NEUROCOGNITIVE AND BALANCE PERFORMANCE FOLLOWING A DUAL-TASK AND SINGLE-TASK TRAINING INTERVENTION IN HEALTHY COLLEGIATE RECREATIONAL ATHLETES

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ABSTRACT

JOSEPH INGRISELLI**:** Neurocognitive and balance performance following a dual- and single-task training intervention in healthy collegiate recreational athletes.
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The purpose of this study was to examine neurocognitive and balance performance in healthy collegiate recreational athletes, prior to and following a dual-task (DT) training intervention compared to matched single-task (ST) controls. Thirty healthy, physically active college aged participants completed neurocognitive and balance assessments prior to and following a four-week training intervention. The single task group showed significantly greater improvement following their four-week training period compared to the dual-task group ($F_{1,26}$=5.478, p= 0.027). Both groups significantly improved neurocognitive domains of complex attention ($F_{1,26}$=6.726, p=0.015), executive function ($F_{1,28}$ = 4.968, p= 0.034), cognitive flexibility($F_{1,28}$ = 6.707, p= 0.015), SOT Vestibular ratio scores ($F_{1,28}$=6.550, p=0.016) and significantly reduced the number of errors committed during the BESS ($F_{1,26}$=42.342, p<.000) following the interventions. Our findings suggest that combining a cognitive task with a balance task did not have any additional benefits to performing these tasks independently.

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CHAPTER I

INTRODUCTION

Introduction

It is estimated that up to 3.8 million sports related traumatic brain injuries occur each year, including those which do not seek medical care (Langlois, Rutland-Brown et al. 2006). Concussions are the most frequent form of traumatic brain injury that occur in sport (Guskiewicz, Weaver et al. 2000). Along with the continuing push for concussion prevention there is also a need to turn attention to management, recovery, and current concepts in concussion rehabilitation. Previously, the focus of concussion research has been on prevention, evaluation and acute management. Although much more is to be understood in these areas, further research is necessary to determine how rehabilitation may play a role in recovery following a concussion. The current consensus for post-concussion care states that once an athlete is removed from competition, the individual should refrain from athletic participation and physical activity while being continually monitored until they are symptom free (Guskiewicz, Bruce et al. 2004; McCrory, Meeuwisse et al. 2009). Sports medicine professionals are often challenged to manage athletes after a concussion as little is understood about the proper care to provide to an athlete during the recovery process, especially in cases with protracted recovery. The first International Symposium on Concussion in Sport, held in 2011 in Vienna, advocated that athletes complete a stepwise gradual progression of exertional activity increasing intensity and duration before return to play following a period of cognitive and physical rest (Aubry, Cantu et al. 2002). The purpose of the exertional progression is to determine if any signs or symptoms of concussion return with physical activity. If there is no re-occurrence of symptoms the next step should be to tax the systems affected by injury to strengthen the weakened areas. The majority of concussions resolve within 7-10 days, during this period rest and serial evaluation of balance, neurocognition and symptoms are the standard of care (McCrory, Meeuwisse et al. 2009). Decreases in cognitive processing speed, verbal fluency, and memory can be seen up to 36 hours post injury and even longer with increased severity of injury (Lovell, Collins et al. 2003; McCrea, Guskiewicz et al. 2003). Sports medicine professionals strive to provide optimal post-injury care to safely return injured athletes to competition for all injuries. However in managing athletes after a concussion, little is understood regarding appropriate intervention and rehabilitation. The brain may return to normal function more quickly with rehabilitation just as other injuries sports medicine professionals are faced with daily, especially in cases where symptoms following concussion are prolonged in duration. Although the majority of concussion symptoms resolve within a 7 to 10 day window (Guskiewicz, McCrea et al. 2003), some physical, cognitive, and emotional symptoms may not resolve for several months to years following injury (Bohnen and Jolles 1992; Gouvier, Cubic et al. 1992; Brown, Fann et al. 1994).

Further research is necessary to determine how a rehabilitation paradigm, where an athlete is cognitively and physically exerted, compares to rest and physical exertion alone. This research is important to determine optimal concussion rehabilitation strategies and the overall benefits from concussion rehabilitation, specifically in cases of prolonged recovery.

