shown evidence for the use of visual information during postural control. In a balance study of 99 healthy participants, balance was decreased when visual cues were absent. The participants performed better on the balance assessment when they were able to use their visual information (Davlin-Pater, 2010). A study of individuals with and without visual impairments showed balance deficits in the absence of visual cues as well (Ray, 2008). In

this study of 46 participants, balance was assessed using the SOT. In the visual impairment group, decreased postural control was found and they showed more postural deficits than the no visual impairment group. However, during the conditions where vision was removed from both groups, there was no significant difference in performance between the groups. This indicates that vision plays a role in postural control as in the absence of vision, postural deficits were found.

Vestibular Control of Posture

The vestibular system is located in the inner ear and provides information regarding body orientation and accelerations of the body (Winter et al., 1990). It signals orientation and movement of the body relative to gravity and inertia (Winter et al., 1990). Peripheral sensors for this system are the semicircular canals, utricle, and saccule, which together are called the labyrinthine system (Leonard, 1998). Self-motion is provided by this system and it is not affected by external stimulus (Guerraz & Day, 2005). The semicircular canals sense angular acceleration of the head and are sensitive to fast head motion (Shumway-Cook & Woollacott, 2001). The otoliths signal acceleration and linear position and are sensitive to slow head movements (Shumway-Cook & Woollacott, 2001). This fast acting system helps maintain balance by activating postural muscles (Leonard, 1998).

The system uses the vestibulocochlear cranial nerve to transmit signal (Everett, 2010). The cochlear portion of this nerve carries auditory information from the cochlear. The vestibular portion carries head orientation and awareness and head acceleration information (Tony Everett,

2010). Information is sent to the cerebellum, thalamus, cerebral cortex, and reticular formation via the brain stem where change in firing rate and pattern is of concern.

In a study of ten individuals, Diener (Diener & Dichgans, 1988) demonstrated vestibular control of posture. In this study they changed the head position putting it away from optimal working range, thus, altering vestibular input. They measured postural sway on a force platform with the head tilted forward, extended, bent 45° to the left, and bent 45° to the right. Postural sway increased when the head was bent to the left and right and even further when the head was extended. In a study of 92 patients with vestibular impairments, balance performance was decreased compared to healthy control subjects during conditions requiring accurate vestibular input, thus showing vestibular contribution to balance (McCaslin, Jacobson, Grantham, Piker, & Verghese, 2011). Furthermore, in a study of vestibular impaired subjects and controls, postural control was significantly decreased in subjects with vestibular impairment during trials where vestibular function was tested (standing on a foam surface with eyes closed) (Fujimoto et al., 2010).

Somatosensory Control of Posture

The somatosensory system provides us with information about the effector systems and receives signals from receptors (Winter et al., 1990). Muscle spindles are one muscle receptor of importance in this system. Muscle spindles are sensitive to change in muscle length (Leonard, 1998). These receptors act as a feedback receptor and a feed-forward mechanism by sending signals to the spinal cord, cerebellum, brain stem, and motor cortex (Leonard, 1998). The information provided by these spindles provides information regarding sense of limb position, or

proprioception (Leonard, 1998). Other sensory information is provided by the following: golgi tendon organs (sense muscle tension), joint receptors (sense joint movement and stress), Pacinian corpuscles (vibration), Meissner's corpuscles (light touch and vibration), Merkel's discs (local pressure), and Ruffini endings (skin stretch) (Shumway-Cook, Woollacott, 2001). Information regarding this sensory feedback is sent directly to motor neurons for a quick response time (Tony Everett, 2010). Information concerning motions between the feet and support surface is the dominant sensory input under normal support conditions (Guo, 2006).

Guo showed somatosensory influence on postural control in a study of 162 subjects using the SOT (Guo, 2006). They examined 57 healthy girls and 105 with adolescent idiopathic scoliosis (AIS). The group of girls with AIS was further divided into those with disturbed posterior tibial nerve somatosensory evoked potentials (PTN-SSEP) and those not experiencing this condition. The PTN-SSEP condition caused altered input from the somatosensory information. The group with PTN-SSEP had increased postural sway on the SOT. Since they were the only group with increased postural sway, it suggests that somatosensory information is crucial in maintaining postural control.

In another study of somatosensory control, four participants applied a blood pressure cuff superior to their ankle. When the cuff was inflated to 300mmHg, it induced ischaemia in the feet, thus, causing altered somatosensory input. Postural sway was measured using a force platform. As the time of ischaemia increased the postural sway increased (Diener & Dichgans, 1988).

Sensory Weighting Hypothesis

With the postural control system receiving signals from three different sensory sources (visual, vestibular, and somatosensory), it must decide which system to attend to. The sensory weighting hypothesis (Everett, 2010) maintains that the central nervous system weights the importance of each input depending on the perceived accuracy of the signal. If a signal from one of the systems is not accurate or not providing useful information relative to the body's position, it will use the information from the other two systems first to maintain balance. Using this reweighting method allows humans to be stable across environments.

Strategies for Standing Postural Control

Depending on the environment, differing strategies can be used to maintain standing postural control including ankle strategy, hip strategy, and stepping strategy. The ankle strategy controls anterior-posterior sway in stance and is used for small perturbations (Jacobs & Burleigh-Jacobs, 2000). It uses a distal to proximal activation strategy (Jacobs & Burleigh-Jacobs, 2000). The gastrocnemius is fired first followed by the hamstrings and then the paraspinals to keep erect posture while restoring center of mass (Montgomery & Connolly, 2003). The hip strategy is used for large, rapid perturbations or when using the ankle strategy is hard (i.e. standing on a narrow beam). It involves flexing the trunk at the hip and counter rotating at the neck and ankle (Jacobs & Burleigh-Jacobs, 2000). The stepping strategy is used for large, rapid perturbations as well. This involves moving the base of foot support under the falling center of mass (Jacobs & Burleigh-Jacobs, 2000). Individuals tend to use this strategy for large perturbations they have not experienced before.

Seated Postural Control

Demands of sitting and standing postural control differ because the center of mass is closer to the base of support during sitting postural control (Roerdink, Hlavackova, & Vuillerme, 2011). Internal and external perturbations are less pronounced in seated postural control due to the lowered center of mass (Roerdink et al., 2011). During seated postural control, the orientation of the pelvis plays a crucial role in maintaining a good seated posture and shape of the spine (Janssen-Potten, Seelen, Drukker, Huson, & Drost, 2001). The lower limbs aid in seated balance as they create a larger base of support (Janssen-Potten, Seelen, Drukker, Spaans, & Drost, 2002). Additionally, the muscles in the lower limbs aid to counterbalance displacements of the center of mass (Janssen-Potten et al., 2002).

Seated Postural Control in Individuals with Spinal Cord Injury

Seated postural control is impaired in individuals with spinal cord injury (SCI) due to sensorimotor deficits caudal to the lesion level, thus causing the need for adapted postural control strategies (Potten, Seelen, Drukker, Reulen, & Drost, 1999). Without full activation of the trunk musculature, the person with SCI is affected more by gravity and posture suffers due to this (Hastings, Fanucchi, & Burns, 2003). The most common strategy utilized by people with SCI is the use of non-postural control muscles to maintain balance (Seelen, Potten, Drukker, Reulen, & Pons, 1998). Individuals with SCI commonly use the latissimus dorsi and the trapezius to compensate for loss of traditional postural control muscles (Seelen et al., 1998). The level of the SCI will determine which trunk muscles can provide postural stability if any (Minkel, 2000). The absence of full trunk and lower limb activation does not allow persons with

SCI to move their center of pressure as much as those without SCI, thus causing balance impairment (Seelen, Potten, Huson, Spaans, & Reulen, 1997). In people without SCI, the center of pressure is typically moved backwards before initiating a forward reaching movement and this coincides with an anterior tilt in the pelvis (Seelen et al., 1997). Those with SCI show only a slight backwards movement of the center of pressure if any before initiating a forward movement. This movement is believed to be caused by the iliopsoas muscle; a muscle commonly experiencing paralysis in one with a SCI (Seelen et al., 1997).

Additionally, pelvis position may be changed for postural control. In a seated postural control study of 20 individuals with SCI and 10 non-SCI control subjects, those with SCI passively tilted their pelvis posteriorly to rest against the seat for support while completing forward reaching tasks in addition to using their erector spinae, latissimus dorsi, and trapezius muscles to help with posture (Potten et al., 1999). Passively tilting the pelvis posteriorly allows the individual to increase the base of support by using the backrest of the chair (Janssen-Potten et al., 2001). However, optimal sitting position is with an anterior pelvic tilt (Bolin, Bodin, & Kreuter, 2000). The pelvis orientation is crucial to balanced posture of the upper body (Bolin et al., 2000). Posterior pelvic tilting is caused by a lack of trunk control, specifically the lumbar and thoracic erector spinae (Janssen-Potten et al., 2001). By posteriorly tilting the pelvis, the base of support is increased (Minkel, 2000). This allows the center of gravity to be shifted behind the base of support thus causing stability (Minkel, 2000). Those with a high level of SCI tend to sit with a posterior tilt in their pelvis, thus causing a C-shaped sitting posture. This C-shaped sitting posture consists of a flattened lumbar spine, kyphotic thoracic spine, and extension of the cervical spine (Bolin et al., 2000)(Minkel, 2000). This position allows for stability during wheelchair propulsion and activities of daily living, however, it is not ergonomical and

commonly predisposes the individual to injury (Bolin et al., 2000). Additionally, by shifting to this position, it reduces the area of weight bearing, thus increasing the chance of pressure sores due to a smaller pressure area (Minkel, 2000). It is suggested that those with a C-shaped sitting posture could be utilizing a wheelchair that is not properly designed for their body (Hastings et al., 2003). Wheelchair design can accommodate for the missing postural control seen in wheelchair users.

Wheelchair Setup to Accommodate for Postural Instabilities

Individuals utilizing a manual wheelchair should have a wheelchair designed specifically for their stability needs. When wheelchairs are designed for the individual it can provide spinal stabilization and accommodate for weak or absent trunk muscles during sitting (Hastings et al., 2003). The center of gravity of the individual in the wheelchair has a considerable effect on the stability that user will experience (Kirby, Sampson, Thoren, & MacLeod, 1995). It is imperative to have proper wheelchair setup to allow for maximal independence in which there is several ways to achieve this. The height of the backrest can enhance forward stability. A low back rest can allow the individual to lean backward to change the center of gravity and become more stable (Kirby et al., 1995). However, a downfall to this is if the individual is unfamiliar to this setup, it could cause them to tip backwards when reaching behind them (Kirby et al., 1995). As previously mentioned, pelvis orientation in individuals with SCI greatly affects stability. A wheelchair that allows the pelvis to tilt posteriorly places the individual in a less favorable position for sitting and functional activities (Hastings et al., 2003). Increased posterior tilt of the pelvis causes increased lumbar flexion and increased forward head position. This posture has been associated with chronic neck and shoulder pain (Hastings et al., 2003). However, with an

inclination of the seat, this posterior tilt of the pelvis can be avoided, thus limiting the C-shaped sitting position that causes pain (Hastings et al., 2003). This causes an acute angle between the backrest and seat which differs from the common wheelchair seat and backrest configuration of 90 degrees. This acute angle allows the ischium to remain in the back of the seat, thus blocking in the pelvis and allowing for optimal pelvis position (Hastings et al., 2003). This inclination has been shown to not jeopardize balance control and decreases overall muscle activity required for sitting, thus limiting fatigue (Janssen-Potten et al., 2001). Whether or not brakes are used can also affect stability. Contrary to belief, brakes limit the reach of the wheelchair user and can cause them to tip over when leaning and reaching (Kirby et al., 1995). When the brakes are unlocked, the center of gravity is higher and farther forward than if the brakes are locked during when rear stability is needed.

Balance Assessment Technology

There are a variety of tools to measure postural control including accelerometers, Wii balance boards, motion capture, and force platforms. A force platform is being used in this study because it is the most commonly used tool to measure postural control. Force platforms have been used for static and dynamic quantitative balance assessments (Riemann et al., 1999). They measure center of pressure (COP) and postural sway by measuring four points of vertical forces (Riemann et al., 1999). COP is the center of the total force being applied to the ground (Palmieri, Ingersoll, Stone, & Krause, 2002). It is representative of the response of the central nervous system to fix imbalance of the center of gravity (Winter et al., 1990). It is the weighted average of all the pressures from the area that is in contact with the ground. Maximum and minimum amplitude are often examined when using the force platform. Amplitude is the

displacement of the COP from its mean and allows assessment in the anterior/posterior and medial/lateral directions (Palmieri et al., 2002). It is assumed that an increase in maximum amplitude denotes a decrease in the ability to maintain posture.

Figures and Tables

Table 3.1: Cantu grading scale for concussion

Grade 1	No loss of consciousness; posttraumatic amnesia less than 30 minutes
Grade 2	Loss of consciousness less than 5 minutes in duration or posttraumatic amnesia lasting longer than 30 minutes but less than 24 hours in duration
Grade 3	Loss of consciousness for more than 5 minutes or posttraumatic amnesia for more than 24 hours

Table 3.2: Colorado Medical Society grading system for concussion

Grade 1	Confusion without amnesia; no loss of consciousness
Grade 2	Confusion with amnesia; no loss of consciousness
Grade 3	Loss of consciousness

Table 3.3: AAN practice parameter (Kelly and Rosenberg) grading system for concussion

Grade 1	Transient confusion; no loss of consciousness; concussion symptoms or mental status abnormalities on examination resolve in less than 15 minutes
Grade 2	Transient confusion; no loss of consciousness; concussion symptoms or mental status abnormalities on examination last more than 15 minutes
Grade 3	Any loss of consciousness, either brief (seconds) or prolonged (minutes)

Table 3.4: Jordan grading system for concussion

Grade 1	Confusion without amnesia; no loss of consciousness
Grade 2	Confusion with amnesia lasting less than 24 hours; no loss of consciousness
Grade 3	Loss of consciousness with an altered level of consciousness not exceeding 2 to 3 minutes; posttraumatic amnesia lasting more than 24 hours
Grade 4	Loss of consciousness with an altered level of consciousness exceeding 2 to 3 minutes

Table 3.5: Nelson grading system for concussion

Grade 0	Head struck or moved rapidly; not stunned or dazed initially; subsequently complains of headache and difficulty in concentrating
Grade 1	Stunned or dazed initially; no loss of consciousness or amnesia; sensorium clears in less than 1 minute
Grade 2	Headache; cloudy sensorium longer than 1 minute in duration; no loss of consciousness; may have tinnitus or amnesia; may be irritable, hyperexcitable, confused, or dizzy
Grade 3	Loss of consciousness less than 1 minute in duration; no coma (arousable with noxious stimuli); demonstrates grade 2 symptoms during recovery
Grade 4	Loss of consciousness for more than 1 minute; no coma; demonstrates grade 2 symptoms during recovery

Table 3.6: Roberts grading system for concussion

Bell Ringer	No loss of consciousness; no posttraumatic amnesia; symptoms less than 10 minutes
Grade 1	No loss of consciousness; posttraumatic amnesia less than 30 minutes; symptoms greater than 10 minutes
Grade 2	Loss of consciousness less than 5 minutes; posttraumatic amnesia greater than 30 minutes
Grade 3	Loss of consciousness greater than 5 minutes; posttraumatic amnesia greater than 24 hours

Table 3.7: Evidence-Based Cantu grading system for concussion

Grade 1 (mild)	No loss of consciousness; posttraumatic amnesia* or post-concussion signs or symptoms lasting less than 30 minutes
Grade 2 (moderate)	Loss of consciousness lasting less than 1 minute; posttraumatic amnesia* or post-concussion symptoms lasting longer than 30 minutes but less than 24 hours
Grade 3 (severe)	Loss of consciousness lasting more than 1 minute or posttraumatic amnesia* last longer than 24 hours; post-concussion signs or symptoms lasting longer than 7 days

* Retrograde and anterograde

Table 3.8: American Academy of Neurology guidelines

Grade 1 (mild)	Transient confusion; no loss of consciousness; symptoms or abnormalities resolve in less than 15 minutes
Grade 2 (moderate)	Transient confusion; no loss of consciousness; symptoms or abnormalities last more than 15 minutes
Grade 3 (severe)	Any loss of consciousness, either brief (seconds) or prolonged (minutes)

Table 3.9: University of North Carolina classification of cerebral concussion

Grade	Level of Consciousness	Cranial Nerves, Cognition, and Coordination (3 Cs)	Headache
0 (mild)	No LOC	Mild confusion but asymptomatic in 10 minutes; passes functional tests without recurrence of signs and symptoms	Possibly develops later
1 (mild)	No LOC	At least 1 of the following is present: 1. Abnormal cranial nerve function lasting <1 hour 2. Abnormal cognition lasting <1 hour 3. Abnormal coordination lasting <3 days	Probable; lasts from 10 minutes to as long as 2 days
2 (moderate)	Brief LOC from 10 seconds to 1 minute or altered consciousness lasting <2minutes	At least 1 of the following is present: 1. Abnormal cranial nerve function lasting >1 hour 2. Abnormal cognition lasting >1 hour 3. Abnormal coordination lasting longer than 3 days	Probable; lasts 24 hours to 4 days
3 (severe)	LOC > 1 minute or altered consciousness lasting >2minutes	2 of 3 Cs are abnormal for more than 24 hours	Likely; lasts longer than 4 days

Table 3.10: Paper and pencil tests for neuropsychology testing

Name	Time To Complete	Description
Trail Making Test	As long as it takes the person to complete the task.	Participant asked to trace a list of 25 numbers as fast as they can. Assesses orientation, concentration, visuospatial capacity, and problem solving capabilities. Time is recorded as to how long it takes the person to complete the task. One second is added for each sequential error.
Wechsler Digit Span Test (WDST)		Participant is presented a series of digits and is asked to repeat the digits either forward or backwards. The total score of the test is the number of successful trials for each part (forwards and backwards). Assesses concentration and immediate memory recall.
Stroop Test		Participant has 45 seconds to complete each subtest of 100 items that are in 5 columns of 20 items. The first subtest asks the person to read color words that are written in black type. The second subtest asks the person to identify the colors red, green, or blue printed in “XXXX”. The third subtest asks the person to read the color of the print of the actual word when the words from the first subtest and mixed with the colors from the second subtest. Assesses cognitive flexibility and attention span. Score is calculated on each subtest then summed together.

Table 3.10: Paper and pencil tests for neuropsychology testing (continued)

Hopkins Verbal Learning Test		Participant is asked to repeat a list of 12 words repeated over 3 learning trials for immediate recall. During the fourth trial, the person is given a list of 24 words and asked identify the original 12 words. After a delay, the participant is asked to recall the same 12 words. The number of correct responses is subtracted from the overall recall score. Assesses memory.
WAIS-3 Digit Symbol Subtest	2 minutes	Participant is asked to fill in boxes underneath numbers with symbols using a key to identify which symbol goes with each number. Participant is asked to fill in as many as they can. Assesses processing speed.
Symbol Digit Modalities Test	90 seconds	Same as the WAIS-3 Digit Symbol Subtest only the numbers and symbols are reversed.

(Guskiewicz et al., 1997)

Table 3.11: Return to play protocol after concussion

Rehabilitation Stage	Functional exercise at each stage of rehabilitation	Objective of each stage
1. No activity	Complete physical and cognitive rest	Recovery
2. Light aerobic exercise	Walking, swimming or stationary cycling keeping intensity <70% maximum predicted heart rate. No resistance training.	Increase heart rate
3. Sport-specific exercise	Skating drills in ice hockey, running drills in soccer. No head impact activities.	Add movement
4. Non-contact training drills	Progression to more complex training drills (e.g. passing drills in football and ice hockey). May start progressive resistance training.	Exercise, coordination, cognitive load
5. Full contact practice	Following medical clearance, participate in normal training activities.	Restore confidence, assessment of functional skills by coaching staff
6. Normal game play	Normal game play	

(P. McCrory et al., 2009)

Chapter 4: Validity and Reliability of a Seated Postural Control Measure

Introduction

With the expansion of knowledge concerning the benefits of exercise and physical activity for persons with disability, there has been an increase in disability sport participation (Gold & Gold, 2007). For instance, in the 2008 Paralympics, nearly 40 times more athletes competed (Liang et al., 2011) than in the first Paralympics in 1952 (Gold & Gold, 2007). This exponential increase in physical activity participation is believed to have occurred in non-elite athletes as well. It is possible that this increase in participation leads to an increase in risk of injury.

The Athletes with Disabilities Injury Registry provides information regarding injuries and their severity in disabled athletes (Ferrara & Buckley, 1996). An injury rate of 9.3/1000 athlete-exposures was found in athletes with disabilities. This is similar to a men's basketball rate of 7/1000 athletic-exposures, women's basketball rate of 7.3/1000 athletic-exposures, and a soccer rate of 9.8/1000 athletic-exposures. When examining the severity of injuries to athletes with disabilities compared to able bodied athletes, severity of injury is quite similar. Athletes with disabilities suffered 52% minor injuries (7 days or less of competition lost), 29% moderate injuries (8-21 days of competition lost), and 19% major injuries (22 or more days of competition lost) compared to the able bodied counterparts who suffered 70% minor injuries, 20% moderate, and 10% major injuries. Through this study it appears that athletes with disabilities face similar injury exposure rates as their able bodied counterparts, yet research in this area is limited. An injury that has received limited in wheelchair athletics is concussions.

There has been a growth in scientific inquiry of concussion due to their potentially devastating effects. While there are a vast number of research focusing on concussion in sport, there has been very few related to disability sports. To our knowledge there has only been one investigation that focused on concussion in disability sport. Specifically, a survey based examination of 263 wheelchair basketball players, revealed concussion incidence rate of 6% (Wessels, Broglio, & Sosnoff, 2012). This rate is similar to able body men's football, which has a concussion incidence rate of 6.8% in games and 5.5% in practice (Dick et al., 2007). However, a limitation of this survey investigation was that it relied on self-report of concussion.

The National Athletic Trainer's Association calls for a sideline examination of symptoms, cognitive function, and standing balance in order to determine whether a concussion has occurred (Guskiewicz et al., 2004). Tests need to be cost efficient, not equipment intensive, and require minimal time to allow quick return to play decisions. Although concussion related symptom scales and cognitive tests have been validated and found reliable in non-disabled athletes and could be easily implemented in wheelchair athletes, their reliability has not been quantified in the wheelchair athlete population.

In contrast, a foundation of concussion screening, standing balance assessments, cannot be readily used in wheelchair athletes. For instance, the Balance Error Scoring System (BESS), (Riemann, Guskiewicz, & Shields, 1999) a common balance assessment is completed while standing on a medium density foam pad in three different positions: feet together, on one foot, and tandem stance. During the test the athlete is asked to remain in the prescribed position for 20 seconds while an evaluator records the number of errors committed during the trials. An error is a change in balance control (i.e. opening eyes, taking hand off hip, touching the ground, abduction of the leg past 30 degrees, remaining out of testing position). Error scores from each

trial are summed at the end of the test to give a balance score. A higher BESS score indicates more postural sway.

However, since the BESS is completed while standing, it may not be possible or appropriate for all wheelchair athletes to complete due to impairments in standing balance seen in most wheelchair athletes. Therefore, there is a gap in the concussion assessments for disabled athletes. It is imperative to fill this gap to properly assess concussions in athletes with disabilities.

In an effort to fill this gap in concussion assessment we have developed a seated postural control assessment [Wheelchair Error Scoring System (WESS)] that can be used to test seated balance. This test can be used on the sidelines as it is not equipment intensive, is practical, and requires minimal time. This will allow the clinician to administer the test during competition and make a quick, informative decision on whether a concussive injury has been sustained and whether further exercise is considered safe.

The purposes of this study was to determine the concurrent validity of the WESS by examining the relationship between the WESS and objective sway measures recorded on a force platform and to determine if the WESS is reliable over time. A secondary purpose was to determine the reliability of the Standardized Assessment of Concussion (SAC) and the Graded Symptom Checklist (GSC) in the wheelchair athlete population as this has not been previously examined.

Methods

Participants

Twenty-two wheelchair athletes were recruited to participate in the investigation. Participants had a variety of disabilities. Inclusion criteria included being 18-65 years old, being able to maintain a seated posture without back support and participation in wheelchair athletics.