Previous research regarding rehabilitation has focused primarily on patients recovering from severe brain injuries. Early intervention has been shown to decrease days off from work due to traumatic brain injury (Relander, Troupp et al. 1972). Although minimizing time lost due to injury is the goal of all sports medicine professionals, extreme care must be taken with advancing an athlete through a rehabilitation progression towards full return to play. Athletes that return to play prematurely may be vulnerable to recurrent damage to the brain (Cantu 1998), with potentially catastrophic results such as second impact syndrome, which has a mortality rate of 50% and a morbidity rate near 100%. Second impact syndrome can occur when an athlete returns to play while still symptomatic and sustains a second head injury, often a low impact blow to the body which indirectly causes acceleration of the brain. Within 15 seconds following a second, even mild, blow the semicomatose athlete will collapse and eventually go into respiratory failure (Cantu 1998). Adequate recovery time is critical to the health of each and every athlete suffering from injury.

Most information regarding concussion rehabilitation is composed of general guidelines with little evidence based justification. These recommendations heavily emphasize an exertional return to play progression following resolution of symptoms after the typical 7-10 day recovery window. It may be appropriate for sports medicine professionals to manage post-concussion rehabilitation in a similar manner as other musculoskeletal injuries, especially with individuals suffering from prolonged concussive symptoms. If concussion symptoms include, but are not exclusive to, cognitive and balance impairment then why not address these issues during the rehabilitation process to facilitate recovery? Sports medicine professionals need to address the functional capacity of systems affected by concussion to put injured athletes in the best position for return to play (Johnston, Bloom et al. 2004). Research in this area will help guide care for athletes following concussion during the transition between cognitive rest and full return to play (McCrory, Meeuwisse et al. 2009).

A rehabilitation strategy utilizing a dual-task paradigm, in which a concussed athlete engages in cognitive and motor tasks simultaneously, may effectively address the systems affected by concussion for a complete recovery and return to sport. A study by Broglio *et al.* observed that normal healthy young adults showed improvements in postural control when balance and cognitive tasks were performed concurrently in a dual-task paradigm (Broglio, Tomporowski et al. 2005). This research study offers interesting insight into how healthy individuals respond to dual-task paradigms and suggests that the paradigm may benefit athletes if implemented during concussion recovery as part of rehabilitation. If improvements following dual-task rehabilitation intervention are seen in healthy people and these types of intervention methods are feasible and useful, then these methods may be expanded to concussed individuals in the future.

Purpose

The purpose of this study was to examine neurocognitive and balance performance in healthy collegiate recreational athletes, prior to and following a dual-task training intervention compared to matched single-task controls. The intent of this research was to determine the utility and feasibility of a dual-task training program to potentially be applied following concussion.

Independent Variables

1. Intervention Groups – Between Subjects
    a. Dual-Task Training- Concurrent Balance and Cognitive Training
    b. Single-Task Control- Separate Single-Task Balance or Cognitive Training

2. Test Time – Within Subjects
    a. Pre-Intervention
    b. Post-Intervention

Dependent Variables

1. Dependent Variables
    a. Balance Performance Variables
        i. Sensory Organization Test (SOT) Composite Score
        ii. SOT Sensory System Ratios
            a. Vestibular Ratio
            b. Visual Ratio
            c. Somatosensory Ratio
        iii. Balance Error Scoring System (BESS) Total Error Score
    b. Neurocognitive Testing
        i. CNS Vital Signs Composite Domain Raw Scores
            a. Verbal Memory
            b. Visual Memory
            c. Psychomotor Speed
            d. Reaction Time
            e. Complex Attention
            f. Cognitive Flexibility
            g. Processing Speed
            h. Executive Functioning
            i. Reasoning

Research Questions

Balance Performance

1. Are there significant differences in balance performance, as measured by the SOT, prior to and following intervention between collegiate recreational athletes completing a four-week dual-task training program and a group of single-task control participants?
2. Are there significant differences in balance performance, as measured by the BESS, prior to and following intervention between collegiate recreational athletes completing a four-week dual-task training program and a group of single-task control participants?