Procedures

Participants were told of experimental procedures, given the opportunity to ask questions, and then asked to provide written informed consent. Once this was obtained, the Standardized Assessment of Concussion (SAC) was completed. Then the participant was asked to sit on a force platform which was placed on a table that was high enough so the participant's feet did not touch the ground. The participant completed the WESS while seated on an AMTI (Watertown, MA) force platform. Each condition and position (seated eyes open, seated eyes closed, balance disk eyes open, balance disk eyes closed, wheelie eyes open, wheelie eyes closed) was repeated twice for a total of 12 trials lasting 20 seconds each.

The SAC evaluates cognitive status by assessing orientation, immediate memory, cognition, and delayed memory recall (McCrea, 2001). The SAC has been found to be valid for concussion assessment and has no practice effects in numerous athletic populations (Valovich, Perrin, & Gansneder, 2003). The administrator asks the participant to answer questions in each of the above mentioned domains. Each correct answer receives one point with a maximum score of 30. The test takes approximately five minutes to administer.

Force platforms are the gold standard for measuring postural control and consequently are routinely used for static and dynamic quantitative balance assessments (Riemann et al., 1999) (Palmieri, Ingersoll, Stone, & Krause, 2002). They measure the center of pressure and postural

sway by measuring four points of vertical forces (Riemann et al., 1999). When a force is placed on the platform, triaxial transducers measure the strain being displaced on them. These triaxial transducers, which allow for multi-dimensional measurement, are in each corner and measure the relative vertical forces to determine center of pressure (Winter, 1979). Force platforms provide a 95% confidence ellipse area which is a reliable indicator of postural control as it encompasses 95% of the sway points. Previous studies have used force platforms to measure seated postural control in both able-bodied populations and populations with disability (Lacoste et al., 2006; Shin & Sosnoff, 2013). By utilizing the force platform to quantify seated postural sway, the concurrent validity of the WESS can be determined (e.g. does the WESS measure seated postural control as indexed by the gold standard).

The WESS involves several seated balances tests [with participant hands on their hips or wheels]: seated eyes open on a firm surface, seated eyes closed on a firm surface, seated on a balance disk eyes open, seated on a balance disk eyes closed, wheelie eyes open, and wheelie eyes closed {Figures 4.1-4.3}. The balance disk is a commercially available air-filled disk (j/fit, Vancouver, WA). A wheelie (only two back wheels on the ground) is a normal every day task that allows for community ambulation (going up and down curbs) and a vast majority of wheelchair users can do this with minimal difficulty. The tests were chosen to manipulate the three systems involved in postural control: vision, vestibulocochlear, and somatosensory. The eyes closed conditions manipulate visual control of postural control. The balance disk condition manipulates the somatosensory condition. Having the participant sit on the balance disk and close their eyes relies strongly on the vestibulocochlear system for input for postural control.

During all of the seated trials and balance disk trials, the participant was asked to maintain a seated posture with their hands on their hips and to remain in this position for the

duration of the trial. They were instructed if they lost their balance they could make the needed adjustments and return to the testing position as quickly as possible. There were two investigators spotting to ensure the participant's safety during testing.

While in the participants own wheelchair, a wheelie was performed (two wheels on the ground) on the force platform. They were asked to hold the wheelie with both hands on their wheels for each trial. Half of the trials were with their eyes closed. To make certain the participant did not tip during the trials, there was an investigator spotting to ensure the participant's safety and a pulley system from the ceiling was attached to the participant's wheelchair.

During each trial, errors are recorded that are indications of change in postural control. Each error was counted as one point toward the test score. An error was noted during the seated and balance disk tasks if the participant lifted their hand(s) off their hips, touched the table, opened their eyes (when appropriate), or remained out of the test position for more than five seconds. An error was noted during the wheelie task if the participant regripped their wheel, opened their eyes (when appropriate), placed all four wheels on the ground, or remained out of test position for more than five seconds. If the individual could not maintain the test position for more than five seconds, a maximum score of ten was recorded. If two errors occurred simultaneously, only one point was given for that error. Errors from all of the trials were summed to give a final WESS score.

Test-Retest Reliability

The participants were asked to return 45 days later to complete the test sequence again to determine the test-retest reliability of the WESS to accurately measure postural control over time and to examine the reliability of the SAC in wheelchair athletes over time. At this time, the participants' performance was once again videotaped. The WESS scores of the first test session and scores from the 45 day retest were analyzed.

Scores from the WESS were analyzed against the measures from the force platform by using bivariate correlations to determine if the WESS has construct validity and accurately measures postural sway.

Intertester and Intratester Reliability

In order to determine intertester and intratester reliability, during each of these tasks (seated, balance disk, and wheelie) an investigator video recorded the trials. Four investigators who were all certified athletic trainers reviewed the video and recorded the number of errors that each participant made on each trial. Scores from the four investigators were compared to determine intertester reliability. Seven days later the investigators watched the same trials again and rescored the trials. Each investigator's two test scores were compared to each other to determine intratester reliability. The same procedure was completed for the initial testing and the 45 day retest.

Statistical Analysis

Bivariate Spearman's correlation analysis was used between errors scores and postural sway area in each position to determine if a significant relationship between the force platform and WESS scores existed. A repeated measure analysis of variance (ANOVA) was used to test for significant improvements between the two test sessions in error scores and 95% confidence ellipse scores. (Riemann et al., 1999) Repeated measures ANOVA was used to determine if there was a difference in scores between positions. Intraclass correlations (ICCs) were used to determine the intertester and intratester reliability of the WESS. An ICC 1,1 was used to determine the intertester reliability and an ICC 2,1 was used to determine intratester reliability. An ICC was also calculated with baseline and 45 day retest scores being averaged together to determine the reliability over time. SAC scores and number of symptoms reported were analyzed using a non-parametric test (Related sample Wilcoxon signed rank test) to establish if there were any significant differences between testing sessions. An alpha of 0.05 was used for all analyses.

Results

Twenty-two participants (14 males, 8 females) ranging in age from 18-25 completed the study. The participants had an average length of disability 14.2 years and had participated in wheelchair athletics for an average of 8.28 years. [Table 4.1] The most common disability represented was spinal cord injury (n=11), followed by other (n=4), cerebral palsy (n=2) and above knee amputation (n=2).

Validity

Repeated measures ANOVA analysis revealed a main effect of position for both sway area ($F=12.4$, $P=0.000$) and WESS scores ($F=5.5$, $P=0.024$), and vision for both sway area ($F=23.81$, $P=0.00$) and WESS scores ($F=12.38$, $P=0.002$). Post-Hoc analysis revealed differences between the seated position and the other two positions {Figures 4.4 and 4.5} and between vision and no vision conditions. {Figures 4.6 and 4.7}

Significant bivariate correlations were found between WESS error scores and 95% confidence ellipse scores in balance disk eyes open, balance disk eyes closed, and wheelie eyes closed conditions ($p < 0.01$). {Table 4.2} Correlation coefficients could not be calculated for the seated eyes open and eyes closed positions and wheelie eyes opened position due to lack of participant variability.

Reliability

Repeated measures ANOVA revealed no significant differences as a function of time on WESS scores ($F=0.003$, $P=0.96$) and 95% confidence ellipse [seated conditions ($F=0.23$, $P=0.64$); wheelie condition ($F=0.2$, $P=0.66$)] {Figures 4.8 and 4.9}. Additionally, there was not a trial effect ($p=0.33$) during either assessment. SAC scores ($P=0.233$){Figure 4.10} and symptoms reported ($P=0.21$){Figure 4.11} were not significantly different between assessments.

The WESS displayed high intratester reliability scores across the 7 day test interval (ICCs 0.65-1; p 's > 0.05) in all conditions for all four testers except for one tester in a single trial. Additionally, the WESS displayed high intertester reliability (ICCs 0.69-0.86; p 's > 0.05) in all but three of the trials. {Tables 4.3-4.10}

An ICC with the baseline and 45 day retest scores averaged together revealed an ICC of 0.956 ($p=0.0$) thus indicating no significant difference between the two testing sessions.

Discussion

The main purpose of this investigation was to test the validity and reliability of a seated postural control assessment to be used in the sideline assessment of concussions in wheelchair athletes. A secondary aim was to determine the reliability of the SAC and GSC in wheelchair athletes. WESS scores were correlated with force platform postural sway measures in the balance disk eyes open, balance disk eyes closed, and wheelie eyes closed conditions. This allows for the use of the WESS to measure seated postural control as it correlates with a standard balance assessment tool in most situations. SAC scores and GSC scores were reliable in this population as there was no significant difference between the two testing sessions.

With WESS scores correlating to force platform measures, it justifies its use in balance assessment on the sideline for concussion screening. Correlations between WESS scores and force platform postural sway measures during the seated eyes open, seated eyes closed, and wheelie eyes open trials could not be calculated due to lack of participant variability. This indicates that the seated condition may not be suitable for detecting smaller postural fluctuations, but rather should be used as a screening tool to determine whether or not it is safe to continue with the seated postural control assessment. If the individual cannot remain in a seated posture with their hands on hips and eyes closed for 20 seconds, then it should be assumed balance deficits are present and further assessment of postural control may be considered unsafe.

Significant differences between the two testing sessions were not found using WESS scores or 95% confidence ellipse. This suggests the WESS and the force platform measured the same construct on both testing days. It is concluded that the WESS has acceptable test-retest reliability. There were no practice effects present as scores between different testing dates were not significantly different on both WESS scores and force platform measures. Additionally, there were no significant differences between the two trials that were completed in each condition and position. This means each testing condition/position (seated eyes open, seated eyes closed, balance disk eyes open, balance disk eyes closed, wheelie eyes open, and wheelie eyes closed) can be completed one time each. Consequently, the time necessary to complete the test could be reduced by half. This justifies its use for sideline assessment as the time needed to complete the assessment is minimal.

The WESS showed high intratester reliability scores in all four testers. The only trial that did not have a high intratester reliability was a wheelie eyes open condition in one tester (ICC=0, $p=0.5$). However, when further examining the scores, this was only due to one discrepancy in scoring over 1500 trials, with an error score of 1, while the rest of the error scores were 0s. Consequently, we conclude that this small difference is insignificant. Additionally, the WESS displayed high intertester reliability. High intratester reliability indicates any differences between the testing scores are most likely due to changes in WESS scores and not from changes in the rater. Different raters can complete the two separate testing sessions and any changes in WESS score would most likely be indicative of changes in WESS score and not differences between the raters given the WESS showed high intertester reliability scores.

The standard sideline balance assessment tool for concussions in ambulatory athletes is the BESS. The WESS was modeled and tested in similar fashion to the BESS to fill the void in

balance assessment in wheelchair users. Both tests are quick, inexpensive, and easy to utilize on the sidelines of athletic events. Given the WESS is comparable and has similar testing instructions to the BESS, this allows clinicians already familiar with the BESS to easily implement the WESS in wheelchair sport and wheelchair users.

We found no significant differences in SAC scores between the two testing sessions. The SAC has previously demonstrated no practice effects in able bodied populations (Valovich et al., 2003). Similar results were found in this population of wheelchair athletes. While these results were expected, use of the SAC has not been examined in this population. This study extended those findings to the wheelchair athletic population making the SAC a useful tool in the repeat assessment of concussion in wheelchair athletics.

Similarly, the GSC showed no significant differences over time in this wheelchair athlete population, thus making it reliable for use in this population. While these results were expected, previous studies have not examined utilization of a symptom checklist in this population.

Limitations

Despite the novel observations of this investigation, there were still several limitations. This investigation was limited to college-aged athletes. This sample may not be representative of the entire wheelchair athletic population. It is possible the results may differ, especially in a group of older individuals who may have a decline in cognitive function. Additionally, given the same tester completed both assessments there is a chance for tester bias. However, we controlled for this by having three additional certified athletic trainers completed the WESS to compare scores.

Conclusion

To accurately assess concussions, cognitive function, symptoms, and balance should all be quantified. Previously, balance assessment was inadequately assessed in wheelchair athletics given the standing requirement of concussion-related balance tests. The WESS has been shown to be a valid and reliable tool to bridge the gap in balance assessment after concussion in wheelchair athletes. Future investigation is needed to determine the sensitivity of the WESS to detecting concussions. Additionally, the WESS should be examined in a nonathletic population to determine if the results are generalizable. This would allow the WESS to be utilized in other situations where a quantifiable seated postural control test is needed to measure postural control when there is an inability to stand.

Figures and Tables

Figure 4.1: Seated position on a table where feet cannot touch the ground



Figure 4.2: Seated on a balance disk on a table where feet cannot touch the ground



Figure 4.3: Wheelie position with front casters off of the ground



Table 4.1: Participant Demographics

Variable	N=22
Age (years)	20 [18-25]
Weight (lbs)	146[95-203]
Male/Female	14/8
Length of disability (years)	14 [5-23]
Previous Concussion History	2

Table 4.2: Bivariate correlation coefficients for WESS scores and 95% confidence ellipse

POSITION	COEFFICIENT	P
Seated Eyes Open	-	-
Seated Eyes Closed	-	-
Balance Disk Eyes Open	0.552	0.008
Balance Disk Eyes Closed	0.716	0.000
Wheelie Eyes Open	-	-
Wheelie Eyes Closed	0.742	0.000

--Calculations could not be measured due to lack of participant variability

Figure 4.4 Difference in position with 95% confidence ellipse area

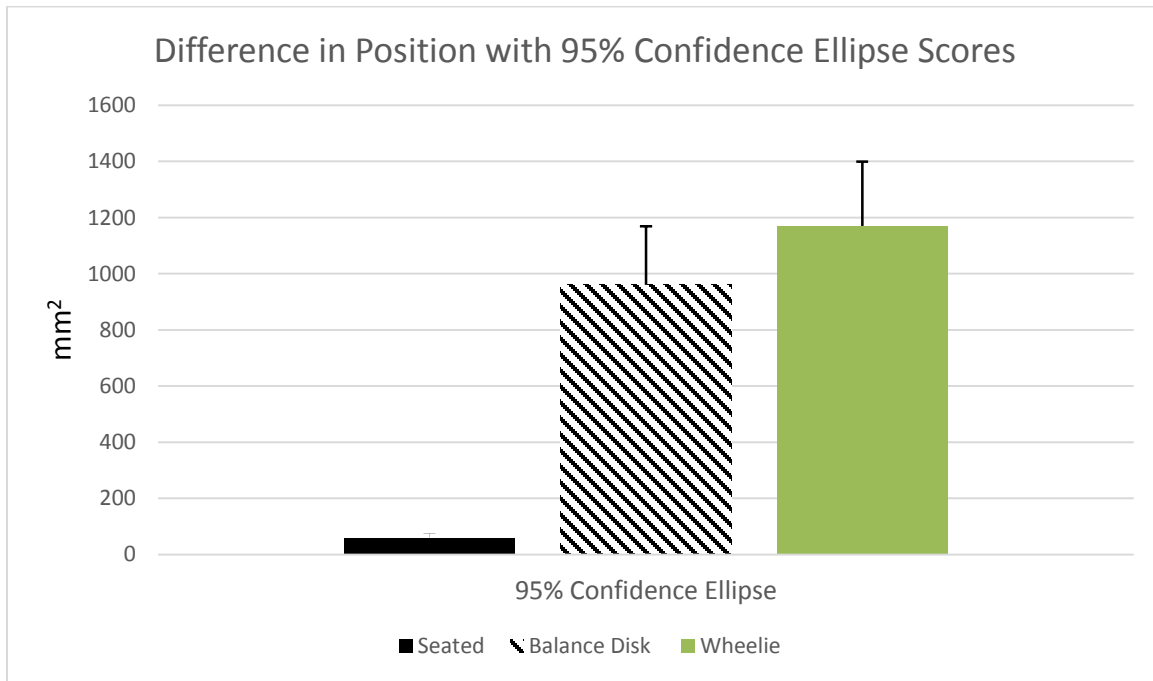


Figure 4.5 Difference in position with WESS scores

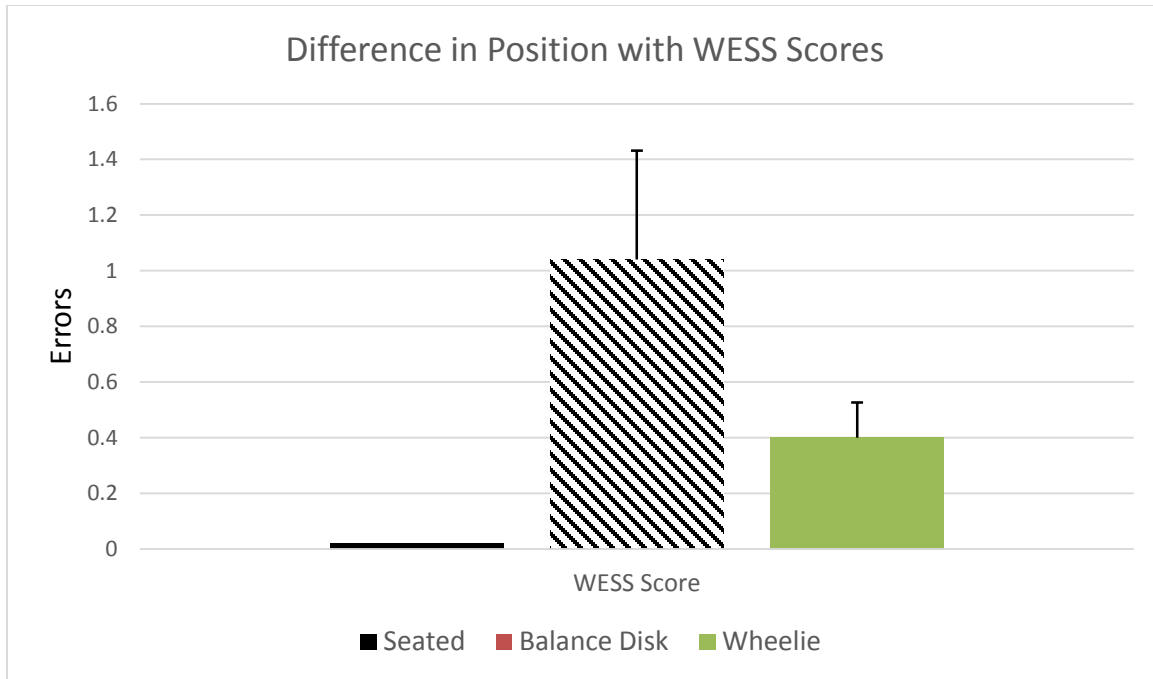


Figure 4.6 Difference in vision during the WESS using 95% confidence ellipse area

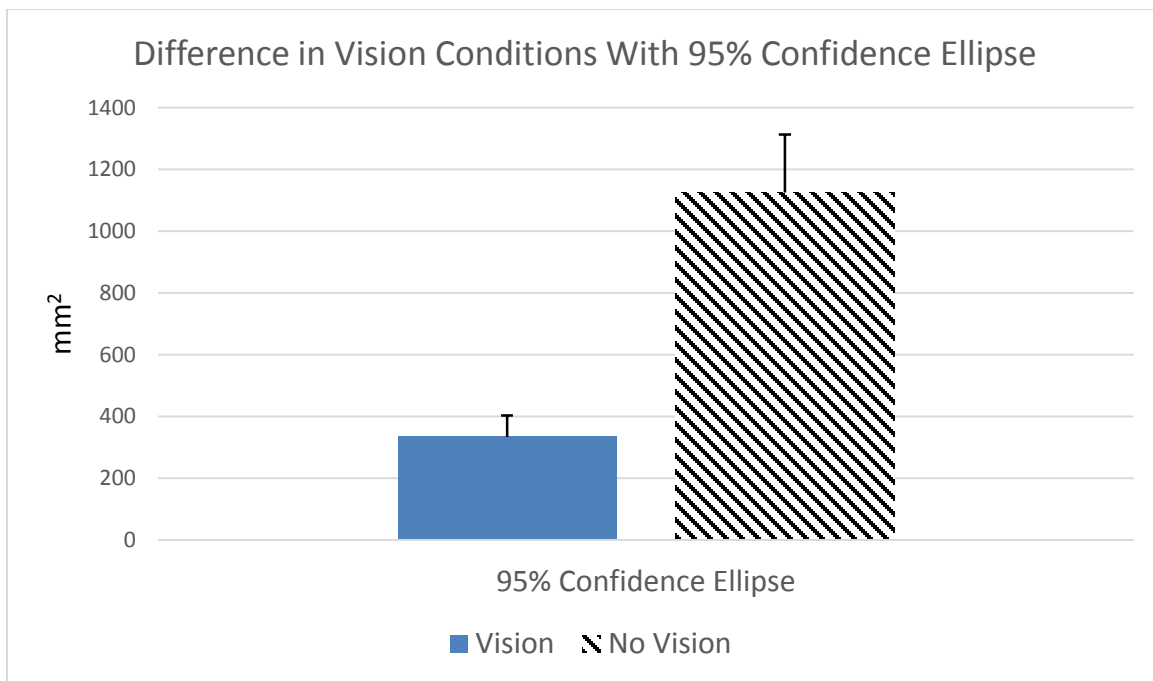


Figure 4.7: Difference in vision during the WESS positions

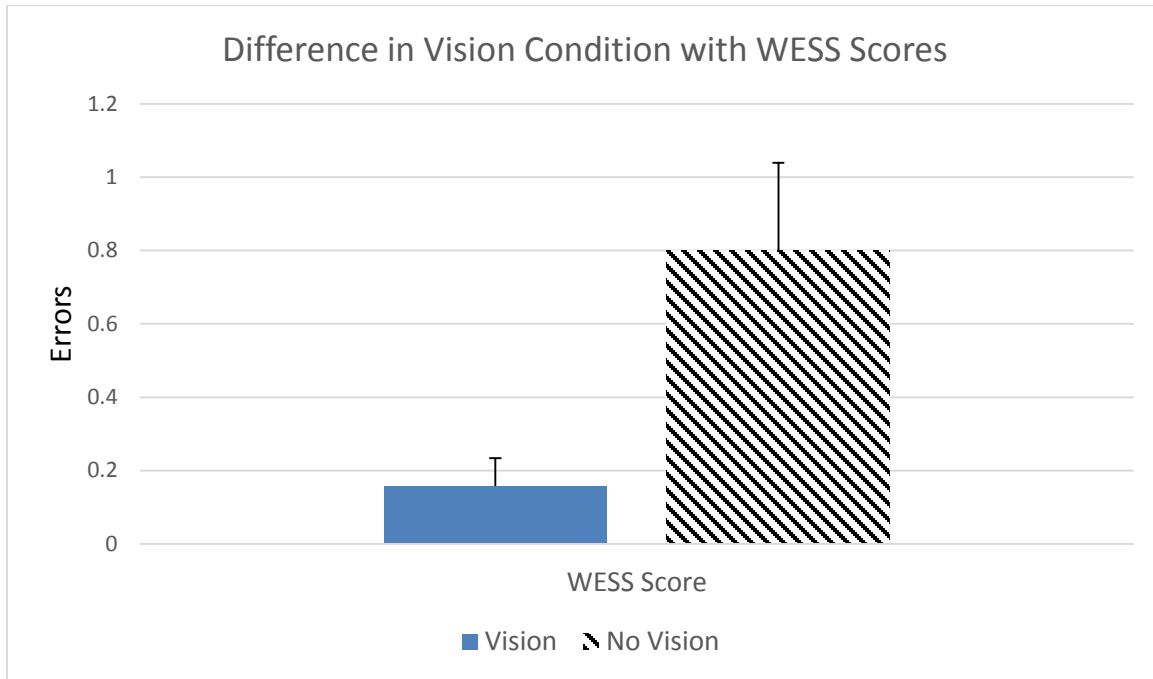


Figure 4.8: 95% confidence ellipse data for baseline and 45 day retest

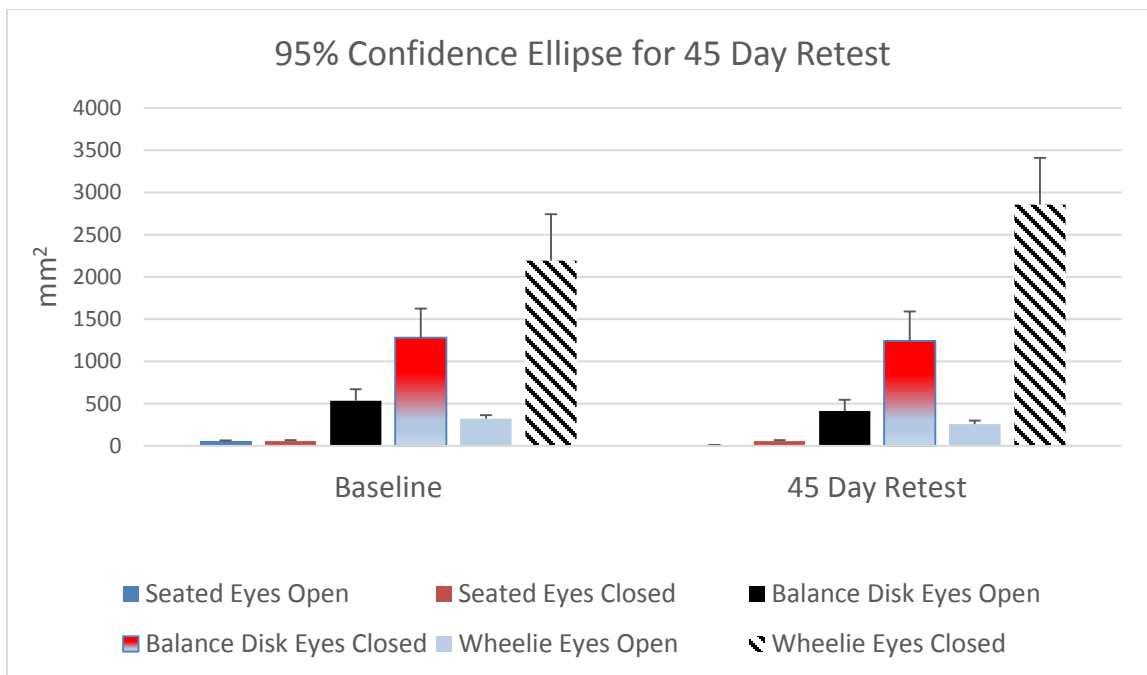


Figure 4.9: WESS scores for individual positions/conditions during baseline and 45 day retest

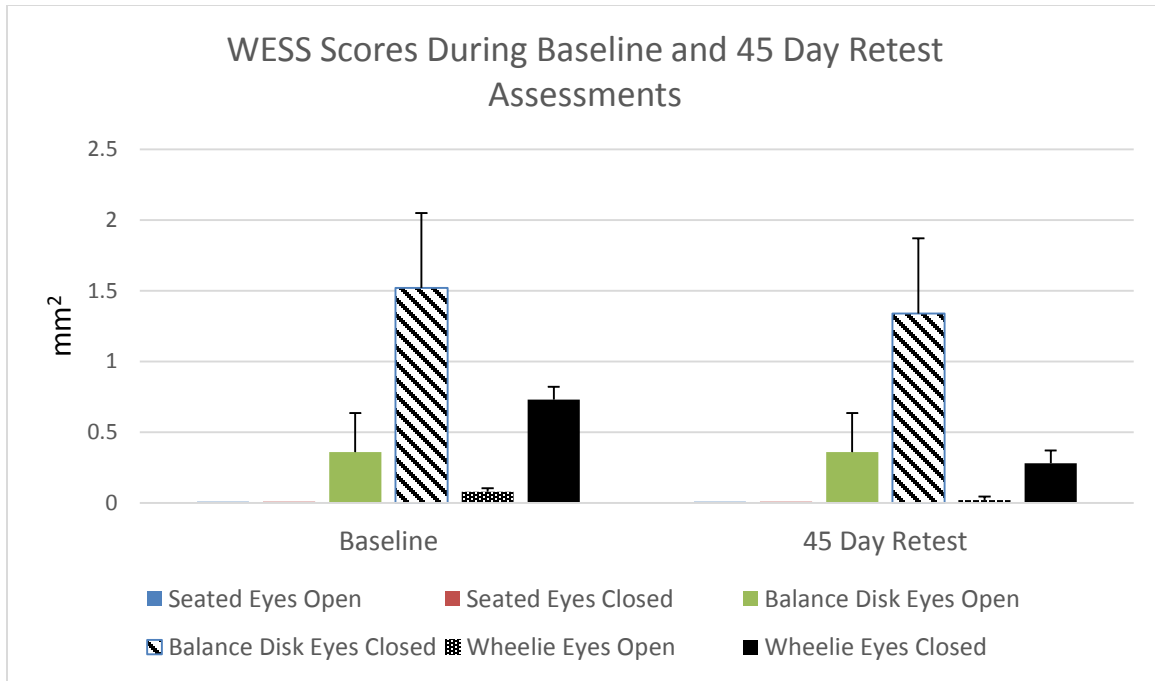


Figure 4.10 SAC scores during baseline and 45 day retest

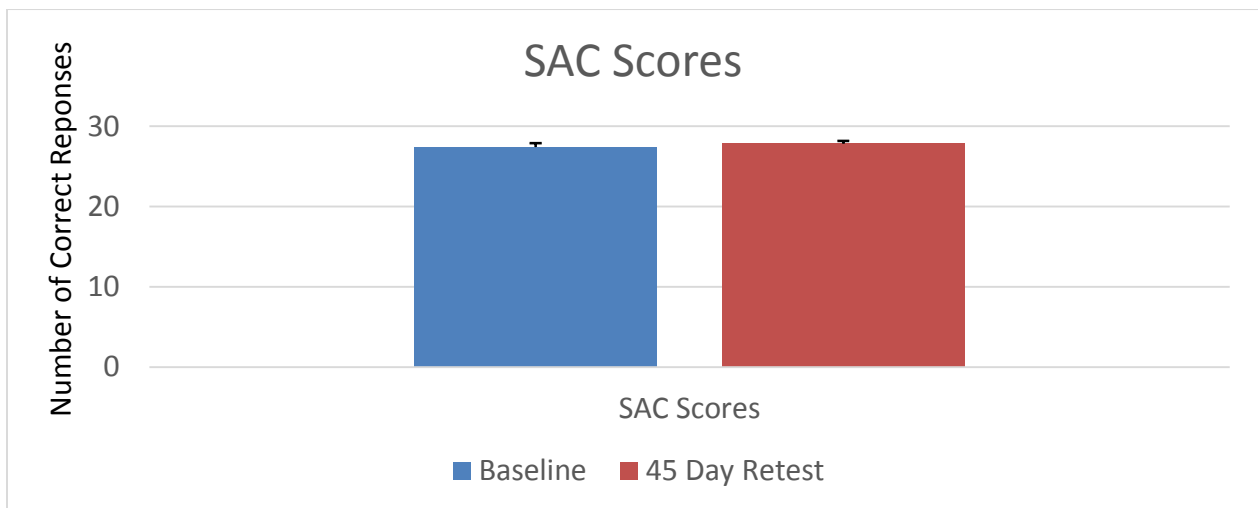


Figure 4.11: Number of symptoms reported during baseline and 45 day retest

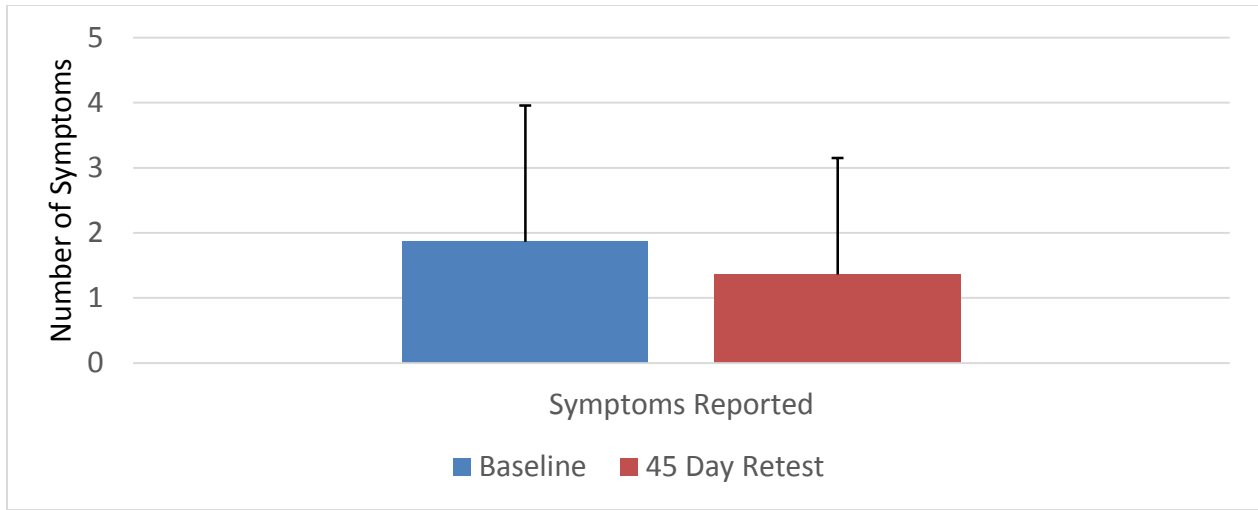


Table 4.3 Intratester Reliability for Tester 1, baseline scores and retest scores

Condition	ICC	Significance	ICC retest	Significance Retest
Seated Eyes Open	--	--	--	--
Seated Eyes Closed	--	--	--	--
Balance Disk Eyes Open	0.992	0.00	1.0	0.00
Balance Disk Eyes Closed	0.998	0.00	0.995	0.00
Wheelie Eyes Open	1.00	0.00	0.00	0.500
Wheelie Eyes Closed	0.987	0.00	1.00	0.00
WESS Total	0.998	0.00	0.999	0.00

Table 4.3 shows the intratester ICCs and significance for trials A and B (which were the baseline videos, and trials C and D (retest) graded twice 7 days apart)

--Conditions with consistent scores of 0 have zero variance and were not scored

Table 4.4 Intratester Reliability for Tester 2, baseline scores

Condition	ICC	Significance	ICC Retest	Significance Retest
Seated Eyes Open	--	--	--	--
Seated Eyes Closed	--	--	--	--
Balance Disk Eyes Open	0.966	0.00	1.00	0.00
Balance Disk Eyes Closed	0.965	0.00	0.990	0.00
Wheelie Eyes Open	--	--	--	--
Wheelie Eyes Closed	0.890	0.00	0.981	0.00
WESS Total	0.946	0.00	0.995	0.00

Table 4.4 Shows the intratester ICCs and significance for Tester 2, trials A and B (which were the baseline videos and trials C and D (retest), graded twice 7 days apart)

--Conditions with consistent scores of 0 have zero variance and were not scored

Table 4.5 Intratester Reliability for Tester 3, baseline and retest scores

Condition	ICC	Significance	ICC Retest	Significance Retest
Seated Eyes Open	--	--	--	--
Seated Eyes Closed	--	--	--	--
Balance Disk Eyes Open	0.946	0.00	0.998	0.00
Balance Disk Eyes Closed	0.743	0.00	0.996	0.00
Wheelie Eyes Open	--	--	--	--
Wheelie Eyes Closed	0.882	0.00	0.986	0.00
WESS Total	0.946	0.00	0.998	0.00

Table 4.5 Shows the intratester ICCs and significance for Tester 3, trials A and B (which were the baseline videos, graded twice 7 days apart)

--Conditions with consistent scores of 0 have zero variance and were not scored

Table 4.6 Intratester Reliability for Tester 4, baseline and retest scores

Condition	ICC	Significance	ICC Retest	Significance Retest
Seated Eyes Open	--	--	--	--
Seated Eyes Closed	--	--	0.655	0.001
Balance Disk Eyes Open	1.00	0.00	0.999	0.00
Balance Disk Eyes Closed	0.998	0.00	1.0	0.00
Wheelie Eyes Open	1.00	0.00	1.00	0.00
Wheelie Eyes Closed	0.996	0.00	0.994	0.00
WESS Total	0.999	0.00	0.999	0.00

Table 4.6 Shows the intratester ICCs and significance for Tester 4, trials A and B (which were the baseline videos, graded twice 7 days apart)

--Conditions with consistent scores of 0 have zero variance and were not scored

Table 4.7 Intertester Reliability for Baseline Scores, Trial A

Condition	ICC	Significance
Seated Eyes Open	--	--
Seated Eyes Closed	--	--
Balance Disk Eyes Open	0.817	0.00
Balance Disk Eyes Closed	0.719	0.00
Wheelie Eyes Open	0.211	0.02
Wheelie Eyes Closed	0.696	0.00
WESS Total	0.791	0.00

Table 4.7 Shows the intertester ICCs, and significance for trial A (which were the baseline videos)

--Conditions with consistent scores of 0 have zero variance and were not scored

Table 4.8 Intertester Reliability for Baseline Scores, Trial B

Condition	ICC	Significance
Seated Eyes Open	--	--
Seated Eyes Closed	--	--
Balance Disk Eyes Open	0.820	0.00
Balance Disk Eyes Closed	0.764	0.00
Wheelie Eyes Open	0.211	0.022
Wheelie Eyes Closed	0.746	0.00
WESS Total	0.828	0.00

Table 4.8 Shows the intertester ICC and significance for trial B (which were the baseline videos reviewed again 7 days after initial viewing)

--Conditions with consistent scores of 0 have zero variance and were not scored

Table 4.9 Intertester Reliability for Retest Scores, Trial C

Condition	ICC	Significance
Seated Eyes Open	--	--
Seated Eyes Closed	0.00	0.474
Balance Disk Eyes Open	0.860	0.00
Balance Disk Eyes Closed	0.726	0.00
Wheelie Eyes Open	0.333	0.001
Wheelie Eyes Closed	0.638	0.00
WESS Total	0.785	0.00

Table 4.9 Shows the intertester ICCs and significance for trial C (which were the retest videos)

--Conditions with consistent scores of 0 have zero variance and were not scored

Table 4.10 Intertester Reliability for Retest Scores, Trial D

Condition	ICC	Significance
Seated Eyes Open	--	--
Seated Eyes Closed	-0.013	0.531
Balance Disk Eyes Open	0.859	0.00
Balance Disk Eyes Closed	0.727	0.00
Wheelie Eyes Open	0.00	0.473
Wheelie Eyes Closed	0.587	0.00
WESS Total	0.734	0.00

Table 4.10 Shows the intertester ICCs and significance for trial D (which were the retest videos reviewed again 7 days after the initial viewing)

--Conditions with consistent scores of 0 have zero variance and were not scored

Chapter 5: Addition of the Paced Auditory Serial Addition Task to a Seated Postural Control Test

Introduction

It is imperative to adequately detect and manage concussions in all populations, given the potential for long-term debilitating head trauma. It is estimated that there are annually 1.6-3.8 million concussions (Langlois, Rutland-Brown, & Wald, 2006). Currently, there are a vast amount of investigations examining varying aspects of concussion. However, concussion research in wheelchair athletics is limited to one incidence study in which concussions were prevalent in 6% of the wheelchair basketball athletes surveyed (Wessels, Broglio, & Sosnoff, 2012).

Cognitive and Balance Deficits After Concussion

After concussive injury, difficulties concentrating, feeling slowed down, and easily distracted are commonly reported symptoms which are indications of disruptions in cerebral function. Attention deficits occur after concussion due to this cerebral dysfunction. Executive and orienting components of attention are found to be affected after concussion while the alerting component remains relatively unaffected (Van Donkelaar et al., 2005). These deficits are evident as those with mild traumatic brain injury had slower reaction time to move attention and were more distractible (Van Donkelaar et al., 2005).

After concussion, reduced speed of information processing also occurs (Ponsford & Kinsella, 1992). It was found that those suffering from concussion had the same accuracy as the

controls but took consistently longer to complete cognitive tasks when the task was not paced (Ponsford & Kinsella, 1992). However, when the cognitive task was paced, like the Paced Auditory Serial Addition Task (PASAT), those with concussion had more errors and were less accurate than the controls. Given the PASAT task is paced, the concussed were not able to sacrifice speed to improve accuracy. Similarly, in another cognitive task (Tower of London task), concussed participants did not have significantly different accuracy than controls, however, they answered less questions in a given amount of time than the controls (Ponsford & Kinsella, 1992). When cognitive tasks require sustained effort and attention, deficits following concussion are typically greater due to a capacity limit. After concussion, there is a reduced capacity limit due to the cerebral dysfunction from injury.

Furthermore, after concussion subcortical activity slows down and there is a spatiotemporal disruption of postural control (Geurts, Ribbers, Knoop, & Van Limbeek, 1996). This may lead to excessive postural sway and an increased dependence on vision for balance (Geurts et al., 1996). Therefore, when balance tasks are completed with the eyes closed, the greatest deficits can be seen.

Concussion Assessment

Concussions may not always be apparent, therefore, it is important to utilize concussion assessment tools to determine if concussion as occurred. Typical concussion assessment evaluates symptoms, cognition, and balance separately. All current balance tests used by sports medicine professionals are completed while standing, thus leaving postural control in wheelchair athletes unquantified. Given this void, a seated postural control task has been developed for the

use of balance assessment after concussion in wheelchair users. This test, the Wheelchair Error Scoring System (WESS), has been found to be a valid and reliable assessment of seated postural control (Wessels et al., 2012).

Current concussion assessment tools are important for marking recovery from concussion, however cognition and balance are tested separately. Given sport involves both cognition and dynamic balance simultaneously, return to play decisions would be most appropriately determined when both are considered concurrently (Teel, Register-Mihalik, Troy Blackburn, & Guskievicz, 2013). Utilization of dual-tasks can meet this demand.

Dual-task Paradigm

A dual-task paradigm involves the concurrent performance of a cognitive and motor task. Dual-tasks force the participant to divide attention between the cognitive and motor tasks. Deficits in performance during divided attention occur when the demands of the task exceed the capacity of processing (Ponsford & Kinsella, 1992). This occurs with greater complexity of the cognitive or motor task as the cognitive task has surpassed the processing capacity. While there are a variety of these paradigms, all of these dual-tasks are gait assessments or standing balance tasks which again are not applicable to wheelchair athletes and users.

Dual-Tasks in Healthy Populations

In an investigation of the dual-task paradigm in healthy participants, 20 participants completed the following; a sensory organization test (SOT), an auditory switch task, and a SOT

and an auditory switch task simultaneously (Resch, May, Tomporowski, & Ferrara, 2011). Completely the tasks simultaneously allowed for examination of the dual-task paradigm. When completed concurrently, balance scores remained while more errors and increased reaction time occurred during the cognitive task. This maintains the “posture first” principle. As the postural control task increased in difficulty, the cognitive task subsequently suffered in performance to allow for maintenance of balance, thus showing the cost of adding a cognition task to balance.

It is commonly found in healthy participants that balance improves with the addition of a simple cognitive task (Ross et al., 2011; Teel et al., 2013). This is due to healthy participants’ ability to divert attention away from conflicting inputs whereas those with concussions may not be able to due to the previously discussed attentional deficits after concussion (Ross et al., 2011). Another possible reason for improved balance performance with the addition of a cognitive task is an externally directed focus. When focus is directed toward the task of balance alone, it may disrupt muscular performance because you do not usually have to focus to complete simple balance tasks so you interfere with the balance system (Ross et al., 2011). However, when focus is directed towards another task, it allows the system to perform naturally.

However, less postural sway does not always occur during dual-task conditions. As the cognitive task increases in difficulty, postural sway increases as well (Pellecchia, 2003; Swan, Otani, & Loubert, 2007). In an investigation of increasing cognitive task difficulties on standing balance in 20 healthy participants, the hardest cognitive task yielded greater postural sway (Pellecchia, 2003). The participants had greater sway when standing on a compliant surface and counting backwards by 3 than standing on a foam pad while not performing any cognitive tasks. Changes are seen in balance and cognitive performance in healthy, non-cognitively impaired

participants completing dual-tasks and other investigators have investigated dual-tasks in concussed populations to see if there are further cognitive and balance deficits.

Dual-tasks in Concussed Populations

It is believed cognitive and balance deficits are exacerbated in those suffering from concussion, thus the increased deficits in performance compared to nonconcussed individuals. For this reason, dual-tasks have been examined in concussed populations. A meta-analysis of these investigations showed those with concussion walked significantly slower and had greater medial lateral sway during dual-task conditions two days post-injury compared to healthy controls (Lee, Sullivan, & Schneiders, 2013). In theory this is due to both tasks competing for brain resources but the attention cannot be appropriately divided among the tasks, thus one task having performance deficits. Similarly, concussed high school students had decreased accuracy on a Stroop test and higher medial/lateral center of mass velocity and displacement compared to controls during dual-task conditions (Howell, Osternig, & Chou, 2013).

In another study of dual-task (gait and Stroop test) in concussed individuals, a majority of the concussed participants demonstrated a variable prioritization of performance (Catena, Van Donkelaar, & Chou, 2011). On some of the trials they had a more cautious gait while in other trials their reaction time increased on a Stroop task. There was a trade-off in performance seemingly from lack of ability to allocate attention to both simultaneous processes. In this investigation the participants did not follow the “posture-first” principle in that attentional resources were not always allotted to maintenance of postural control first. It appears the

participants were not aware of their poor balance and thus not able to give the appropriate focus to postural control (Catena et al., 2011).

Seated Dual-task Assessment in Healthy Wheelchair Users

To determine if the addition of a cognitive task influences performance on the WESS, a dual-task condition was created using a modified paced auditory serial addition task (PASAT) and the WESS. The WESS is performed both with eyes opened and eyes closed to manipulate visual input of postural control. For this reason, a modified PASAT was selected because it is an auditory test thus allowing for use during the eyes closed condition. Furthermore, the PASAT was first used for assessment of concussion and post-concussion syndrome in 1974 by Gronwall and Wrightson.(D. Gronwall & Wrightson, 1974). Through administering the PASAT they were able to distinguish differences between the concussed and post-concussion groups and the control group. The PASAT examines two essential components for detecting deficits after concussion: rapid rate of information processing and controlled processing (Cicerone, 1996). With new numbers auditorially presented every 2 to 3 seconds, it requires the participant to quickly process the information to provide the appropriate response which appears to account for majority of the attentional deficits after concussion (Cicerone, 1996).

It was the purpose of this investigation to determine the effects of adding a cognitive task to the WESS in a group of wheelchair athletes and to determine the appropriateness of its use in concussed athletes.

Methods

Manual wheelchair users (16 males, 10 females) participated in this investigation after informed consent was provided by each participant. Demographic information as well as fatigue and stress levels, illness, recent surgery, or injury were recorded before completion of any trials. Fatigue and stress levels were also recorded using a Likert-scale after completion of each trial. Inclusion criteria included the ability to sit upright without support, reporting no concussions within the past month, and at least 18 years of age.

Procedures

Once the participant expressed understanding of the tasks, they were allowed three practice trials of the PASAT to control for practice effects. After completion of the practice trials, the WESS was completed on a force control platform in which an additional trial was added to each position (seated, disk, wheelie) to allow for completion of the WESS and PASAT simultaneously with the eyes closed. Audio files were created for each PASAT trial and the files were given at random. Files were played through external speakers by an administrator and responses were recorded as correct or incorrect. Each condition was completed twice for 20 seconds for a total of 18 trials. Upon completion of each trial, fatigue and muscle spasm levels were recorded on a Likert-scale to determine whether performance was affected by fatigue and/or muscle spasms. Participants were not told to direct their attention to either task.

Outcomes

Participants were then provided instruction on the modified Paced Auditory Serial Addition Task (PASAT) and the wheelchair error scoring system (WESS). The PASAT was

originally designed in 1974 for testing cognitive function after traumatic brain injury (Gronwall & Wrightson, 1974). The PASAT assesses attentional processing and capacity, concentration, and information processing speed and is commonly used for cognitive assessment. It is an auditory task in which a recording is played of a series of numbers. The participant is required to add together the two most recent numbers heard and give their answers out loud. Numbers are given at a rate of two or three seconds, depending on the test (Gronwall, 1977). The final score is the number of correct responses (Gronwall, 1977). In the first study utilizing the PASAT with concussed individuals, PASAT scores of concussed participants, controls, and those with post-concussion syndrome were compared (Gronwall & Wrightson, 1974). As the speed of information was increased, the concussed group and the post-concussion group had significantly reduced performance compared to the controls. The concussed groups were not able to process the information quick enough thus resulting in a reduced channel capacity and decreased performance. The PASAT has been shown to have practice effects (Tombaugh, 2006) which are due to the complexity of the task. It appears the greatest effects occur between the first and second trials. For this reason, it is suggested that practice trials occur before being rated on performance. Learning the task helps reduce anxiety about the task thus making performing the task easier (Tombaugh, 2006). For the purpose of the current investigation, numbers were given at a rate of every 2 seconds to allow for 9 total numbers given each 20 second trial.