Neurocognitive Performance

3. Are there significant differences in neurocognitive performance, as measured by components of CNS Vital Signs, prior to and following intervention between collegiate recreational athletes completing a four-week dual-task training program and a group of single-task participants?

Research Hypotheses

Balance Performance

1. Athletes that complete the dual-task training program will have significantly better balance performance, as measured by the SOT, with significant improvement in SOT somatosensory, visual, and vestibular ratios, following intervention compared to those in the single-task group.

2. Athletes that complete the dual-task training program will have significantly better balance performance, as measured by the BESS, in comparison to those in the single-task group.

Neurocognitive Performance

3. Athletes that complete a dual-task training program will significantly improve on neurocognitive performance, as measured by components of CNS Vital Signs with significant improvement in the domains of complex attention, cognitive flexibility, reasoning, and executive functioning, compared to those collegiate recreational athletes in the single-task group.

Statistical Hypotheses

Null Hypotheses

Balance Performance

1. There will be no significant differences in athletes before and after completing a dual-task training program compared to those within the single-task group on balance performance as measured by the SOT.
2. There will be no significant differences in collegiate recreational athletes before and after completing a dual-task training program compared to those within the single-task group on measures of BESS.

Neurocognitive Performance

3. There will be no significant difference in neurocognitive performance, as measured by CNS Vital Signs, in athletes that complete a dual-task training intervention compared to those collegiate recreational athletes within the single-task group.

Alternate Hypotheses

Balance Performance

1. There will be a significant difference in athletes before and after completing a dual-task training intervention compared to those within the single-task group on balance performance as measured by the SOT.
2. There will be a significant difference in collegiate recreational athletes before and after completing a dual-task training intervention compared to those within the single-task group on balance performance as measured by the BESS.

Neurocognitive Performance

3. There will be a significant difference in neurocognitive performance, as measured by CNS Vital Signs, in athletes that complete a dual-task training intervention compared to those collegiate recreational athletes within the single-task group

Definitions

1. **Dual-Task –** Engaging in cognitive and balance tasks simultaneously.
2. **Single-Task –** Engaging in separate balance or cognitive training.
3. **Collegiate Recreational Athletes –** A male or female student ages 18-25 who is currently participating in at least 30 minutes of exercise 3 times per week.
4. **Balance –** The process of maintaining an individual's center of gravity within the body's base of support (Guskiewicz 2011).

Delimitations

1. All athletes were between the ages of 18-25 and enrolled at the University of North Carolina at Chapel Hill.

2. All athletes reported exercising 3 times per week for at least 30 minutes or more each time.
3. All subjects were tested at least four weeks apart pre- and post- intervention.
4. Subjects with the following were excluded:
    - Concussion within the past six months
    - A history of two or more concussions
    - Neurologic disorder
    - Vestibular disorder
    - Hearing disorder
    - Vision disorder not correctable by contact lenses or glasses
    - ADHD
    - Learning disability
    - A lower extremity injury in the past 6 months effecting balance

Limitations

1. Subjects represented a sample of convenience.
2. Testers were not blinded to group assignment.
3. Subject motivation may have been low while performing selected tasks.
4. Compliance with home intervention sessions may have been low due to exercises were self-reported in an activity log.
5. Subject’s recreational training may have effected improvement with intervention tasks.

Assumptions

1. Subjects performed to the best of their ability and extended full effort on every task during each session.
2. The subjects used in this study were a representative sample of all athletes.
3. Subjects were truthful in activity logs and home intervention reports.

CHAPTER II

REVIEW OF THE LITERATURE

Concussion management and the critical time period from injury to full return to play present a unique challenge to sports medicine professionals. Like other athletic injuries suffered during sport there is a need to address the systems affected and deficits that occur due to concussive injury. Recent concussion related research has focused on clinical recognition, symptomatology, and return to play guidelines. Still little is known about concussion rehabilitation strategies and the active role the clinician should take in this process, specifically following more complicated concussive injuries. This review of literature is designed to examine research pertaining to concussion rehabilitation, identify current knowledge and understanding of concussion rehabilitation amongst sports medicine professionals, and discuss areas where future research is still needed pertaining to sport related concussion.