The WESS is a seated postural control test that quantifies seated balance in three different positions: seated, on a balance disk, and in a wheelie. A wheelie is an everyday wheelchair skill that allows for community ambulation (i.e. Going up curbs). During the two seated positions the participant has their hands on their hips. In the wheelie, both hands are on their wheels. Each position is completed with eyes opened and eyes closed. Each position and condition is

performed for 20 seconds for a total of 6 trials. The participant is rated on balance performance in each condition by a trained evaluator. Errors are noted by evaluators if the participant commits one of the following: takes their hand off their hips, opens their eyes (when applicable), comes out of the wheelie, regrips their wheels during the wheelie condition, or remains out of the testing position for more than five seconds. Error scores for each trial are summed to give a WESS score. A higher WESS score is an indication of more postural sway.

Analysis

Balance

Balance was assessed using the WESS and 95% confidence ellipse. 95% confidence ellipse area is determined using measures provided by the force platform. To determine if there was a difference with addition of the cognitive task, a repeated measures analysis of variance (ANOVA) was conducted to examine significant differences between the three conditions (eyes open, eyes closed, PASAT) in the three positions (seated, balance disk, and wheelie) on WESS scores. Because only 10 participants were able to complete the wheelie on the force control platform due to chair width, a repeated measures ANOVA with condition (eyes open, eyes closed, PASAT) and position (seated, balance disk) on 95% confidence ellipse was computed. An alpha of 0.05 was used for all analysis.

Cognition

The PASAT was used to measure cognition during the dual-task conditions. Accuracy of PASAT responses was calculated as correct response/total PASAT numbers given. The total number of correct PASAT responses was also recorded. A repeated measures ANOVA was conducted to determine differences in PASAT scores across the three positions (within subjects variable) using both accuracy scores and average PASAT score for each position (6 ANOVAs). An alpha of 0.05 was used for all analysis.

Dual-Task

Dual task cost was calculated using the following equation: $(\text{Dual task} - \text{single task}) / \text{single task performance} \times 100$. A single T test was used with dual task cost tested against a test value of 0 to determine if there was a significant dual task cost to performing the PASAT with each position.

Other Factors

In an effort to determine if changes in balance were due to fatigue or muscle spasm we utilized a Likert scale. All scores were zero so no further analysis was performed. Similarly, the participant was asked to record whether or not they were experiencing any sickness. Sickness was not reported by any participant so no further analysis was performed.

Results

Twenty-six manual wheelchair users ranging in age from 18-24 participated in this investigation (16 males, 10 females). The participants had an average length of disability 16.47 years (range 4-24 years) and had participated in wheelchair athletics for an average of 8.21 years (range 2-15 years). The most common disability represented was spinal cord injury (n=9), followed by spina bifida (n=5), and cerebral palsy (n=4). [Table 5.1].

Balance

Repeated measures ANOVA revealed a main effect for condition ($F=10.62$, $p=0.00$), position ($F=10.977$, $p=0.003$), and an interaction between condition and position ($F=3.61$, $p=0.02$) for WESS scores. Post-hoc analysis revealed a significant difference between each of the conditions (eyes open, eyes closed, and PASAT). Significant differences were also found between each position in the WESS scores. Means and standard error for each condition and position are seen in figure 5.1 and 5.2.

A repeated measures ANOVA revealed a main effect for position ($F=17.897$, $p=0.00$) and a trend for condition ($F=3.08$, $p=0.06$) for 95% confidence ellipse. Post-hoc analysis revealed a significant difference between the two positions. Means and standard deviations can be found in figure 5.3 and 5.4.

No significant effects on balance and cognition were found in the seated position (p 's > 0.05).

Fatigue levels did not affect the participants as each reported no change in levels of fatigue after each trial. All of the participants reported they were not currently experiencing any spasms that were affecting their balance ability.

Cognition

Average PASAT scores revealed no significant difference between the positions ($F=2.197$, $p=0.124$). {Figure 5.5} PASAT accuracy scores also showed no significant differences between positions ($F=1.293$, $p=0.283$). {Figure 5.6}

Dual-Task

A one sample T test analysis revealed a dual-task cost for the wheelie condition ($t=5.226$, $P=0.001$). Dual-task costs were not significant for the other two positions.

Discussion

The main purpose of this investigation was to determine the effects of adding a cognitive task to the WESS. Addition of the cognitive task improved balance performance seen by a decrease in WESS errors indicating improved balance performance. Previous studies have found that addition of a cognitive task improves standing balance performance as well (Ross et al., 2011; Swan et al., 2007).

Consistent with previous work, addition of a cognitive task improved seated balance, however, this was the first investigation of our knowledge to examine dual-tasks in seated balance with wheelchair users. In an investigation of 98 women aged 18-27 with no history of neurological or auditory impairments, participants completed cognitive and standing postural control tasks concurrently. It was found that postural control improved with difficult cognitive

tasks (Swan et al., 2007). Specifically, participants showed less postural sway during complex cognitive tasks compared to simple cognitive tasks and postural control tasks alone.

There are several theories why this occurs. One theory states this is due to diverting attention away from postural control, a fairly automatic process (Swan et al., 2007). With attention being diverted, less overcorrections are made and the subconscious process takes over.

Another theory corresponds with the constrained-action hypothesis which states an internal direction of focus disrupts automatic process of the motor system (Wulf, McNevin, & Shea, 2001; Wulf, Weigelt, Poulter, & McNevin, 2003). The simple task of balance alone is fairly natural given it is an everyday task that usually occurs simultaneously with other tasks (Resch et al., 2011). However, when the participants are asked to complete balance tasks singly, they may divert their attention to the balance task and override the natural process. The addition of the cognitive task allows balance to occur subconsciously rather than as a conscious process (Broglio, Tomporowski, & Ferrara, 2005). With attention now being divided between the cognitive and balance task, muscle tension is reduced which causes decreased sway velocity (Resch et al., 2011). Given participants were able to externally focus their attention on the cognitive task during this investigation, it is maintained balance performance increased due to an externally directed focus.

In the current investigation there were no significant differences in PASAT scores across the three positions. Even though the difficulty of the postural control task changed, it did not affect cognitive performance. Future investigations should examine whether changing the difficulty of the cognitive task would impact cognitive performance.

Our study was designed to examine the potential use of this dual-task for concussion assessment in a wheelchair athlete population. Combining a cognitive task measuring information processing speed (i.e. PASAT) and seated postural control measures (i.e. WESS) might be more sensitive for diagnosing concussion and marking the course of recovery. The use of this dual-task paradigm should be examined in a population of concussed wheelchair athletes.

Limitations

Given our sample was a healthy group of college students, it is possible these results are not generalizable to the entire wheelchair user population. Older individuals may be affected more by a dual-task due to advanced aging. Additionally, we did not screen for cognitive deficits so impairments in cognitive function may have already been present.

Some have expressed concerns of the PASAT measuring addition skills thus limiting its interpretation if the individuals were limited by the mathematical task. For this reason, simple addition problems are used to limit the impact of mathematical ability. Given our population of all college students, the potential limitation of using simple addition problems should be null.

Given the complexity of the dual-task, it is possible there may have been practice effects. However, we attempted to control for practice effects by having each participant practice the PASAT. It has been previously demonstrated that the greatest practice effects occur between the first and second trials (Tombaugh, 2006). Therefore, we had each participant complete three practice trials to control for these practice effects.

Conclusion

Seated balance performance improved with the addition of a cognitive task. The addition of the cognitive task diverted attention away from the balance task thus allowing the natural process to override and limit interferences between the cognitive and balance systems. With concussion, in a dual-task condition it is expected one would find greater deficits due to both balance and cognition competing for attention and the individual not being able to allocate attention to both processes simultaneously due to injury. Additional investigations examining the effects of combining the WESS and PASAT as a dual-task condition in concussed individuals are needed to determine the effectiveness of diagnosing concussions in wheelchair users.

Figures and Tables

Table 5.1: Disabilities represented in this investigation

Disability	# of participants
Spinal Cord Injury	9
Spina Bifida	5
Cerebral Palsy	4
Amputation	2
Minimal Disability	1
Other	Osteogenesis Imperfecta, Sacral agenesis, Nerve damage to lower extremities (2)

Figure 5.1: WESS score across the three conditions

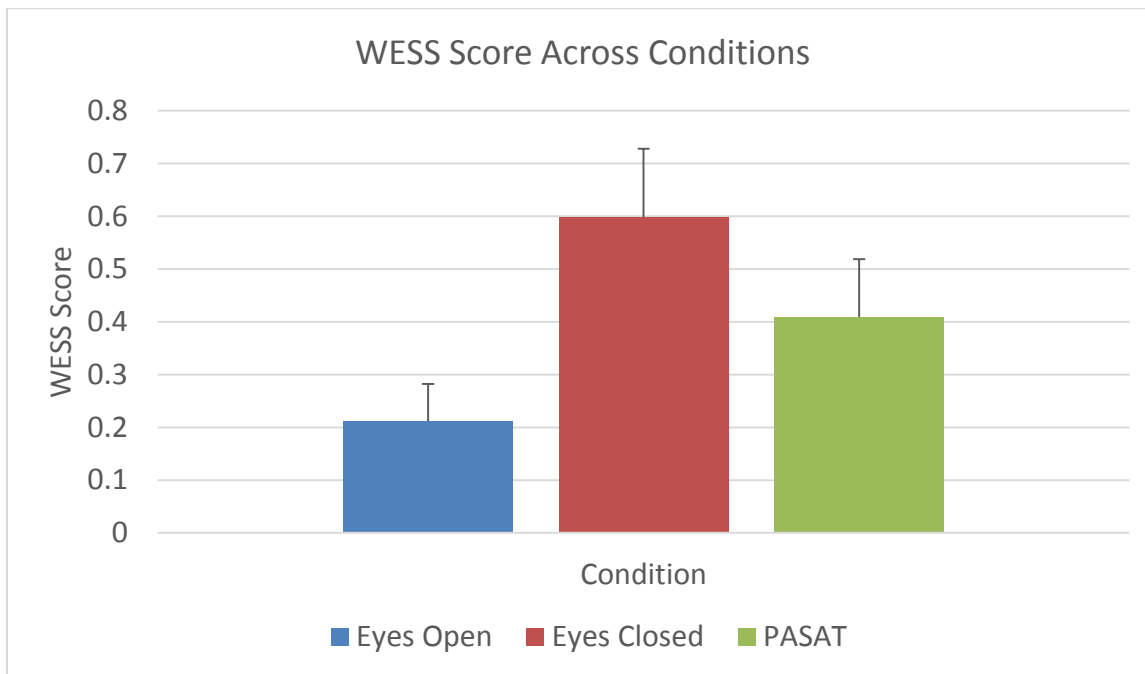


Figure 5.2: WESS scores across the three positions

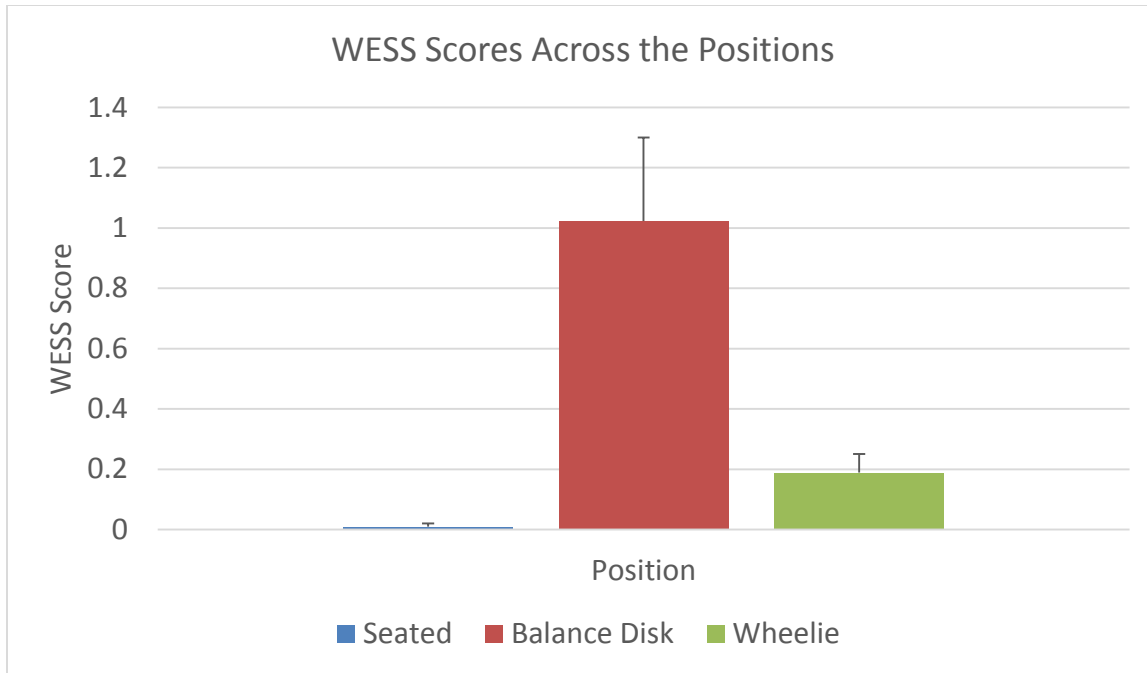


Figure 5.3: 95% confidence ellipse for position

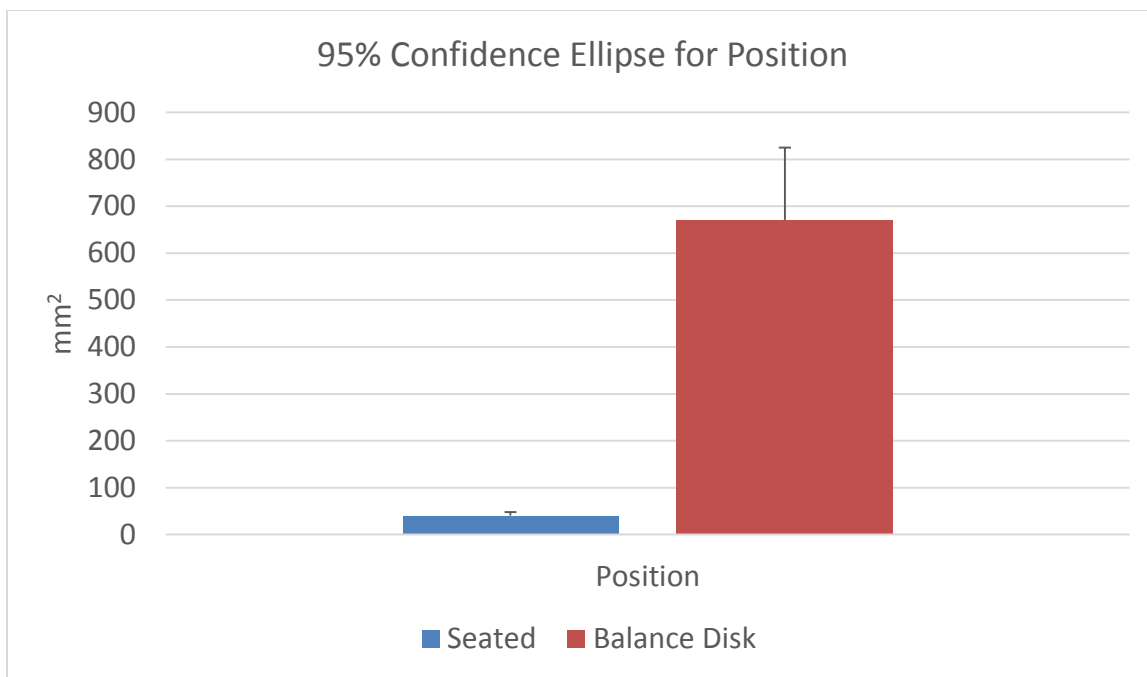


Figure 5.4: 95% confidence ellipse area for the three conditions

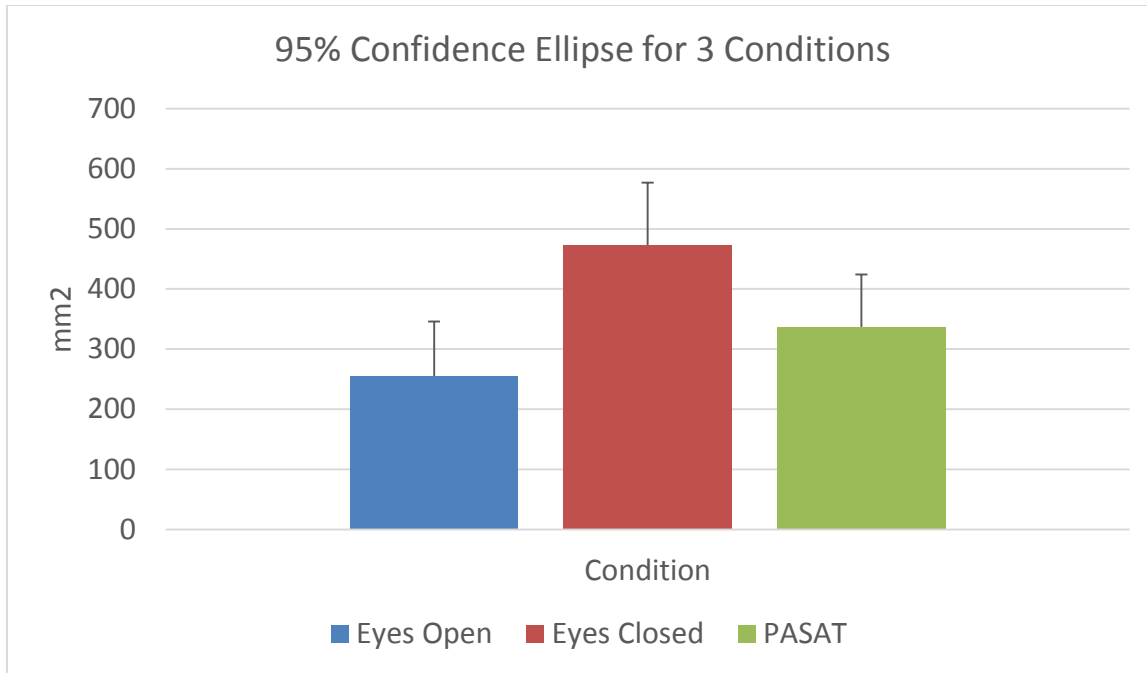


Figure 5.5: Average PASAT score during the WESS

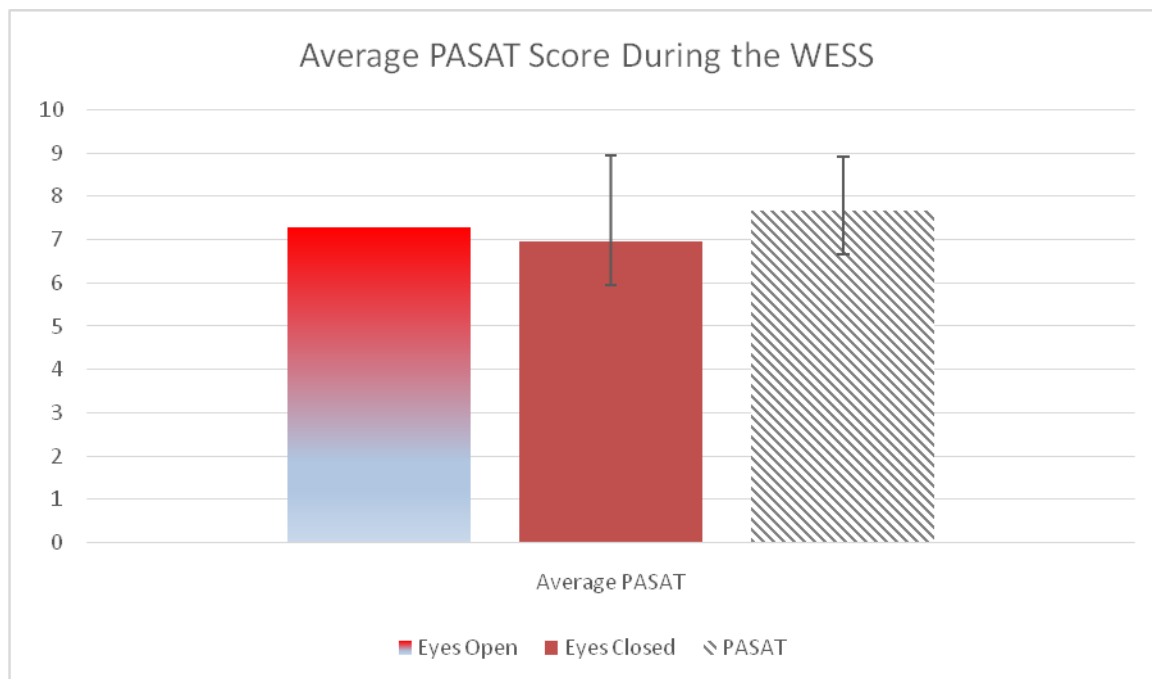
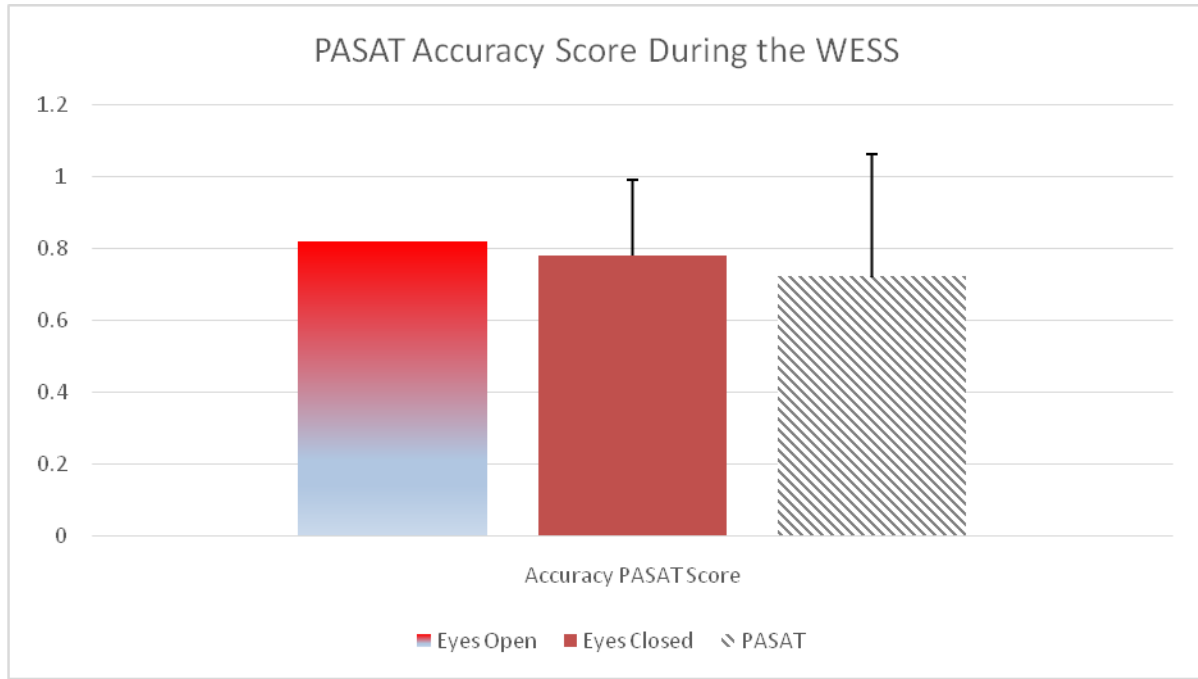


Figure 5.6: PASAT accuracy during the WESS



Chapter 6: Determining the Sensitivity of the WESS to Detect Changes in Postural Control Associated With Concussion

Introduction

With the death of several high profile athletes believed to be suffering from long term consequences of multiple concussions, there has been a push for proper management and diagnosis of concussion to limit these potentially long term debilitating injuries. While this increased awareness is imperative, it is also crucial to expand these discussions to all aspects of sport. There has been limited research on concussions in disability sport. With the concussion incident rate of wheelchair basketball reported at 6% (Wessels, Broglio, & Sosnoff, 2012), it is crucial to close this gap of knowledge.