Definition of Concussion

Over the years the medical diagnosis of concussion has taken on many different definitions amongst clinicians. In November of 2001 the first International Symposium on Concussion in Sport was held in Vienna, Austria to discuss a unitary model of understanding for concussion in sport. Amongst other things this conference also served to provide recommendations on improving concussion management to ensure the safety and health of individuals participating in athletics. During this conference, the definition of concussion was revised. Concussion was defined as, "A complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces." Within this definition common features of concussion were identified and read as follows:

1. Concussion may be caused by direct blows to the head, face, neck, or other parts of the body which may transmit force to the head.

2. Impairment of neurological function is often short lived and typically resolves spontaneously.

3. Symptoms often reflect functional impairment rather than structural brain damage.

4. Concussion often presents as a multitude of clinical symptoms, which may or may not include loss of consciousness, which often follows a sequential resolution.

5. Concussion is often not identifiable with the use of neuroimaging studies (Aubry, Cantu et al. 2002).

Since 2001, the second and third International Conference on Concussion in Sport has been held in Prague in 2004 and in Zurich in 2008. Through each conference the definition of concussion has remained relatively constant. Specific to post-injury management, the most recent consensus developed a specific graduated return-to-play protocol (McCrory, Johnston et al. 2005; McCrory, Meeuwisse et al. 2009). This protocol provides sports medicine professionals with a universal progression to safely return the athlete to sport.

As the basis of knowledge regarding sport-related concussion expands, it is now understood that concussion is not structural damage to the brain that is evident with current imaging techniques, but is functional impairment that results in a global disruption of neurologic function (Guskiewicz, Bruce et al. 2004). A clear definition and growing understanding has resulted in a growing recognition of sport-related concussion.

Epidemiology of Concussion

Concussion is the most common head injury sustained by athletes and is of growing concern not only in the United States but in all areas of the world (Guskiewicz, Weaver et al. 2000). In a study conducted by the National Population Health Survey conducted by Statistics Canada in 1996-1997 it was reported that 85% of concussion in people ranging in age from 16 to 34 occurred while participating in sports (Gordon, Dooley et al. 2006). Recent data suggests that between 1.6 million to 3.8 million sport related concussion occur in the United States each year (Langlois, Rutland-Brown et al. 2006). This epidemiological study also acknowledges that these estimates may be low due to cases in which no medical care was sought.

In 2004, 1,532 varsity football players from 20 high schools in Milwaukee, Wisconsin completed preseason and postseason concussion questionnaires. This study reported that 30% of the high school football players had sustained a concussion while playing football. Of the 229 high school football players that reported suffering a concussion only 47.3% actually reported the injury in season. A majority of these athletes thought that their concussion was not serious enough to warrant medical attention and were fearful of not being able to participate in sport due to their injury (McCrea, Hammeke et al. 2004).

High school and collegiate football players who suffer a concussion are nearly three times more likely to suffer a second concussion the same season. Guskiewicz et. al reported 5.1% of high school and collegiate football players sustained a concussion. About one-third (30.8%) of all of the football players that sustained a head injury returned to participation that same day. Of those athletes returning to play on the same day 14.4% went on to suffer a grade II concussion (Guskiewicz, Weaver et al. 2000). Although athletes may report being asymptomatic and are able to pass exertional testing they may still be suffering from impairment due to concussion. It seems possible that concussion rehabilitation could help address deficits seen following injury and may help lower the re-occurrence rate of concussion during current and future seasons.

These numbers provide important insight into the prevalence of concussion in sport. With this epidemiological evidence it is also understood that athletes may be returning to play too quickly due to underreporting and lack of athlete education. Premature return to play not only predisposes the athlete to more severe injury, but also returns an athlete to competition without addressing the systems affected by concussion. Future research is necessary to investigate concussion incidence to further understand concussion and concussion recovery to facilitate concussion rehabilitation strategies to address impairment post-injury.