To properly assess whether a concussion has occurred it has been suggested to examine self-reported symptoms, cognitive function, and balance (Guskiewicz et al., 2006). When all three of these domains are used, concussions can be detected between 89-96% of the time (Broglio, Ferrara, Macciocchi, Baumgartner, & Elliott, 2007). Validated and reliable cognitive tests and symptom scales can be easily implemented in wheelchair athletes (Chapter 4). To assess balance following a suspected concussion, a majority of medical professionals use the Balance Error Scoring System (BESS). The BESS is performed standing and is not appropriate for wheelchair athletes. Therefore, there is a gap in concussion assessment for athletes with disabilities as there is no current way to quantify changes in seated balance. It is imperative to fill this void to properly assess concussions in people with physical disabilities.

The Wheelchair Error Scoring System (WESS) has been designed to assess seated postural control. The WESS has been shown to be a reliable and valid assessment tool for

quantifying seated postural control. (Chapter 4) The purpose of this investigation is to determine the sensitivity of the WESS to concussions by detecting subtle postural control deficits that may be present after concussion.

Methods

Participants

Five athletes with disability participated in this investigation. Three of the athletes were members of a collegiate wheelchair basketball program and two were members of a collegiate wheelchair track program. Five control subjects completed the same testing battery to observe changes that may occur due to repeat assessment or change in time. Level of disability and how it affects each individual is unique to each case of disability. While there are not perfect matches for our controls and concussed participants, we attempted to match the controls as close as possible within our given population. All were college aged students between 19-25 years old consisting of 5 females and 5 males.

Procedures

After a suspected head injury occurred, each athlete reported the incident to their certified athletic trainer. Demographic information and informed consent were collected before any testing began. Four of the five participants were baseline tested on the Wheelchair Error Scoring System (WESS), the Standardized Assessment of Concussion (SAC), and a graded symptom scale to obtain normalized values for each participant. One of the wheelchair track athletes was

not initially baseline tested due to her not being considered at high risk of concussion with wheelchair track. The other track athlete was initially playing on the wheelchair basketball team so he completed baseline assessment. All five participants were tested using the same testing battery after suspected head injury occurred.

Outcomes

The WESS is a seated postural control assessment. It consists of three test positions in which each test position is tested twice (eyes opened, eyes closed) for 20 seconds per trial. The individual is tested on their balance performance while seated on a table, seated on a balance disk, and in a wheelie maneuver. Errors are recorded during the trials. An error was noted during the seated and balance disk tasks if the participant lifted their hand(s) off their hips, touched the table, opened their eyes (when appropriate), or remained out of the test position for more than five seconds. An error was noted during the wheelie task if the participant regripped their wheel, opened their eyes (when appropriate), placed all four wheels on the ground, or remained out of test position for more than five seconds. If the individual could not maintain the test position for more than five seconds, a maximum score of ten was recorded.

The SAC is a measure of cognition, specifically, it indexes orientation, immediate memory, concentration, and delayed recall and takes approximately five minutes to complete. A summation score from the aforementioned areas provides a quick reference of cognitive function with a maximum score of 30 which shows better cognitive performance. The SAC was shown to be sensitive and specific to concussions (McCrea, 2001) and has been shown to have no practice effects which makes it ideal for repeat administrations (Valovich, Perrin, & Gansneder, 2003).

The graded symptom scale measures the participant's symptoms and allows them to rate the severity of each symptom experienced. Assessing the severity of each symptom allows a clinician to mark progress or digression post-injury. These scales focus on symptoms related to cognition, information processing, balance, and memory (Piland, Ferrara, Macciocchi, Broglio, & Gould, 2010).

In addition, participant in case #5 also completed two additional trials during the WESS in order to complete the Paced Auditory Serial Addition Task (PASAT) simultaneously with the balance task, thus testing a dual-task paradigm. The PASAT was originally designed for use in concussion assessment in 1974 (Gronwall & Wrightson, 1974). The PASAT is an auditory addition task that requires the addition of the two most recently heard numbers played from a recording. The participant says the sum of the two numbers out loud and an investigator records whether or not the answer was correct. Each trial lasts 20 seconds with nine total PASAT numbers given during each trial. The participant was allowed to practice the PASAT 3 times before testing began. This was allowed to minimize practice effects which are typically seen between the first and second trials off the PASAT (Tombaugh, 2006). The participant completed a PASAT while performing the seated position and balance disk position with eyes closed.

The participant in case #5 also completed a survey during her testing sessions in which she recorded levels of fatigue or muscle spasm, sickness, or injury. Additionally after each trial occurred, the participant recorded levels of fatigue or spasm that were experienced during the trial to indicate whether fatigue or spasm influenced postural control during the trial. A detailed account of each case is given below.

Analysis

Effect size was calculated for each measure for each time period (Baseline, 24 hours, 48 hours) in which the concussed group was compared to the controls.

Case 1

A 19 year old male was playing in a collegiate wheelchair basketball game when he fell due to spinning quickly and not being able to get his hands down to protect his head from hitting the ground. He continued play for short duration after his injury then decided it was necessary to discontinue play due to presence of symptoms. He initially reported dizziness and feeling “a little off” after getting up which subsided by the time he stopped playing.

Subject uses a manual wheelchair as his primary means of mobility for the past nine years and has played wheelchair athletics for seven of those years. Subject had his spinal cord removed at thoracic vertebrae 6 and down due to a spinal tumor at the age of 11. He reports never having a previous concussive injury. Subject is a class I on a IV point wheelchair basketball scale indicating that he has the least amount of motor function on the court.

Baseline assessment, which occurred three months prior, was completed by the same certified athletic trainer that completed the post-injury assessment. The participant recorded experiencing no symptoms during baseline assessment. His cognitive assessment revealed a SAC score of 30/30 and his balance assessment had a WESS score of 0.

During post-injury assessment the participant reported feeling distracted and a headache with a total severity of 8. His SAC score was a 26/30 and WESS score was 2. Subject appeared

mildly unsteady during assessment and appeared to have an altered state compared to before the game. An altered state was noted due to the participant seeming out of it and slow to answer questions. Given his symptoms, change in cognition and balance, and mechanism of injury it was determined the participant had sustained a concussive injury. Subject was withheld from further exercise until his symptoms resolved.

Concussion assessment was completed again 48 hours after injury. He still noted 2 symptoms (feeling in a fog, and sensitivity to light) with a total severity of 6. His SAC score increased to 29/30 and his WESS score was 1.

Final assessment was completed 72 hours post-injury. At this time, he reported experiencing no symptoms, had a SAC score of 29/30 and a WESS score of 0. At this time, it was deemed the subject was no longer experiencing concussive symptoms given his assessment scores. Subject reported no difficulties with every day activities and stated he was feeling recovered from his concussion at this time. {Figures 6.1-6.4}

The control for case #1 was a 20 year old male with a spinal cord injury at thoracic level 8. He has had his disability since birth. Baseline, 24 hour assessment, and 48 hour assessment scores can be found in figures 6.1-6.4. Scores for each measure changed minimally over the testing sessions.

Case 2

A 19 year old female was completing a wheelchair track work out on a stationary wheelchair roller when her racing wheelchair came unhooked from the roller apparatus and she

fell off and hit her head. She reported to the certified athletic trainer within 24 hours in which post-injury assessment then occurred.

Subject is a manual wheelchair user due to being born with spina bifida. She has used a wheelchair for 12 years as her primary means of mobility and has participated in wheelchair athletics for 10 years. She is a wheelchair track athlete with a classification of T53. She reported having sustained a concussive injury in the previous year when her wheel went into a grate while pushing her wheelchair and she crashed and hit her head on the sidewalk. After this injury, the participant went to the emergency room and had a computed tomography scan. Results from the computed tomography scan showed no advanced brain injury and she was diagnosed with a concussion.

Subject initially reported the following 18 symptoms after the most recent head injury with a combined severity of 54: blurred vision, dizziness, drowsiness, easily distracted, fatigue, feeling in a fog, feeling slowed down, headache, inappropriate emotions, loss of orientation, memory problems, poor balance/coordination, poor concentration, sadness, sensitivity to light, sensitivity to noise, sleep disturbance, and vacant stare. Her main complaint was feeling out of it and was having trouble sleeping. Her SAC score was 27/30 and WESS score was 11. Within 48 hours her scores began to improve. However, when she participated in her academic classes, her symptoms began to worsen. When she was finished with class, she rested in a quiet environment and her symptoms returned to pre-class values.

On the third day post-injury she began to feel worse than she had on the previous two days and states she had barely slept in the past two days. She was instructed to go to the emergency room to ensure she was not experiencing other head injury (i.e. subdural hematoma). After a computed tomography scan, it revealed there were no other head injuries occurring and

she was diagnosed with a concussion by a physician. Post-concussion analysis was to resume when subject was asymptomatic. She continued having symptoms for five more days before another assessment was completed.

Nine days after initial assessment, the subject only reported 2 symptoms (blurred vision, feeling in a fog) with a combined severity of 2. Her SAC score was 29/30 and her WESS score was 1. She stated she was feeling recovered from her concussion and she was no longer having difficulty with her academic work.

Over the course of her recovery, there is marked improvement in scores each day coinciding with recovery with symptom resolution by day 9. WESS performance was consistent with the other scores (symptoms and SAC scores) that have already been established as indicators of concussion. {Figures 6.5-6.8}

An aged-matched control was utilized to compare baseline values since pre-injury normalized values were not available for this participant. The aged match control was a 20 year old female born with spina bifida. 24 hour and 48 hour assessments can be found in figure 6.5-6.8. Scores for each measure changed minimally over the testing sessions.

Case 3

A 25 year old male track athlete was pushing in his racing wheelchair when he swerved to miss a pothole and hit a parked vehicle. He was propelled out of his racing wheelchair and hit his head on the vehicle. Subject was wearing a helmet at the time of injury. Participant reported experiencing symptoms of a concussion so he was instructed to be seen by his certified athletic trainer.

Subject utilizes a manual wheelchair as his primary means of mobility due to acquiring acute transverse myelitis. He has utilized the wheelchair for 9 years and has participated in wheelchair athletics for 8 years. He is a wheelchair track athlete with a classification of T54. He reported having no history of concussions prior to this incident.

At the time of injury, he states he did not lose consciousness and remembers everything that happened, however, he felt in a fog and not like himself. By the time he returned to the training facility and was seen by the certified athletic trainer he was beginning to feel less out of it.

Baseline assessment and post-injury assessment were completed by the same certified athletic trainer. During baseline assessment, the participant reported no symptoms. Baseline SAC score was 30/30 and WESS score was 0. Baseline assessment was completed 7 months prior to injury.

After suspected head injury the participant reported 2 symptoms (feeling slowed down and feeling in a fog) with a severity of 5. His SAC score was 28/30 and WESS score was 1. The next assessment was completed 72 hours later. At this time, he reported no symptoms, had a SAC score of 30/30 and WESS score of 0.

Given deficits in all three areas (symptoms, cognition, and balance) compared to baseline values and the mechanism of injury, it was determined the participant had obtained a concussion. Participant withheld from exercise until he was asymptomatic then started a return to play protocol. {Figures 6.9-6.12}

The control for case #3 was a 20 year old male with a spinal cord injury at level thoracic 8-12. The control has had his disability for 5 years. Baseline, 24 hour, and 48 hour assessments

can be found in figures 6.9-6.12. Scores for each measure changed minimally over the testing sessions.

Case 4

A 19 year old female wheelchair basketball player was completing a strength and conditioning workout when she sustained a head injury due to a medicine ball hitting her in the head. She immediately contacted the certified athletic trainer as she was not feeling well and was evaluated for head injury.

The participant was born with paralysis of the lower half of her body and had played wheelchair sports for 7 years. She ambulates with straight leg braces and uses an everyday wheelchair for long distances. Participant reports no previous concussive injury. Participant is a 3 on a 4 point wheelchair basketball classification system.

Baseline assessment occurred approximately 5 months prior to injury by the same certified athletic trainer who completed post-injury assessment. During the initial assessment, she reported fatigue as her only symptom with a severity of 2. Her cognitive assessment revealed a SAC score of 27/30 and her balance assessment revealed a WESS score of 0.

Immediately following injury, the subject reported 8 symptoms (blurred vision, fatigue, feeling in a fog, feeling slowed down, headache, memory impairment, balance/coordination impairment, and seeing stars) with a total severity of 18. Her SAC score was 26/30 and her WESS score was 3.

Forty-eight hours have initial injury, she reported 2 symptoms (fatigue, feeling slowed down) with a total severity of 2. Her SAC score improved to a 28/30 and her WESS score decreased to 0. {Figures 6.13-6.16}

Given the uniqueness of this participant's disability, a male with a similar disability was used because he was the closest to her level of function. This male was 18 years old, born with his disability, and utilizes straight leg braces similar to the concussed participant. Baseline, 24 hour, and 48 hour assessments can be found in figures 6.13-16. Scores for each measure changed minimally over the testing sessions.

Case 5

Participant was at wheelchair basketball practice when she clipped someone's wheelchair and she fell. Participant was unable to use her hands to protect herself from falling and she hit her face on the gymnasium floor. Participant stated she did not feel "right." She immediately removed herself from practice and refrained from exercise. She contacted the same certified athletic trainer who completed baseline assessment and post-injury evaluation occurred.

Participant is a 21 year old female who is a wheelchair basketball player and is classified as having minimal disability (knee injuries). She has had her disability for 4 years and has played wheelchair sports for 3 years. Participant ambulates and does not use a wheelchair for mobility. Participant has no previous concussive injury.

During baseline assessment, the participant reported experiencing no symptoms. Her SAC score was a 30/30 and her WESS score was 0. During the WESS she did not complete the wheelie condition because she does not have the skill level necessary. Participant completed an

additional trial of the WESS seated position while completing the PASAT with her eyes closed. Her PASAT accuracy score for this position was 0.89. She also completed an additional trial of the WESS balance disk position while completing the PASAT with her eyes closed. Her accuracy score for this position was 0.89.

Post-injury she reported experiencing the following symptoms: drowsiness, easily distracted, feeling “in a fog”, headache, confusion, difficulty concentrating, seeing stars, sensitivity to light, not “feeling right”, and feeling slowed down. Total symptom severity was 23. Her SAC score was 26/30 and her WESS score was 4. Her PASAT accuracy for both seated and balance disk position was 0.78. The participant reported no recent surgeries, injuries, fatigue, muscle spasm, or sickness. After each WESS trial, the participant reported no additional fatigue or muscle spasm. Participant had a delayed time to response when completing SAC and communicating with the certified athletic trainer. After concussion assessment, she stated her symptoms began to worsen due to cognitive and balance testing. Given the deficits in all scoring domains, it was determined she had suffered a concussion.

Twenty-four hours later the participant completed concussion assessment again to monitor progress. At this time, she reported the following symptoms: headache, dizziness, sensitivity to light, sensitivity to noise, feeling slowed down, feeling in a fog, difficulty concentratin, difficulty remembering, fatigue, drowsiness, trouble falling aslweep, more emotional, and irritable. Combined severity of these symptoms was 17. SAC score was a 26 and WESS score was 0. PASAT accuracy was 0.89 for both seated and balance disk positions. The participant reported no recent surgeries, injuries, fatigue, muscle spasm, or sickness. After each WESS trial, the participant reported no additional fatigue or muscle spasm. Participant states concussion assessment causes her symptoms to worsen. Participant attempted to complete her

academic work, however, it caused her symptoms to worsen so she refrained from as much academic work as possible.

During the 48 hour post-injury assessment, participant reported a slight decrease in number of symptoms (headache, sensitivity to light, sensitivity to noise, feeling slowed down, feeling in a fog, difficulty concentrating, difficulty remembering, drowsiness, and trouble falling asleep) with a combined severity of 22. SAC score increased to 29 and WESS score was once again 0. PASAT accuracy was 0.89 in the seated position and 1 in the balance disk position. Once again, concussion assessment caused symptoms to worsen. For this reason, we abstained from concussion assessment as to not further aggravate her symptoms.

Seven days post-injury the participant stated she was feeling nearly completely recovered from her concussion so concussion assessment was completed again to measure her progress and possibilities of starting a return to play protocol. Her only reported symptom was difficulty concentrating with a severity of 1. At this time her SAC score returned to a baseline value of 30 and WESS score was 0. PASAT accuracy scores for the seated position was 0.79 and 1 for the balance disk position. At this time, participant was able to coherently answer questions in a timely manner as opposed to the delayed answer she had after initial injury. {Figures 6.17-6.21}

The control for case #5 was a 23 year female with minimal disability. Baseline, 24 hour, and 48 hour assessments can be found in figures 6.17-6.21. Scores for each measure changed minimally over the testing sessions.

Effect Size

Effect size was calculated for each measure (Number of symptoms, severity of symptoms, SAC, and WESS) {Table 6.1}

Discussion

The most significant finding of these case studies is that each participant had an increase in the number of errors on the WESS after head injury, indicating a decrease in postural control. These decreases in postural control corresponded with increased symptoms of concussion and a decrease in cognitive function. This findings indicate that the WESS may be sensitive to detecting concussion-related changes in seated balance.

After concussive injury, each participant had a decrease in postural control marked by increased number of errors on the WESS. Balance deficits associated with concussion typically resolve within 3 days of the injury (McCrea et al., 2003). Four of the five participants were congruent with this trend when their balance performance returned to baseline within 3 days post-injury. The single participant whose balance did not return within 3 days had experienced previous concussive injury. Lasting postural control deficits have been seen in previous cases of concussion. In a study of those with a history of previous concussion and those with no concussion history, the concussion history group had altered postural control dynamics compared to the control group (Sosnoff, Broglio, Shin, & Ferrara, 2011). This suggests that postural control deficits after concussion may not disappear within three days in those who have had previous concussion. This may have been the circumstance in case #2, thus leading to her prolonged deficits given she may have already had postural control deficits from her previous concussion.

Interestingly, the one participant who did not utilize a wheelchair or other assistive mobility device for ambulation had similar decreases in seated postural control. This participant does not have any muscular impairments and could have completed a traditional standing postural control assessment (i.e. BESS), however, given her involvement in the wheelchair athletics she was tested in the same way as her teammates in a seated manner. The observed potential sensitivity to concussion in a non-disabled athlete is encouraging as it suggests the WESS is able to account for postural control errors in both disabled and able-bodied populations, thus possibly expanding its use to other populations.

Each case of concussion reported here had an increase in the number and severity of symptoms after head injury. In previous studies, trademark signs appear to be confusion, amnesia (Guskiewicz, 2003), and decreased balance (Guskiewicz, Riemann, Perrin, & Nashner, 1997) with headache being the most commonly reported symptom (Guskiewicz, 2003)(Lovell, Collins, & Bradley, 2004). Fatigue is also commonly reported in the days after a concussion (Lovell et al., 2004). In this investigation, 4 out of the 5 participants reported headache, feeling in a fog, and feeling slowed down. The other two most commonly reported symptoms were visual disturbance and feeling distracted.

While symptoms may appear at the initial time of injury, some may be delayed by several hours (McCrorry et al., 2005). This appears to have occurred in case #5 as the number of symptoms increased during the 24 hours assessment compared to symptoms reported immediately post-injury.

Symptom duration and severity varies with each concussion. Full symptom resolution usually occurs within 10 days (McCrorry et al., 2013), however, some symptoms may resolve sooner. Typically, symptoms will resolve and return to normal. The one participant who had

experienced a previous concussion experienced an increased time to recover compared to the other participants. Three of the other participants recovered within 3 days post injury while she required 10 days for symptom resolution. This is consistent with previous research in that subsequent concussions require more recovery time (Guskiewicz, 2003). Additionally, those who have suffered a previous concussion are more likely to experience a second concussive injury than someone who has never experienced one before (Guskiewicz, 2003).

A one point decrease in score on the SAC has been found to be 95% sensitive and 76% specific in identifying concussions in an investigation of a concussed population (McCrary, 2001). This investigation compared controls who had an average increase of less than one point on the SAC to those with concussion. In that investigation, those with concussion had a four point drop compared to baseline values. This indicates those who are not experiencing concussion typically have an increase in SAC score compared to their baseline value. The five participants had SAC decline of 1-4 points during post-injury assessment. During subsequent time frames, SAC scores returned to baseline values. In one participant the SAC scores exceeded baseline scores.

In case 5 the participant completed 2 additional trials during the WESS to see the effects of adding a cognitive task to WESS. Post-injury the participant had a decrease in cognitive accuracy to 0.78 in both the seated and balance disk conditions. After 24 hours, these values returned to baseline. During the 48 hour post-injury and 7 day post-injury assessments, the participant's PASAT accuracy score increased to 1 during the balance disk position. In previous studies, the balance task performance increases with the addition of a cognitive task (Ross et al., 2011; Teel, Register-Mihalik, Troy Blackburn, & Guskiewicz, 2013). However, since the participant was already committing 0 errors on the WESS at this time, it is possible balance

performance had increased however the WESS was not sensitive enough to detect this change. It is also possible after repeat administration of the PASAT the participant had practice effects. However, we attempted to minimize practice effects on the PASAT by administering the recommended three practice trials (Tombaugh, 2006).

WESS performance decreased during the balance disk and PASAT trial (2 errors) compared to baseline value, however, it was the same as the balance disk alone trial (2 errors). While there were cognitive and balance deficits present after concussion, there were not additional deficits present when they two were completed simultaneously. While we expected more errors to occur, this could have been due to either task not being challenging enough. Future studies should further examine the effects of adding cognitive tasks of varying difficulties to the WESS.

An effect size was seen during each time frame assessment. For symptoms, there was a medium to large effect size during the 24 and 48 hour assessments. It is important to note during baseline assessment the effect size was negative meaning the concussed group had less symptoms than the control group, however, after concussion, they had a positive effect size, thus indicating an even larger change between the two groups. Similar results were found with the WESS scores in that baseline effect size was negative and at 24 hours there was a positive medium effect size showing a large change in the mean WESS score between the two groups after concussion. By the 48 hour assessment, balance had restored to baseline values as there was not an effect size present at this time. During the 24 hour assessment there was not a significant difference between the groups using SAC scores. However, there was a small effect size seen during the 48 hour assessment. While the groups were small, significant differences

could be seen during the post-concussion assessment which is consistent with previous concussion research.

Over the course of the three assessment sessions, the controls' scores had minimal change across the time frame. This is another indicator that all together, these 3 testing tools can be used for concussion assessment in wheelchair athletes as the concussed had a change in all 3 scores while the controls did not.

Limitations

A limitation to this investigation was the small number of 5 concussions that were examined. It is necessary to examine more cases of concussion in wheelchair athletics to determine if the WESS can detect statistically significant changes in postural control after head injury. An attempt was made to capture more concussion through testing several other collegiate wheelchair basketball teams. Unfortunately, medical professionals in wheelchair athletics are limited and while concussions occurred, they were not reported to the appropriate medical professional. However, the study is important given it is the first to examine in detail concussions occurring in wheelchair athletics.

Conclusion

The results from the five case studies support the need for further investigations to determine the sensitivity of the WESS in detecting changes in postural control associated with concussions. With each case study showing increased WESS scores after concussive injury, this

strongly suggests the WESS would be an appropriate test for quantifying seated postural control in wheelchair users during concussion assessment.

Figures and Tables

Figure 6.1: Number of symptoms reported in case #1 during 4 assessments

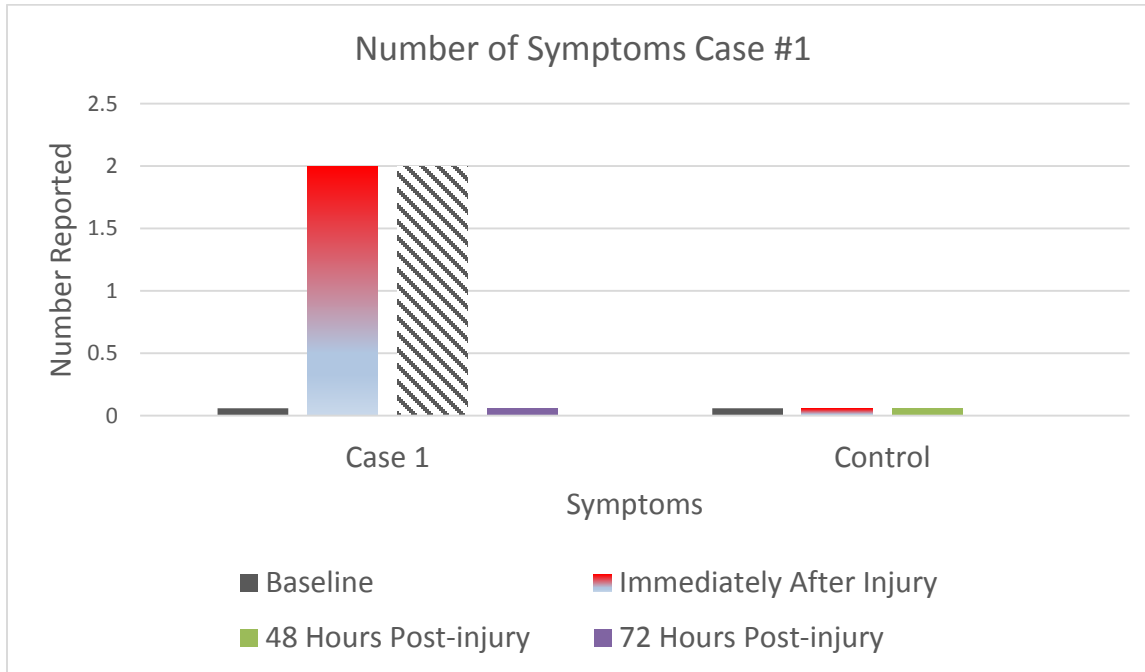


Figure 6.2: Severity of reported symptoms in case #1 during 4 assessments

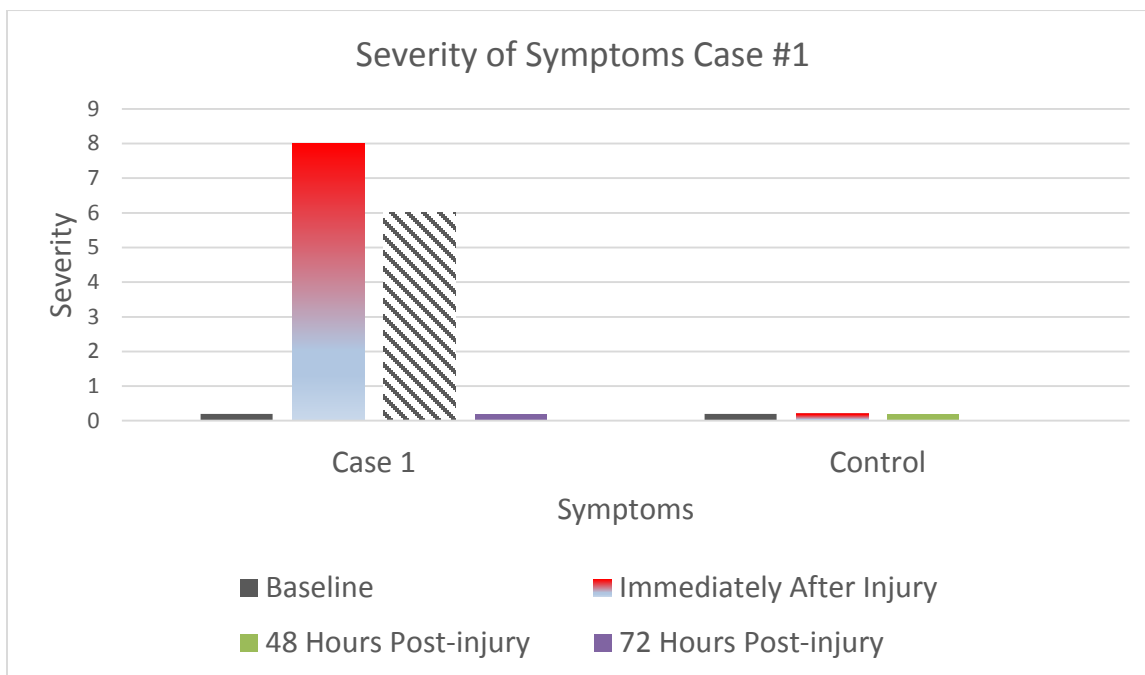


Figure 6.3: SAC scores of case #1 during 4 assessments

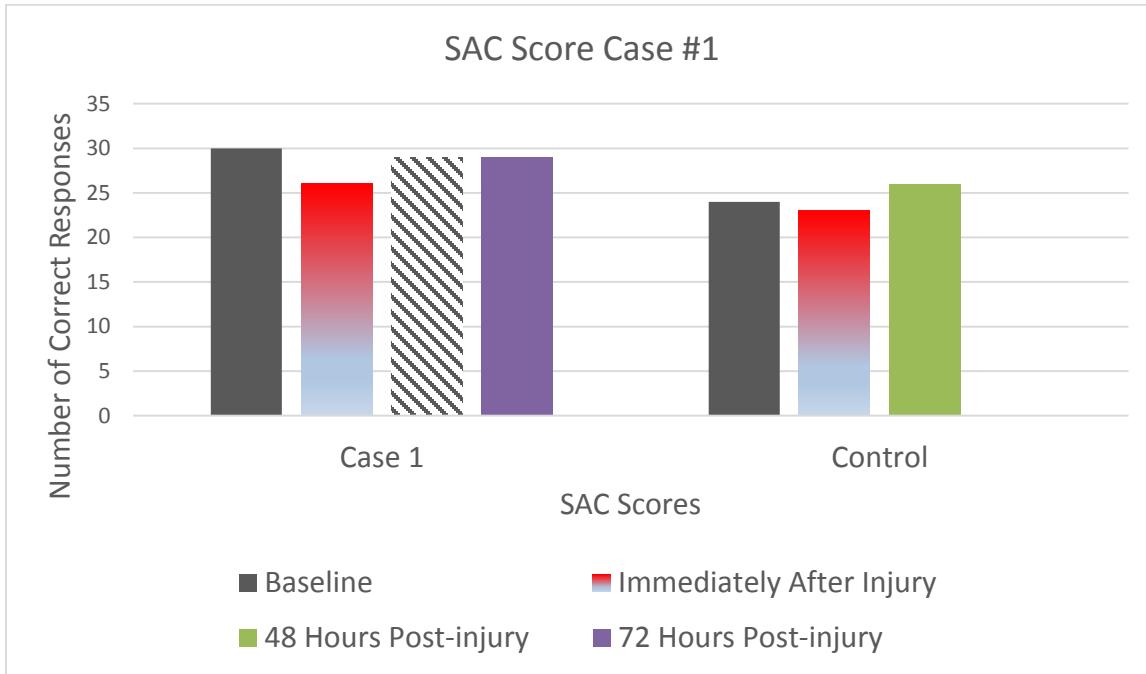


Figure 6.4: WESS scores of case #1 during 4 assessments

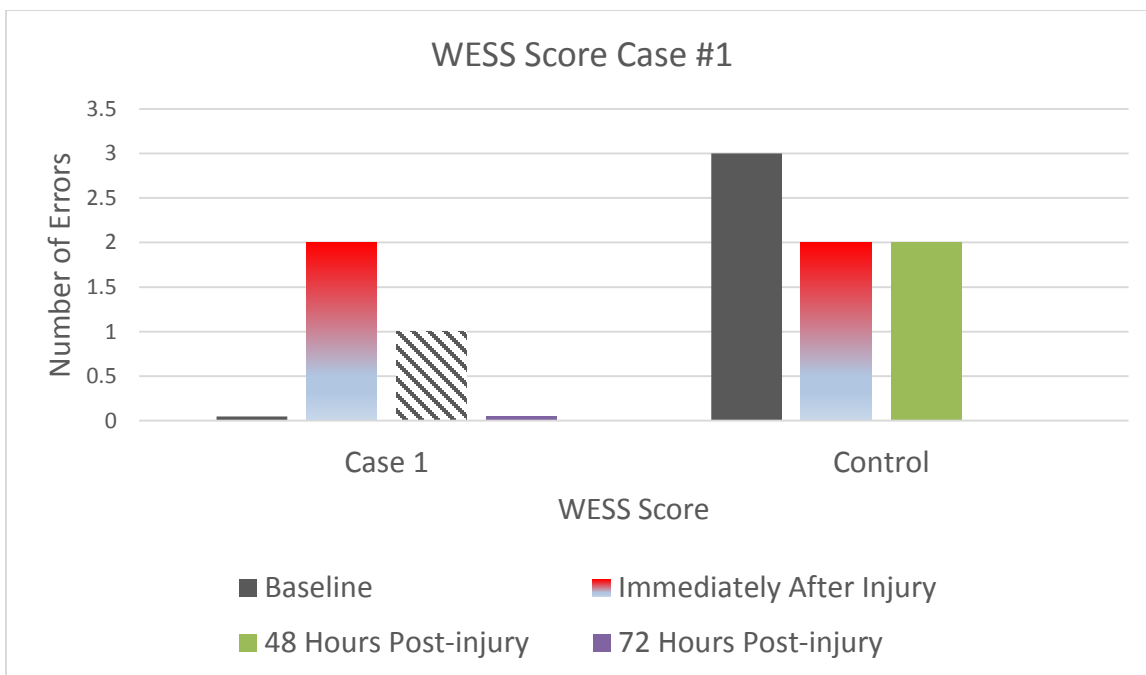


Figure 6.5: Number of reported symptoms during case #2 during 4 assessments

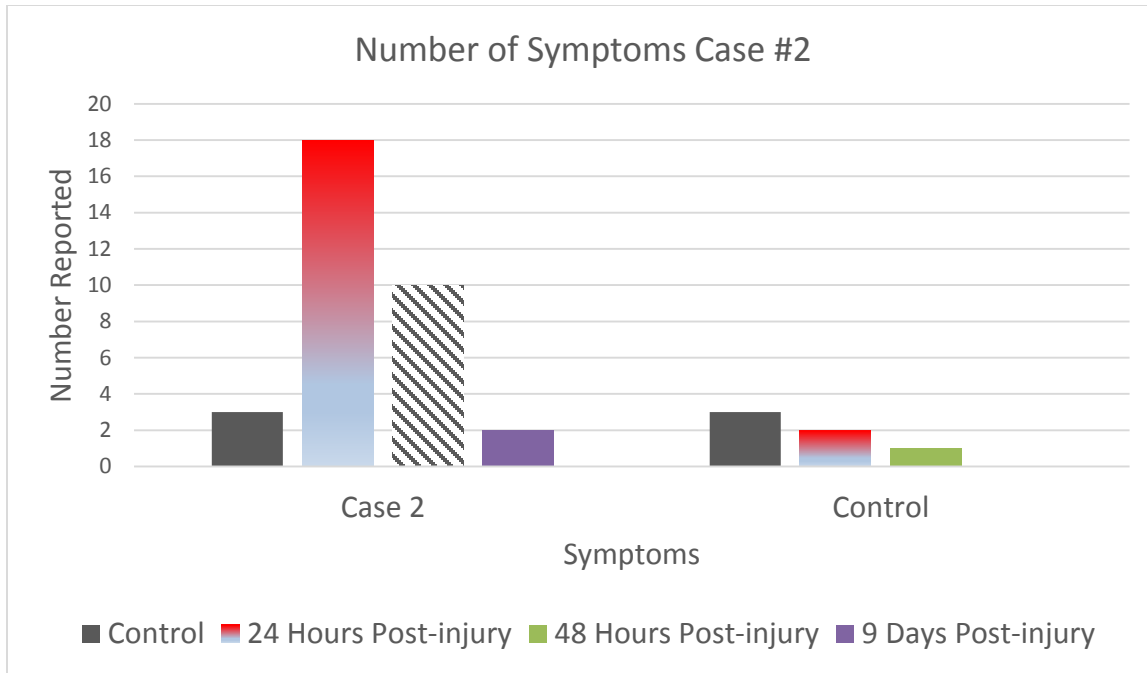


Figure 6.6: Severity of reported symptoms in case #2 during 4 assessments

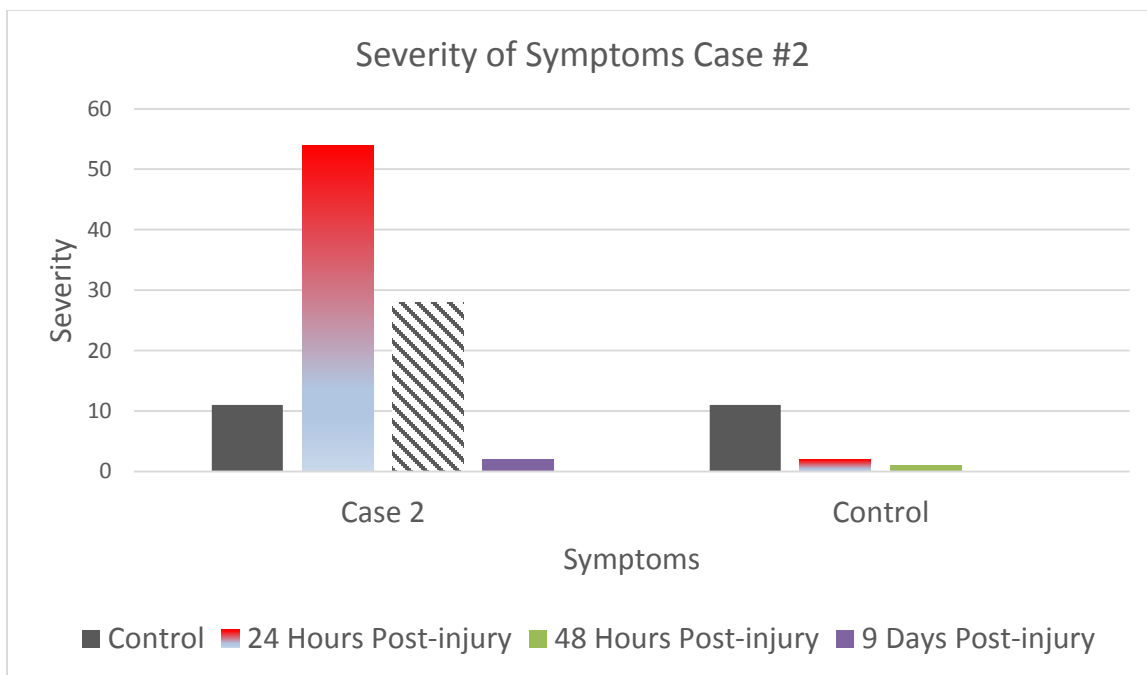


Figure 6.7: SAC scores in case #2 during 4 assessments

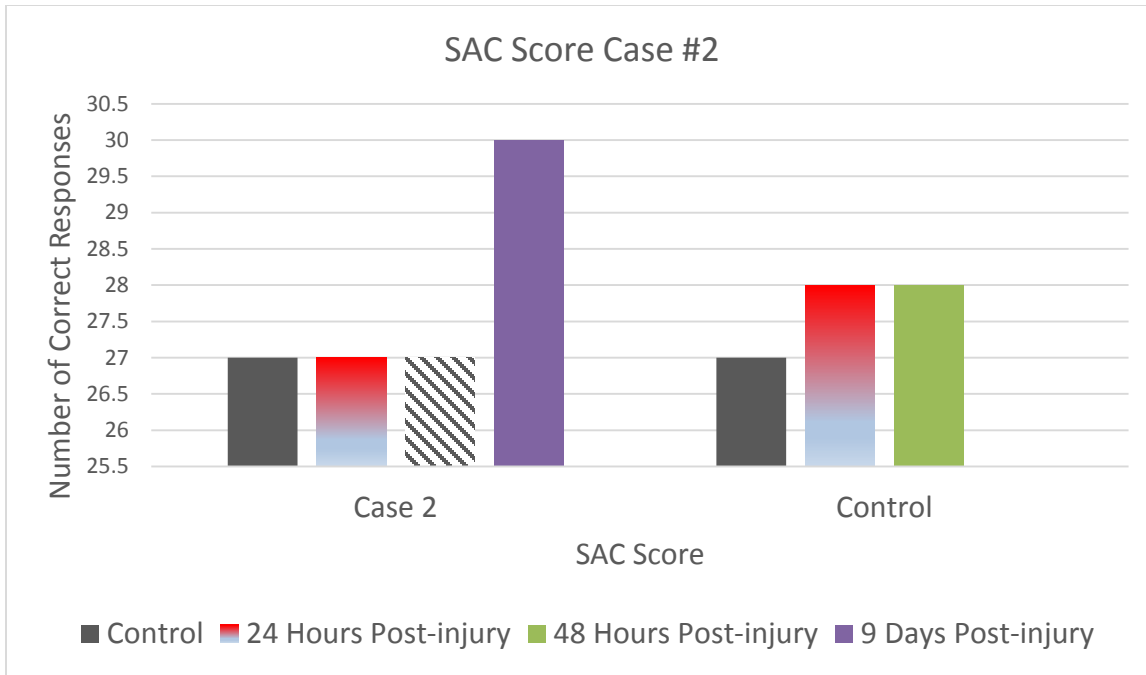


Figure 6.8: WESS Scores in case #2 during 4 assessments

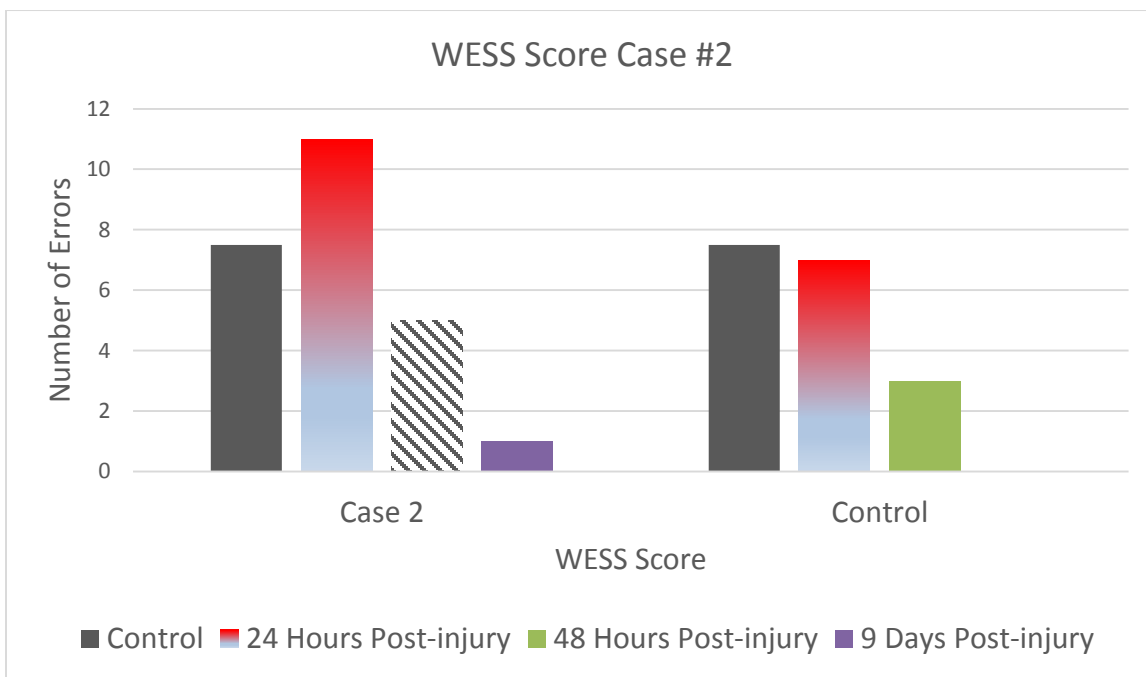


Figure 6.9: Number of symptoms in case #3 during 3 assessments

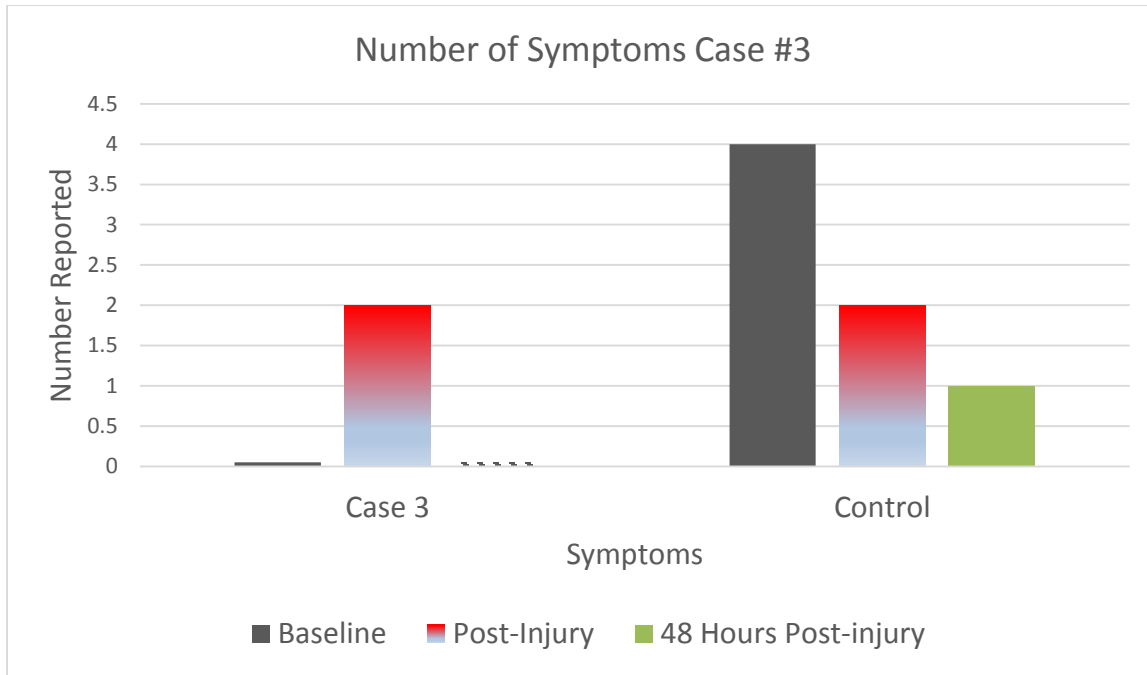


Figure 6.10: Severity of symptoms in case #3 during 3 assessments

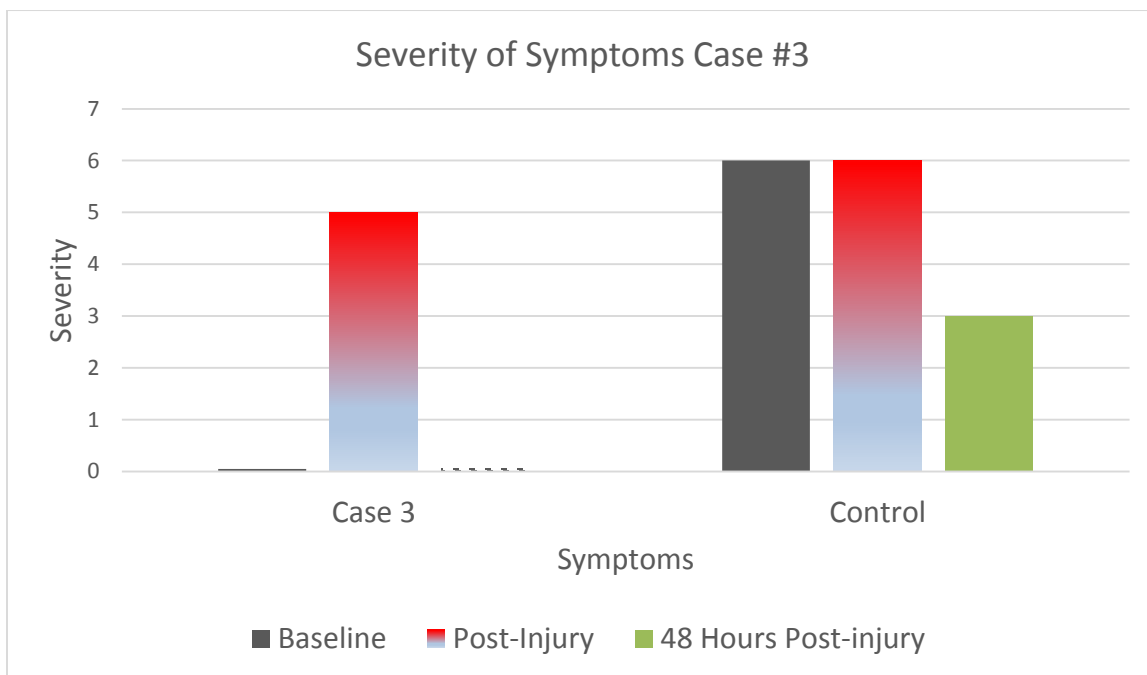


Figure 6.11: SAC scores in case #3 during 3 assessments

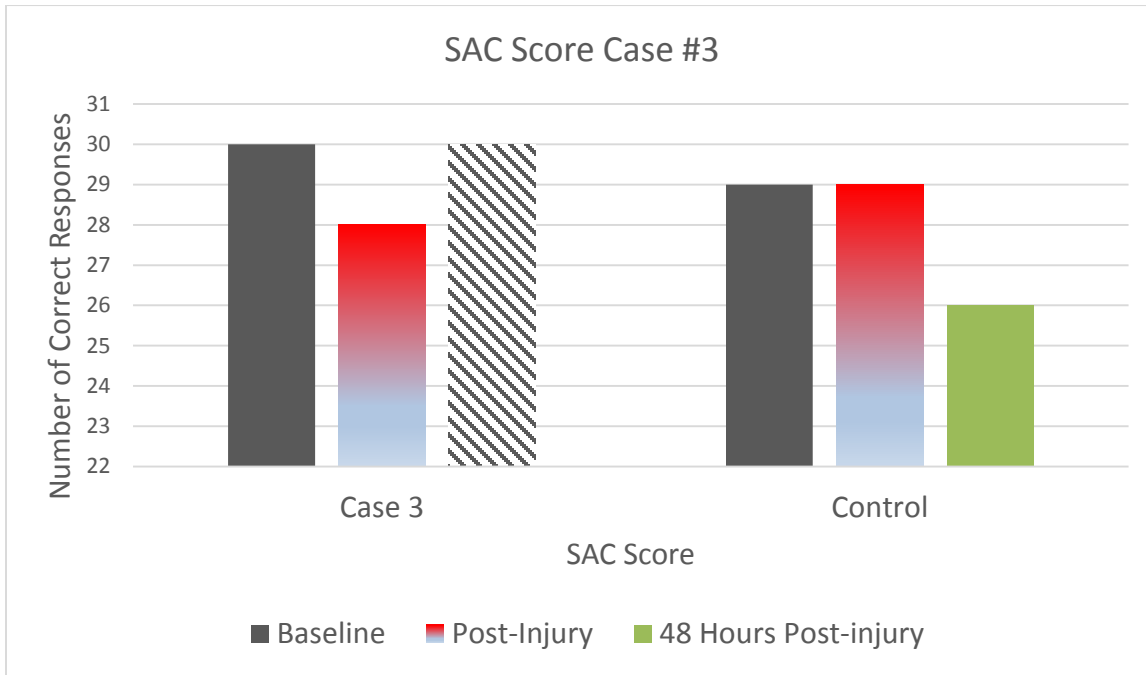


Figure 6.12: WESS scores in case #3 during 3 assessments

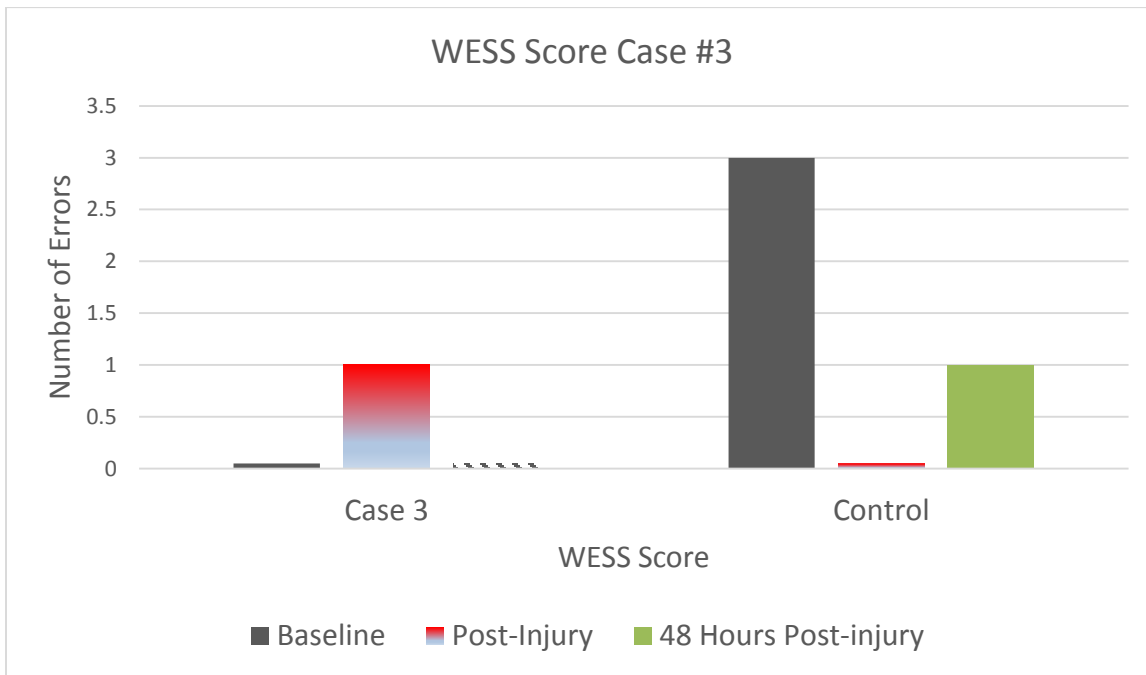


Figure 6.13: Number of symptoms in case #4 during 3 assessments

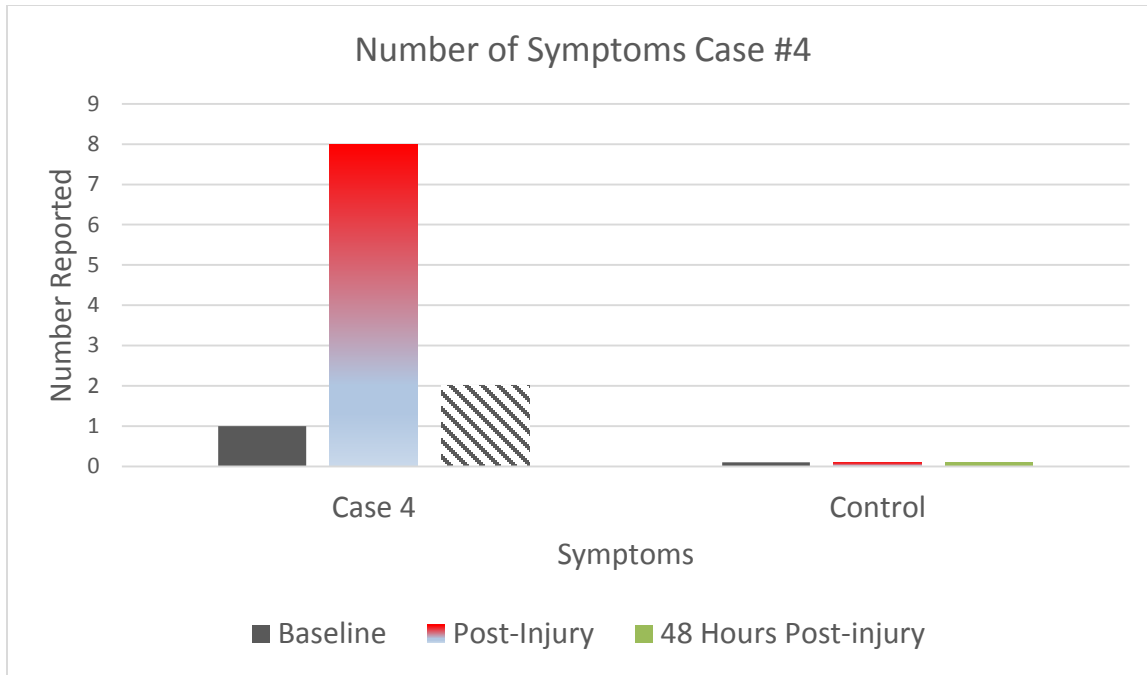


Figure 6.14: Severity of symptoms in case #4 during 3 assessments

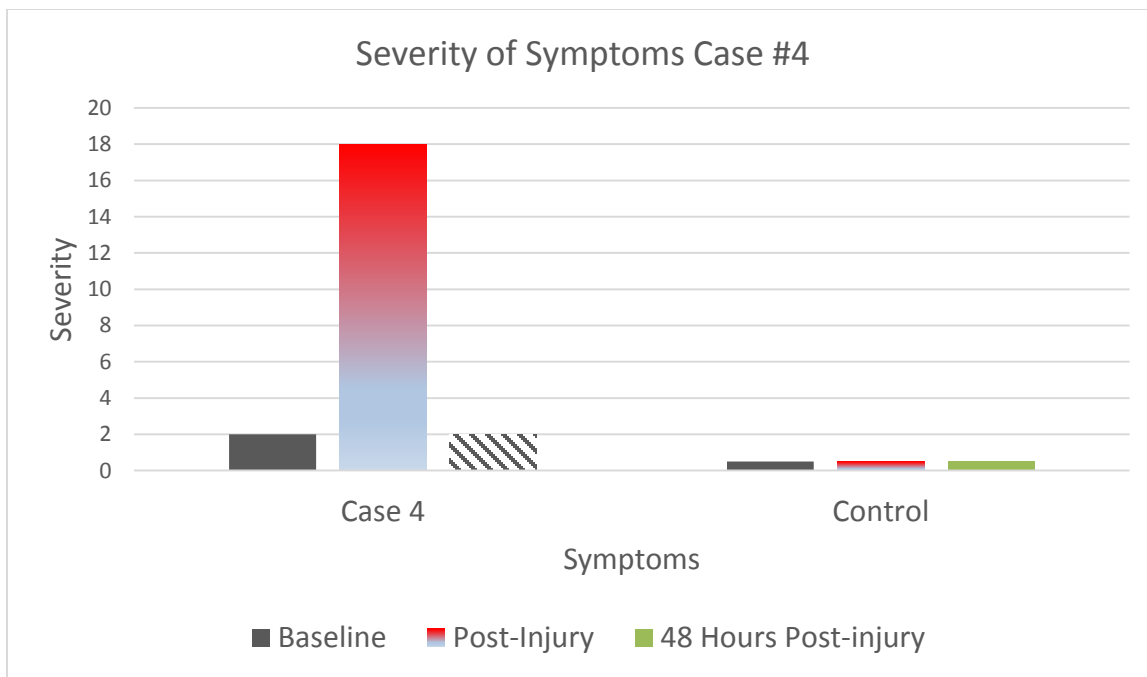


Figure 6.15: SAC scores in case #4 during 3 assessments

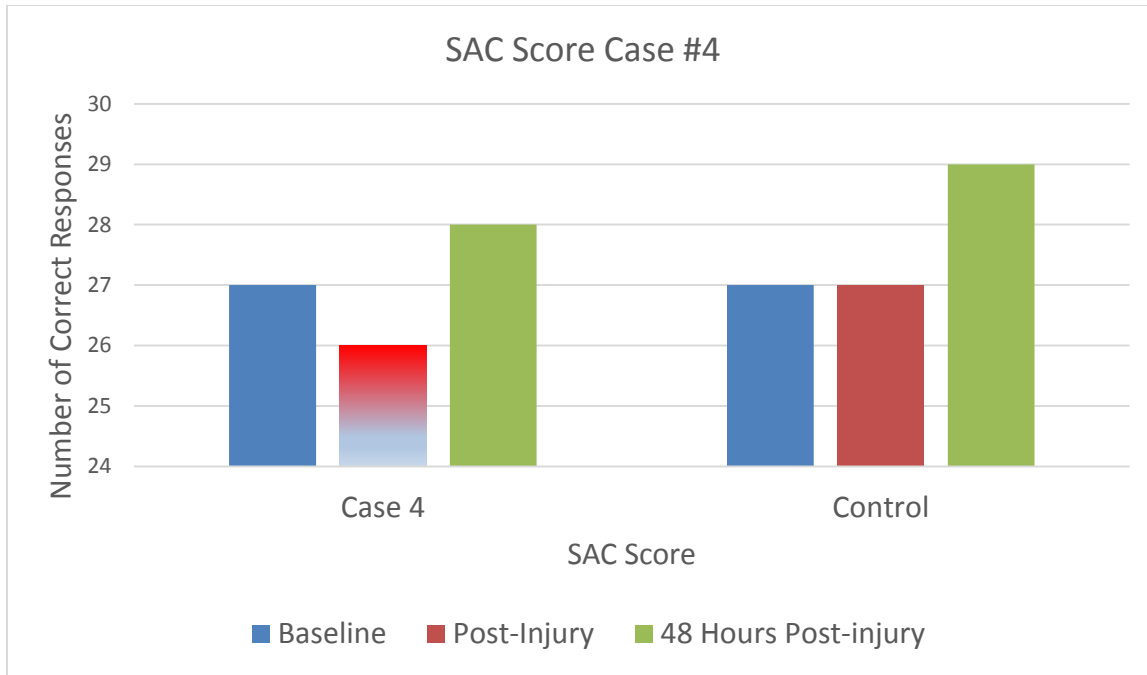


Figure 6.16: WESS scores in case #4 during 3 assessments

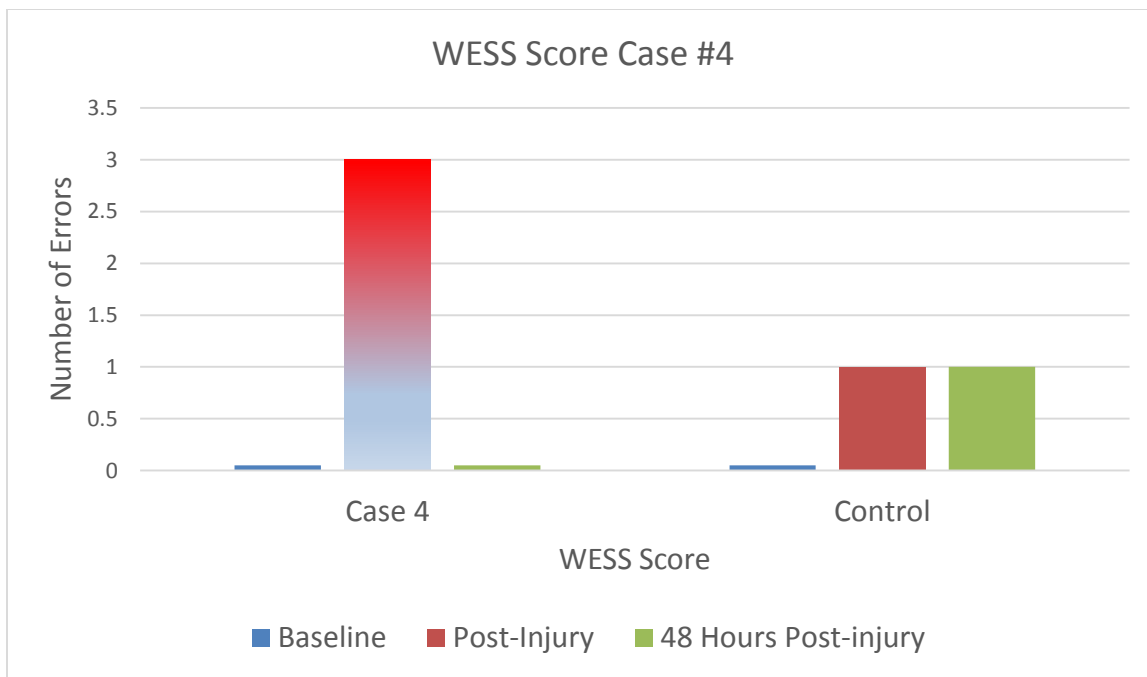


Figure 6.17: Number of symptoms in case #5 during 5 assessments

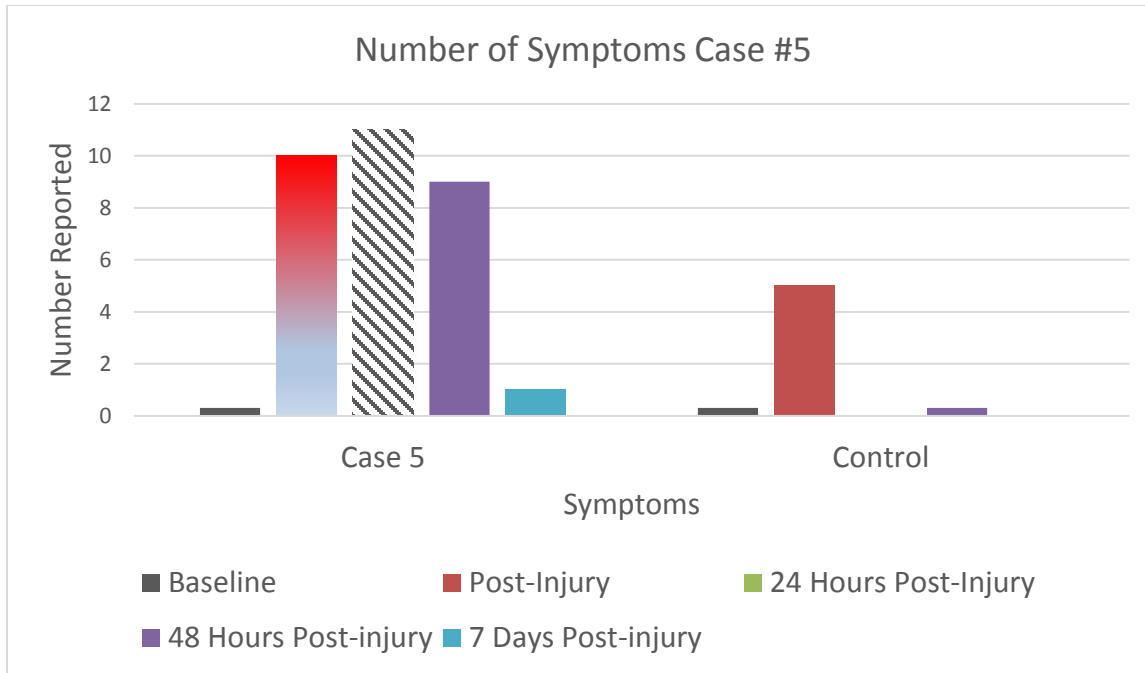


Figure 6.18: Severity of symptoms in case #5 during 5 assessments

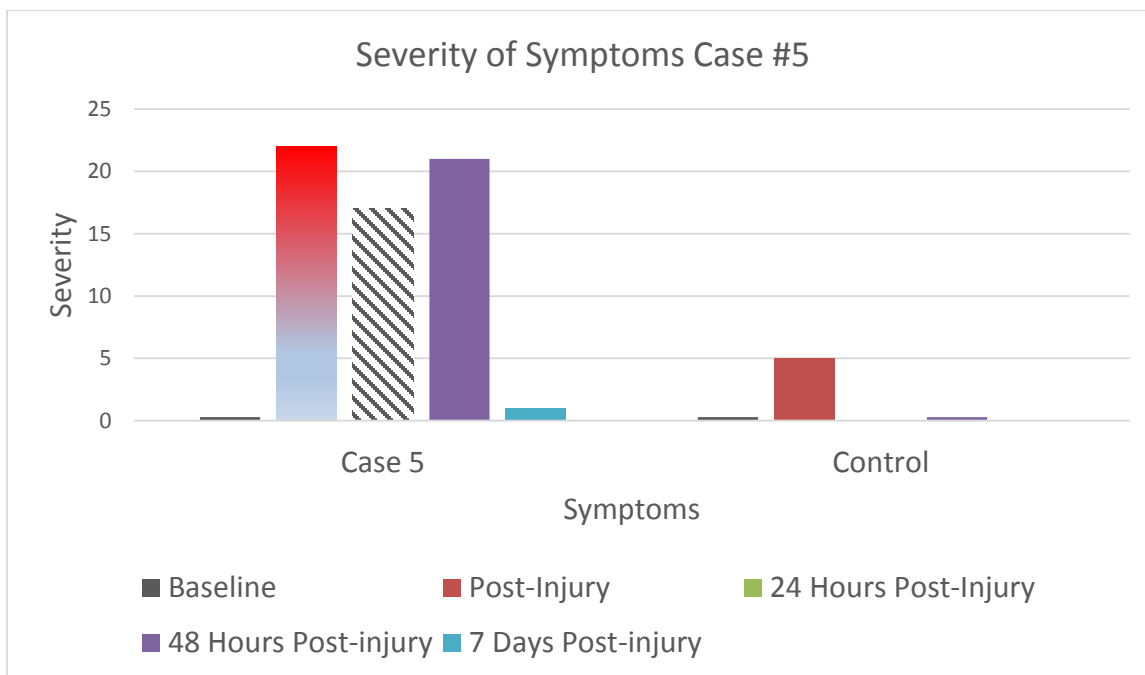


Figure 6.19: SAC scores in case #5 during 5 assessments

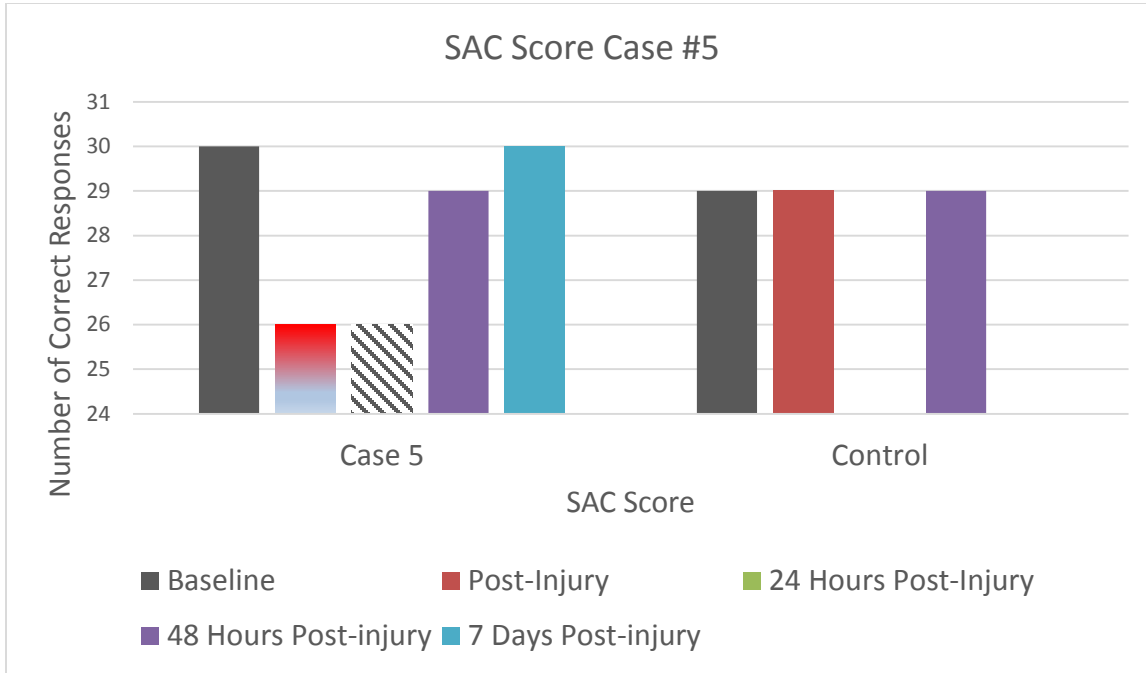


Figure 6.20: WESS scores in case #5 during 5 assessments

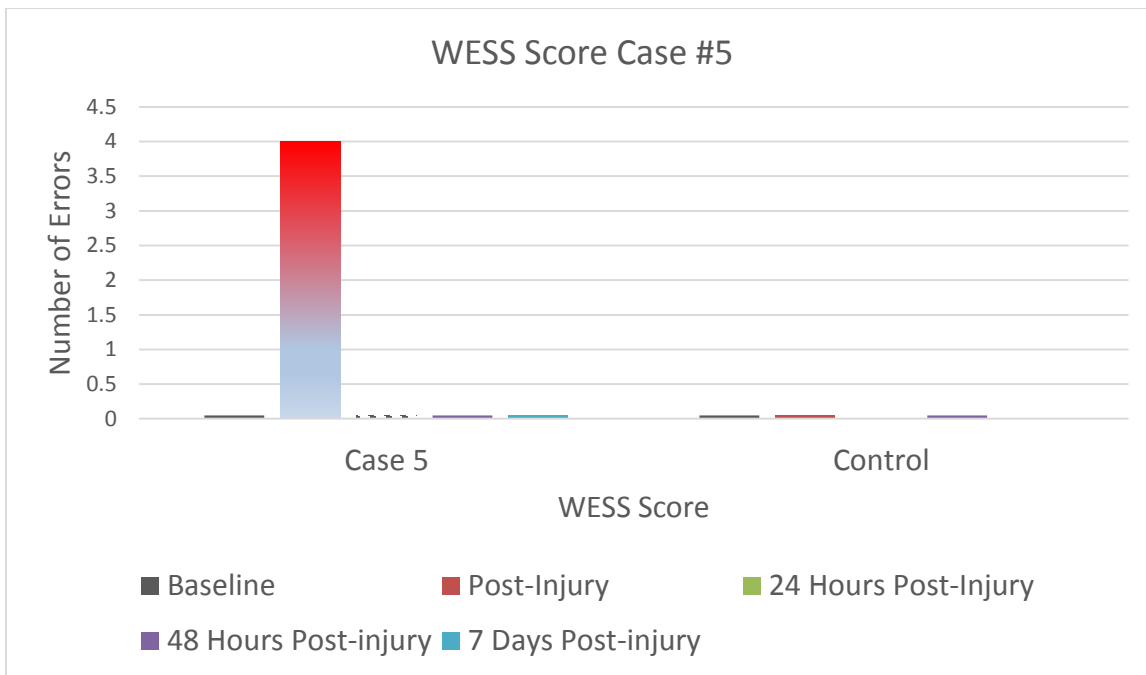


Figure 6.21: PASAT accuracy scores in case #5 during 5 assessments

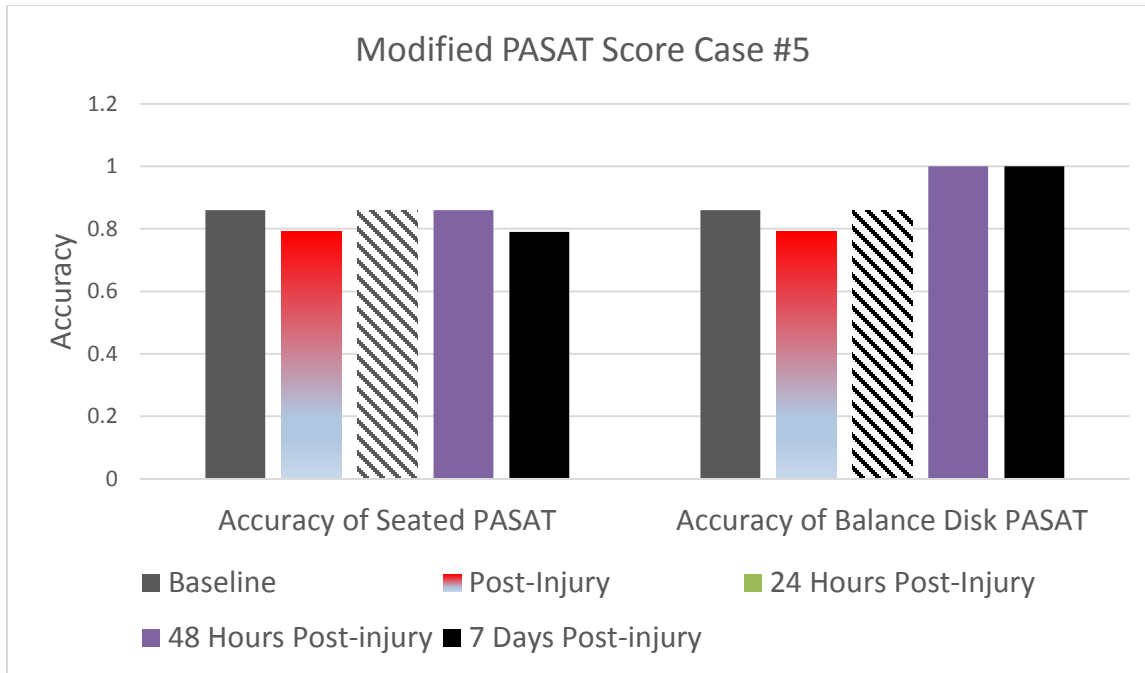


Table 6.1 Effect size for each measure

Measure	Cohen's D
Baseline Symptoms	-0.35
Baseline Symptom Severity	-0.34
Baseline SAC	0.49
Baseline WESS	-0.47
24 hours Symptoms	0.73
24 hours Symptom Severity	0.80
24 hours SAC	-0.14
24 hours WESS	0.53
48 hours Symptoms	0.78
48 hours Symptom Severity	0.74
48 hours SAC	0.35
48 hours WESS	-0.07

Chapter 7: Conclusion

Concussion assessment guidelines call for the evaluation of symptoms, cognition, and balance. Sports medicine professionals use graded symptom scales, various cognition tests, and standing balance measurements to meet these guidelines. However, standing balance measurements are not appropriate for the use in wheelchair athletics, thus leaving a gap in the assessment of balance in athletes with disabilities. The WESS, a seated postural control test, was developed to meet this need. This test has been found to be both valid and reliable and display high levels of intertester and intratester reliability. The WESS detected changes in postural control following concussion in 5 cases.

This is the first study to examine concussions in wheelchair athletics. Previous research only investigates injury incidence in this population, not specifically concussion. Given concussions have been shown to have cumulative effects and lasting deficits in cerebral function it is imperative to address this brain injury. There are hopes that by properly detecting and managing concussions, reductions in lifelong deficits and dysfunctions can occur. This study helps bridge the gap in research in wheelchair athletics to help in the detection and management of concussions. Future investigations need to further examine the relationship of the WESS to detecting postural control deficits after concussion to determine the statistical significance of using the WESS for concussion assessment.

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Appendix A: Concussion Incidence in Wheelchair Basketball

Introduction¹

Wheelchair basketball is a highly competitive sport played at the junior, collegiate, recreational, national, and international levels. With increased awareness of disabilities there has been a rise in interest in disability sport. This increase is highlighted by the increase in number of elite athletes performing at each concurrent Paralympics from 1952 to present (Gold & Gold, 2007). With increasing veterans returning from the current wars with disabilities, participation in wheelchair sports is expected to increase in the coming years. Increased participation in adapted athletics calls for increased awareness in all aspects of disability sport.

Despite increased participation, there is limited research examining injury incidence rates in disability sports. The few investigations that have been conducted have focused exclusively on elite athletes (Nyland, Snouse, Anderson, Kelly, & Sterling, 2000; Reynolds, Stirk, Thomas, & Geary, 1994; Webborn, Willick, & Reeser, 2006) and non-contact sports (e.g. wheelchair track (Ferrara & Davis, 1990) and swimming (Taylor & Williams, 1995). Regardless of these limitations, these investigations demonstrate that injury rates in disability sport are similar to able bodied sports (Ferrara & Davis, 1990). This data shows a need for growth in medical professionals with knowledge of physical disabilities providing coverage for adapted athletics.

One aspect of disability sport injuries that has not been evaluated is concussion incidence. It is well established that there are an estimated 1.6-3.8 million traumatic brain injuries (TBI)

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occur each year in able-bodied sport and recreational activity in the United States (Langlois, Rutland-Brown, & Wald, 2006). Concussions are a mild traumatic brain injury (mTBI) often seen in athletic participation. A number of studies examining concussion incidence rates in varying able-bodied sports have been reported. The incidence rate varies according to the nature of the sport with greater incidence in contact sports. Incident rates range from 2.6% in women's gymnastics (Marshall, Covassin, Dick, Nassar, & Agel, 2007) to 21.6% in women's hockey (Agel, Dick, Nelson, Marshall, & Dompier, 2007). Females also tend to have a greater concussion incidence than males. For instance, in able-bodied basketball the concussion incident rates are 3.6% in men's basketball (Dick, Hertel, Agel, Grossman, & Marshall, 2007) and 6.5% in women's basketball (Agel et al., 2007).

It is also well established that mTBIs often go unreported or unrecognized for several reasons including lack of knowledge of signs and symptoms or a tendency for athletes to mask symptoms so they will not be held from competition (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). In a previous study, 52.7% of the concussed athletes did not report their concussion. The most common reason for not reporting the concussion was they didn't think it was serious enough (66.4%) (McCrea et al., 2004). If athletes return to play while still experiencing symptoms from a concussion and another head injury occurs, the ensuing results can be catastrophic (Cantu & Voy, 1995).

The purpose of this investigation is to determine the incidence rate of concussion and reporting of concussion in disability sport, specifically wheelchair basketball. It is hypothesized that concussion rates will be similar to able bodied sports if not slightly higher due to nature of the sport. It is also hypothesized that those with a higher level of injury will be more likely to sustain a concussion than other disabilities.

METHODS

Participants

A sample of 263 wheelchair basketball players were surveyed at wheelchair basketball tournaments during the 2009-2010 season. Participants ranged in age from 18-60 years and played in collegiate, national, women's, Championship, and Division III wheelchair basketball divisions. There was a wide array of disabilities represented in the sample ranging from spinal cord injury to lower limb amputation {Table A.1 and A.2}.

Procedures

During wheelchair basketball tournaments throughout the 2009-2010 season, wheelchair basketball players were asked to participate in the current investigation. After providing informed consent, participants completed a concussion survey. The survey was based off a previous concussion incidence investigation (McCrea et al., 2004). Specifically, participants were provided a description of concussion and asked if they had sustained a concussion in the most recent season and/or previous seasons. If they reported an injury they then reported the number of days they experienced symptoms, and how many days they refrained from sport due to the injury. They were then asked to indicate to whom they reported their concussion and if they did not tell anyone their reasoning behind it.