Anatomy

To better understand the dysfunction and pathophysiology associated with concussion and its rehabilitation process a basic understanding of neuro-anatomy and function is necessary. The brain is a complex system with several distinct areas affected by concussion. These areas affected should be considered when developing concussion rehabilitation strategies. The most common areas affected by concussion include:

Frontal Lobe

The frontal lobe is the most anterior portion of the cerebrum. It is associated with voluntary controlled movements, anticipatory postural adjustments, initiation and sequential movements, and motor and motor programming of speech.

Temporal Lobe

The temporal lobe is located bilaterally on the sides of the brain in the area of the ear. This area of the brain processes auditory and visual information. It is also responsible for visual and auditory memory.

Parietal Lobe

The parietal lobe is located just posterior to the frontal lobe. The parietal lobes main role is to discriminate texture, size, and shape of objects. It also helps the rest of the body discriminate head movement and position.

Occipital Lobe

The occipital lobe is the posterior portion of the brain. This area is the primary site for processing visual information including light intensity, shape, location, and size.

Cerebellum

The cerebellum is located just inferior to the occipital lobe. The primary functions of the cerebellum are to regulate balance, limb movement, and fine motor movements.

Brain Stem

The brain stem is formed by the medulla oblongata and pons which acts as the connection between the cerebellum and the spinal cord. The brain stem controls involuntary functions such as heart rate, respiratory rate, vasodilation and vasoconstriction, coughing and vomiting.

Cranial Meninges

The cranial meninges serve as a protective covering between the brain and surface of the skull. The meninges are separated into three layers: the dura matter, arachnoid matter, and pia matter. The most superficial of these layers is the dura mater. These layers also house arterial and venous blood supply, and cerebrospinal fluid is secreted by the choroid plexus deep within the subarachnoid space.

Cerebrospinal Fluid

A watery fluid within the brain that allows it to float and serves as a buffer to repetitive microtrauma and concussive blows (Cech and Martin 2002; Starkey and Ryan 2002).

Neurometabolic Cascade Following Concussion

Animal research has shown that following concussion multiple physiological changes occur at the cellular level. Immediately following injury there is a release of neurotransmitters and ion fluctuations, which negatively influence cellular physiology. Axonal stretching results in the opening of voltage-dependent potassium channels increasing extracellular potassium (Katayama, Becker et al. 1990). Sodium and potassium channels must work harder in order to restore neuronal membrane potential caused by this ionic shift. This extra work causes an increased need for adenosine triphosphate (ATP) and a spike in glucose metabolism (Ackermann and Lear 1989). With increased demand for ATP there is increased glycolysis causing a rise in lactic acid levels (Meyer, Kondo et al. 1970). An abnormally high level of lactic acid cause neuronal tissue acidosis facilitating neuronal dysfunction. After injury blood flow to the brain decreases worsening the depletion of glucose supply. Damaged cells go into a state of energy crisis. After the initial rush of glucose metabolism the brain enters a period of depressed metabolism. A reduction in magnesium is also seen here (Vink, McIntosh et al. 1987). Mechanical stretching causes axonal damage which results in membrane disruption and in some cases membrane depolarization. This depolarization sets the stage for increased calcium ion production which can eventually lead to the over production of free radicals and eventually cell death. Post concussive deficits occur often as a result of neuronal dysfunction rather than cell death (Giza and Hovda 2001). This diffuse axonal injury, increased lactate production, accelerated glycolysis, and decreased cerebral blood flow demonstrated in animal models following concussive injury may be responsible for prolonged recovery lasting longer than 7 days (Giza and Hovda 2001; Guskiewicz, McCrea et al. 2003).

Acute Effect of Concussion

As previously defined concussion is often not identifiable with the use of neuroimaging studies (Aubry, Cantu et al. 2002). Based on this premise, an accurate diagnosis of concussion relies heavily on a multifaceted approach. This approach includes thorough medical history, cranial nerve assessment, range of motion, strength testing, and subjective symptoms. Assessment of cognitive function testing short-term memory, working memory, attention, concentration, visual spatial capacity, information processing speed, and reaction time and a balance assessment are also necessary (Guskiewicz and Cantu 2004).