Data Analysis

Descriptive statistics were calculated to determine frequency of concussion, whom was told about the incident, and reasons for not reporting. Odd's ratio was used to determine if a disability type or gender was a better predictor of concussion than other groups. Chi squared analysis was used to determine if a difference between concussion rates and gender occurred. A significance level of $p < 0.05$ was used for all analysis and SPSS (v17, Chicago, IL) was used for analysis.

RESULTS

263 participants completed the concussion survey, including 188 males and 75 females (Tables 1 and 2). The participants averaged 28 (± 9) years with 11 (± 10) years of wheelchair use and 11(± 7) years of wheelchair sports experience. The most common disability represented in the sample was T1-T12 spinal cord injury ($n = 78$), followed by spina bifida ($n = 46$) and minimal disability ($n = 39$).

6.1% of the sample reported experiencing a concussion in the current season. Of those experiencing concussions during the current season, 20% did not report their concussion. Of those not reporting the incident, 67% said they did so because they did not want to be removed from activity. Other reasons for not reporting their injury included not thinking the injury was serious enough (50%) and not knowing it was a concussion (50%). {Table A.3} Of those participants that did report their concussion 60% indicated that they reported it to the coach and 48% reported it to the athletic trainer. {Table A.4}

Overall, 19% of the participants ($n=50$) reported having a concussion in previous seasons or the current season. Of those 50 individuals, 52% of them reported sustaining more than one

concussion during disability sport participation with a total of 102 total (current and previous seasons) concussions reported. 54% of the time the individual did not refrain from activity during the duration of their concussion symptoms.

Once the incidence rate was determined it was of interest to examine what characteristics (i.e. disability, gender) were related to concussion incidence. When broken down by gender, 6.67% of the female respondents reported sustaining a concussion during the current athletic season, while 30.6% reported a concussion during their athletic career. Of the male participants, 5.82% reported experiencing a concussion during the current season, with an overall rate of 14.36%. Females had a concussion rate significantly greater than males and were over 2.5 times more likely to sustain a concussion than males (odds ratio= 2.64, $p=0.002$). Wheelchair users were half as likely to sustain a concussion than those who did not use a wheelchair as their primary means of mobility (odds ratio= 0.538 $p=0.05$).

DISCUSSION

The purpose of this investigation was to determine the incidence rate of concussions and reporting concussions in wheelchair basketball. A secondary goal was to determine factors that are related to concussion incidents. Our primary findings suggest that concussions occur in approximately 6% of all wheelchair basketball athletes in a given season; female athletes sustained concussions 2.5x more often than males, and wheelchair users were half as likely to be injured than all other disabled athletes.

Incident rate

To our knowledge, there have been no previous investigations or reports of concussion incidence occurring during wheelchair basketball. Within the current sample of 263 basketball players, 6.1% reported a concussion within the current season. This rate is greater than able-bodied basketball (6.5% for females and 3.6% for males) and less than American football (6.8%) (Agel et al., 2007; Dick et al., 2007; Dick, Hertel et al., 2007). This difference in basketball incidence rates could be due to the equipment used in wheelchair basketball. With the use of wheelchairs there is an increased chance of making head contact with hard objects (i.e. metal), therefore increasing the chance for a head injury.

Gender and mTBI

Previous studies have suggested that females are more likely to sustain a concussion than males in able bodied sports (e.g. women's basketball) (Agel et al., 2007). For instance, concussion incidence in able bodied basketball as well as hockey is approximately twice as great in females than in males (Agel et al., 2007; Agel et al., 2007; Dick, Hertel et al., 2007). A similar gender discrepancy was found here with 30.6% of females and 14.36% of males reporting a previous concussion.

The reason(s) that females are at a greater risk for concussion is currently is unknown. It has been speculated that female's smaller stature and proportionally weaker neck musculature places them at greater risk for concussion (Agel et al., 2007). It has also been speculated that females have a tendency to be more honest in their injury reporting, while males are culturally encouraged to continue engaging in activity so they are not removed from play (R. W. Dick, 2009). Therefore, incident rates may be similar for each gender; however males' head injuries

are going unreported. Further work is needed to determine what factors contribute to the gender discrepancy in concussion incidence.

Disability and mTBI

Wheelchair users were half as likely to sustain a concussion than those who did not use a wheelchair as their primary means of mobility. It was expected that those who had more function and stability (i.e. minimal disability) would be able to better protect themselves when falling due to greater muscle control. However, it is now speculated that athletes with more function may travel at greater speeds placing them at greater risk of injury. Another possibility is that these athletes have a higher center of mass and may have a wheelchair set up placing them in a less stable position and making them more prone to tip over.

Reporting Concussion

Although concussions are a serious injury, it is commonly thought that concussions often go unreported (McCrea et al., 2004). 20% of the participants in the current investigation did not report their concussion, less than in a study of high school football players 52.7% did not report their concussion (McCrea et al., 2004). When asked why they did not report the incident, the majority reported they did not want to be taken out of the game (67%). Half of the participants also reported not thinking it was serious and they did not know it was a concussion (50%). This shows a lack of awareness of the serious nature of a brain injury and consequences of neglecting proper management of this injury. Although concussion education interventions have been successfully carried out in able-bodied sport, minimal information has been provided to the

disability sport community (CDC). Based on the current results, it is suggested that concussion education be targeted to the disability sport community.

When concussions were reported, the coach was the person most commonly reported to (60%). Those less commonly reported to were the athletic trainer (48%), doctor (32%), teammate (28%), and parent (24%). Ideally, any time a concussion occurs the injured individual should notify medical personnel to assure proper management of the brain injury. A previous study in able-bodied sports showed the certified athletic trainer was the most common individual reported to (77%) (McCrea et al., 2004). However, this was not the case in our investigation as the coach was the individual most commonly reported to. This helps show a need for educating all coaches in the proper management of this injury to ensure proper health care for the athletes.

Symptom Management

Cerebral concussion is a brain injury that can have long lasting effects (Langlois et al., 2006). While symptoms will eventually resolve, function may be impaired for the remainder of the individual's life (Langlois et al., 2006). Current sport medicine guidelines maintain that after a concussion occurs, the injured individual should refrain from activity until they are asymptomatic (Guskiewicz et al., 2006). However, in the current investigation, 54% of the concussions were not handled properly as the individuals returned to activity before being asymptomatic. If an individual sustains another head injury before the first brain injury has resolved, catastrophic consequences may occur (Cantu & Voy, 1995). For this reason it is important to properly assess and manage concussions. While the reason for not refraining from activity until asymptomatic was not reported, this might suggest a need for educating athletes on

the necessity of properly managing concussions and the consequences of failure to properly handle the brain injury.

Implications