Acutely, there are numerous signs and symptoms that athletes may experience following a concussion. These signs can be defined within the following domains: somatic, cognitive, emotional; and physical (McCrory, Meeuwisse et al. 2009). Typical symptoms following a concussion include but are not exclusive to headache, balance deficits, nausea, and visual problems, feeling “foggy” or “dazed”, tinnitus, and or irritability. Physical signs may include gait abnormality, vomiting, speech pathology, poor coordination, and significant decrease in athletic ability (McCrory, Johnston et al. 2005). Of concussed NCAA Division I, II, and III football athletes from 1999-2000 77.8% did not experience any loss of consciousness, post traumatic amnesia, or retrograde amnesia following injury (McCrea, Prichep et al. 2010). Although some athletes may present with loss of consciousness and post traumatic amnesia, a majority of athletes do not experience these two signs of concussion. The presence of loss of consciousness and post traumatic amnesia results in significantly lower Standardized Assessment of Concussion Scores (SAC scores), a measure of mental status, immediately following concussion (McCrea, Kelly et al. 2002).

Symptoms of concussion may not present themselves immediately following the mechanism of injury. Symptoms may take anywhere from 15 minutes to 3 hours to present themselves following a concussion (Guskiewicz, McCrea et al. 2003; McCrea, Prichep et al. 2010). Athletes that present with extended periods of on-the field mental status changes are 5 times more likely to suffer a significant memory deficits 36 hours post-concussion (Lovell, Collins et al. 2003).

Initially following injury there is a spike in symptom severity, cognitive impairment, and balance issues. On average these symptoms resolve within 7 days following concussion (McCrea, Guskiewicz et al. 2003). Objectively, quantitative electroencephalograms have shown changes in brain function can be seen up to 8 days post injury in high school and collegiate football players (McCrea, Prichep et al. 2010). Cognitive impairment typically reaches peak severity 48 hours post injury and on average resolves in 5 to 7 days. Balance deficits following concussion on average begin to improve 24 hours post injury and typically resolve in five days. Deficits in cognitive processing speed and verbal fluency are also seen 7 days following initial injury (Cavanaugh, Guskiewicz et al. 2006; McCrea, Prichep et al. 2010).

Understanding the acute effects of concussion is critical for clinicians so they can follow proper and safe concussion rehabilitation guidelines towards return to play. Although most concussions resolve within 7 to 10 days, clinicians also have to deal with the effect of multiple concussions and more severe concussions which result in substantially longer recovery times (Guskiewicz, McCrea et al. 2003). Athletes suffering from prolonged recovery ranges from 7.4 to 30% as history of concussion increases from zero to three or greater (Guskiewicz, McCrea et al. 2003). Concussive injury and post concussive symptoms, which do not resolve within the 7 day average, present additional problems for the athlete and clinician. Future research is needed addressing persistent symptoms and impairment through concussion rehabilitation strategies.

Symptomatology

Concussion is associated with common signs and symptoms that are reported by the athletes. Among NFL football, collegiate football, and high school athletes the most commonly reported symptoms of concussion are headache, dizziness, and confusion (Guskiewicz, Weaver et al. 2000; Delaney, Lacroix et al. 2002). Other signs and symptoms may include nausea, seeing stars, double vision, fatigue, and sleep disturbances (Aubry, Cantu et al. 2002). Loss of consciousness and post traumatic amnesia were previously believed to be key symptoms for defining concussion and concussion severity but concussion is rarely associated with loss of consciousness or post traumatic amnesia. In a study investigating collegiate and high school football players 8.9% of individuals suffering from concussion experiences a loss of consciousness and 27.7% experienced post traumatic amnesia (Guskiewicz, Weaver et al. 2000).

Symptoms reported to a clinician can vary in type and severity. Initially post-injury athletes typically report between 3 to 7 different symptoms (Erlanger, Kaushik et al. 2003). An accurate subjective assessment of symptoms gives clinicians' key insight into physiological changes and injury severity following concussion so the appropriate course of action may take place both immediately and following during the recovery process. Although this subjective assessment is important, previous studies report that only 47.3% of high school football athletes that sustained a concussion actually reported these symptoms (McCrea, Hammeke et al. 2004). Subjective reporting of concussion symptoms is possible through graded symptoms checklists. These checklists allow sports medicine professionals to obtain baseline measures as well as to track concussion symptom resolution over time through repeated administration (Guskiewicz, McCrea et al. 2003; McCrea, Guskiewicz et al. 2003; Guskiewicz, Bruce et al. 2004). Symptomatology is crucial for diagnosing concussion but a multifaceted approach including assessment of balance and neurocognition are necessary identifying deficits after injury.

Postural Stability

Balance or postural stability is defined as the process of maintaining ones center of gravity within the body's base of support. In order to maintain equilibrium the central nervous system must integrate afferent information from the vestibular, somatosensory, and visual systems to effectively execute a musculoskeletal task. The vestibular system serves two primary purposes to maintain the eyes fixed on a stationary target when the head and body is in motion and to maintain balance with additional input from visual and somatosensory systems. This is accomplished through the semicircular canal and vestibular labyrinth in the inner ear. Under normal conditions somatosensory and visual information is enough to maintain balance (Guskiewicz 2011).

Balance assessment is an important factor in the evaluation of concussion. Two tests which have been shown to be valid and reliable tools that clinicians can use to expose balance deficits include the Balance Error Scoring System (BESS) and the Sensory Organization Test (SOT). The BESS and SOT have been shown to expose balance impairment from 3 to 7 days following concussion (Guskiewicz, Riemann et al. 1997; Riemann and Guskiewicz 2000; Guskiewicz, Ross et al. 2001; McCrea, Guskiewicz et al. 2003; Register-Mihalik, Mihalik et al. 2008).

The SOT uses technical force plate systems designed to disrupt an individual's sensory selection process by changing the orientation of visual and somatosensory inputs. The SOT uses six different conditions each condition altering either the visual, somatosensory, and or vestibular systems while measuring an individual's anterior to posterior sway (Guskiewicz 2011). Although the SOT is a useful system in identifying postural instability following concussion the instrumentation is not easily accessible by many clinicians due to its cost and overall size. A more clinically realistic tool for balance evaluation is the BESS.

The BESS was developed at the University of North Carolina at Chapel Hill and requires an athletes to complete 20 second trials of three different stances including double leg, single leg, and tandem stance on a firm and medium density foam surface for a total of six trials (Guskiewicz, Riemann et al. 1997; Riemann and Guskiewicz 2000; Guskiewicz, Ross et al. 2001; McCrea, Guskiewicz et al. 2003). The BESS is an effective, affordable way for clinicians to identify deficits in postural stability following concussion. Each subjects performance is scored by adding 1 error point for each error committed during each condition. Errors included lifting ones hands off the iliac crest, opening of the eyes, a step, stumble, or fall, moving the hip into greater than 30 degrees of abduction, lifting the forefoot or heel, and or remaining out of test position for greater than 5 seconds (Guskiewicz 2011).

It has been reported that in collegiate football athletes BESS error scores indicating postural stability have ranged from 1.46 to 5.66 errors above pre-season baseline testing following post game or practice evaluation and up to 3 days post injury (McCrea, Guskiewicz et al. 2003). The BESS can be administered in a multitude of settings. The sideline during an athletic event may present an environment where the athlete has extraneous sensory information. In this sideline setting the BESS has been observed to result in poorer balance when compared to a controlled setting such as an empty locker room (Onate, Beck et al. 2007). This should be taken into consideration when administering the BESS test to an injured athlete.

The Balance Error Scoring System and Sensory Organization Test provide objective information on static balance. These measures are extremely helpful with tracking an athlete's recovery following concussion. As these deficits are made more easily identifiable clinicians can better target the systems affected by concussion during the rehabilitation process.

Neuropsychological Assessment

At all levels of sport the use of neuropsychological testing is becoming an increasingly common tool for the evaluation and management of sport-related concussion. Neuropsychological tests include multiple subtests which measure cognitive domains that may be impaired after concussion. These domains include attention, concentration, cognitive processing (speed and efficiency), learning and memory, working memory, executive functioning, reaction time, and verbal fluency (Guskiewicz, Bruce et al. 2004). Deficits in neuropsychological performance following concussion have been seen to persist up to 14 days after initial injury (McCrea, Kelly et al. 2002; Lovell, Collins et al. 2004; McClincy, Lovell et al. 2006).