With more knowledge available concerning the enduring effects of concussions, it is important to educate players and personnel of the importance of proper identification and management of concussions. It is imperative that those involved with disability sport handle these injuries with caution to better ensure lasting effects can be minimized. To properly assess whether a concussion has occurred it has been suggested to examine symptoms, cognitive function, and balance (Guskiewicz et al., 2006). Cognitive tests and symptom scales that have already been established can be easily implemented in wheelchair athletes. A majority of medical professionals use the Balance Error Scoring System (BESS) to assess balance. However, this poses a problem with wheelchair athletes as the BESS is completed while standing and this may not be possible for all wheelchair athletes. Therefore, this leaves a gap in the battery of concussion assessments as there is no current way to quantify changes in balance in a seated posture. It is imperative to fill this gap to properly assess concussions in people with physical disabilities.

Conclusion

This investigation suggests concussions occur in wheelchair basketball at rates similar to, if not slightly higher than, able bodied basketball. Further research needs to be completed concerning concussions and education of concussions in disability sport. With an increase

knowledge of enduring effects of concussions there is an increased demand for athletic trainers to provide proper management after concussion injuries. There is also a need for a proper battery of concussion assessment as postural control tasks are currently all performed standing and may not be suitable to all wheelchair athletes.

Tables

Table A.1: Demographics

Variable	Median	Range
Age (years)	25	42
Height (cm)	175.26	121.92
Weight (kg)	73	106
Gender (males/females)	188/75	ND
Length of wheelchair use (years)	10	44
Length of playing wheelchair sport (years)	10	33.67

Note: Values are means \pm standard error

Table A.2: Disability

Disability	Males	Females
C1-C7 Spinal cord injury	2	1
T1-T12 Spinal cord injury	61	17
L1-L5 Spinal cord injury	17	4
Spinal cord injury unspecified	8	3
Spina Bifida	31	15
Cerebral Palsy	3	3
One lower limb amputation	23	5
Two lower limb amputations	9	1
Minimal Disability	22	17
Other	15	6

Table A.3: Why Concussion Was Not Reported

Why Concussion Was Not Reported	Percentage of Athletes
Didn't want to be taken out of the game	67%
Didn't think it was serious	50%
Didn't know it was a concussion	50%
Thought getting a concussion was part of the game	42%
Didn't want to let their teammates down	33%

Note: Categories are not mutually exclusive.

Table A.4: Who Concussion Was Reported To

Concussion Reported To	Percentage of Athletes
Coach	60%
Athletic Trainer	48%
Doctor	32%
Teammate	28%
Parent	24%
No one	20%
Other	10%

Note: Categories are not mutually exclusive.

Appendix B: Graded Symptom Scale and Standardized Assessment of Concussion

Symptom	None	Mild	Moderate	Severe			
Headache	0	1	2	3	4	5	6
“Pressure in head”	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or Vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred Vision	0	1	2	3	4	5	6
Balance Problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like “in a fog”	0	1	2	3	4	5	6
“Don’t feel right”	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6
Total # of Symptoms							
Symptom Severity Score							

Appendix C: Wheelchair Error Scoring System Manual

Wheelchair Error Scoring System (WESS)

Materials needed:

- Balance disk
- Table
- Stop watch
- WESS score card
- Spotter

WESS Test Administration:

Read the instructions to the subject as they are written in the WESS Testing Protocol. During the 20 second test, record errors on the WESS Score Card as they are described below.

Scoring the WESS:

Each of the twenty-second trials is scored by counting the errors, or deviations from the proper posture, accumulated by the subject. The examiner will begin counting errors only after the individual has assumed the proper testing position.

Errors: An error is credited to the subject when any of the following occur:

- ◆ moving the hands off of the iliac crests
- ◆ opening the eyes (on eyes closed trials)
- ◆ touch table with hand
- ◆ flexion of the hips beyond 30°
- ◆ coming out of a wheelie (for wheelie task)
- ◆ changing grip on the wheels (for wheelie task)
- ◆ taking a hand off the wheels (for wheelie task)
- ◆ remaining out of the proper testing position for greater than 5 seconds

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

-if a subject commits multiple errors simultaneously, only one error is recorded. For example, if an individual touches the table, opens their eyes, and removes their hands

from their hips simultaneously, then they are credited with only one error.

-subjects that are unable to maintain the testing procedure for a minimum of five seconds are assigned the highest possible score, ten, for that testing condition.

Testing Positions:

Seated on table:

Seated on a table with knees bent over the edge of the table and feet not touching the ground with hands on hips and eyes opened or closed



Seated on balance disk:

Seated on a balance disk on a table with knees bent over the edge of the table and feet not touching the ground with hands on hips and eyes opened or closed



Wheelie task:

While seated in the participant's own wheelchair, a wheelie will be performed with the front casters off the ground, both hands on the wheels, and eyes open or closed



Directions to the participant for the WESS Protocol:

Direction to the subject: I am now going to test your balance.

Please be seated on the table with your knees bent over the edge of the table.

Seated on Table:

Direction to the subject: The first stance is seated on the table with your knees over the edge. You will be sitting with your hands on your hips with your eyes closed. You should try to maintain stability in that position for entire 20 seconds. I will be counting the number of times you move out of this position. If you do move out of the testing position, simply open your eyes, regain your balance, get back into the testing position as quickly as possible, and close your eyes again. There will be a person positioned by you to help you get into the testing stance and to help if you lose your balance.

Direction to the subject: Sit up straight, put your hands on your hips and when you are set the testing time will begin.

[Start timer when subject is set]

Seated on Balance Disk:

Direction to subject: Sit on the balance disk on the table with your knees bent over the edge. Again, you should try to maintain stability for 20 seconds. I will be counting the number of times you move out of this position.

Place your hands on your hips. When you are set the testing time will begin.

[Start timer when subject is set]

Wheelie:

Directions to the subject: Now perform a wheelie with both hands on your wheels.

Again, you should try to maintain stability for 20 seconds. I will be counting the number of times you move out of this position.

Place your hands on your wheels and get into the wheelie position. When you are set the testing time will begin.

[Start timer when subject is set]

Wheelchair Error Scoring System

	Number of Errors
Sitting On Hard Surface	
Eyes Open	
Eyes Closed	
Sitting on Balance Disk	
Eyes Open	
Eyes Closed	
Wheelie	
Eyes Open	
Eyes Closed	
Total	

Each Trial is 20 seconds

Errors for seated tasks:

Opening Eyes

Hands off hips/lap

Touch table with hand(s)

Remaining out of test position for more than 5 seconds

Errors for wheelie:

Opening eyes

Come out of wheelie

Re-gripping the wheels

Take hand(s) off wheels

Remaining out of test position for more than 5 seconds

Appendix D: Factors Affecting Balance Survey

Have you changed your chair configuration since the last testing date? (ex. new cushion, wheels, changed the dump)

YES NO If yes, what? _____

Have you had any recent surgeries?

YES NO If yes, when? _____

Have you had any recent injuries?

YES NO If yes, when and what body part? _____

Are you currently experiencing any sickness?

YES NO

Please rate your current fatigue level.

	None	Mild	Moderate	Severe			
Fatigue	0	1	2	3	4	5	6

Are you currently experiencing any spasms?

	None	Mild	Moderate	Severe			
Spasms	0	1	2	3	4	5	6

After each trial please rate your level of fatigue if any, and the amount of spasms you are experiencing if any.

Seated Eyes Open

Symptom	None	Mild	Moderate	Severe			
Fatigue	0	1	2	3	4	5	6
Spasms	0	1	2	3	4	5	6

Seated Eyes Closed

Symptom	None	Mild	Moderate	Severe			
Fatigue	0	1	2	3	4	5	6
Spasms	0	1	2	3	4	5	6

Seated Eyes Closed with PASAT

Symptom	None	Mild	Moderate	Severe			
Fatigue	0	1	2	3	4	5	6
Spasms	0	1	2	3	4	5	6

Balance Disk Eyes Open

Symptom	None	Mild	Moderate	Severe			
Fatigue	0	1	2	3	4	5	6
Spasms	0	1	2	3	4	5	6

Balance Disk Eyes Closed

Symptom	None	Mild	Moderate	Severe			
Fatigue	0	1	2	3	4	5	6
Spasms	0	1	2	3	4	5	6

Balance Disk Eyes Closed with PASAT

Symptom	None	Mild	Moderate	Severe			
Fatigue	0	1	2	3	4	5	6
Spasms	0	1	2	3	4	5	6

Wheelie Eyes Open

Symptom	None	Mild	Moderate	Severe			
Fatigue	0	1	2	3	4	5	6
Spasms	0	1	2	3	4	5	6

Wheelie Eyes Closed

Symptom	None	Mild	Moderate	Severe			
Fatigue	0	1	2	3	4	5	6
Spasms	0	1	2	3	4	5	6

Wheelie Eyes Closed with PASAT

Symptom	None	Mild	Moderate	Severe			
Fatigue	0	1	2	3	4	5	6
Spasms	0	1	2	3	4	5	6