Neuropsychological testing may be used to evaluate concussion and should be used to identify baseline levels of neurocognitive function (Collins, Grindel et al. 1999; Echemendia, Putukian et al. 2001; Erlanger, Saliba et al. 2001; Lovell, Collins et al. 2003; McCrea, Guskiewicz et al. 2003). These baseline measures should be obtained from athletes before his or her respective sport seasons and help clinicians objectively measure cognitive function. Following concussion neuropsychological testing can be used as a comparison for tracking an individual's recovery.

The timing of neuropsychological testing administration after injury is a topic of debate. Currently two approaches to determine timelines for serial neuropsychological testing are commonplace in the clinical setting. The first approach endorses neuropsychological testing once the athlete reports he or she is asymptomatic. The second approach utilizes neuropsychological testing at set intervals for example day 1 post injury or day 7 post injury to track recovery (Guskiewicz, Bruce et al. 2004). It should be noted that the second approach should not be used in the clinical setting when an athlete is still symptomatic because it may introduce a practice effect that could promote premature return to play (McCrea, Barr et al. 2005). Although neuropsychological testing is helpful in monitoring concussion recovery several factors are known to influence test performance. These factors include previous history of concussion, educational background, cultural background, age, test anxiety, medications, distractions, sleep deprivation, and attention deficit or hyperactivity among others (Grindel, Lovell et al. 2001). Because these factors may influence neuropsychological performance, a multifaceted approach to concussion evaluation is necessary to assess concussion recovery. Neuropsychological testing is just one piece of information, which should be combined with other clinical factors in determining the most appropriate rehabilitation strategy for concussion rehabilitation.

Long-Term Cumulative Effects of Concussion

Previous research has shown that a history of concussion predisposes an athlete to repeated mild traumatic brain injury. Athletes with a previous history of three or more concussions are three times more likely to sustain a repeated concussion then those athletes with no previous history of concussion. Athletes with a history of concussion are also more likely to experience loss of consciousness, anterograde amnesia and confusion following a concussion (Collins, Lovell et al. 2002). The recovery period following a concussion is also prolonged with repeated concussions. Athletes with a previous history of concussion are more likely to take greater than 7 days to recover from concussion, a longer period of recovery compared to athletes with no previous injury (Guskiewicz, McCrea et al. 2003). Some individuals may even suffer from post-concussion symptoms for months to years (Ryan and Warden 2003). This is partly due to the altered brain physiology following cumulative concussions. The brains of athletes with previous concussion may be in a state of energy crisis, calcium ion influx, and long-term neurotransmission impairment (Sanders, Sick et al. 2000; Giza and Hovda 2001).

Recurrent concussion not only affects an athlete in the weeks following concussion, but also much later in life. Recurrent concussions have been linked to increased prevalence of mild cognitive impairment, significant memory problems (Guskiewicz, Marshall et al. 2005), and depression (Guskiewicz, Marshall et al. 2007). Recurrent concussion has also commonly been linked to symptoms including Alzheimer’s disease, paranoia, poor judgment, outbursts of anger or aggression, irritability, confusion, and reduced concentration (Guskiewicz, Marshall et al. 2005; McKee, Cantu et al. 2009). Several studies and case reports of retired NFL players have shown evidence of chronic traumatic encephalopathy and cognitive impairment later in life following their careers as professional athletes (Guskiewicz, Marshall et al. 2005; Omalu, DeKosky et al. 2005; Omalu, DeKosky et al. 2006). With the growing knowledge base that concussion impairment may persist longer than 7 days following injury, research is necessary to address concussion with hopes of improving the care provided to athletes. Few research studies have focused on rehabilitation following injury and how intervention may aid clinicians in safely returning an athlete to pre-concussion ability while reducing the risk for later cognitive impairment and life complications. Athletes suffering from prolonged recovery which persists outside of the typical 7-10 day recovery window would benefit from rehabilitation strategies to address persistent deficits seen following injury.

Postconcussion Syndrome

Although the majority of concussion symptoms resolve within a 7 to 10 day window (Guskiewicz, McCrea et al. 2003), some individuals may suffer from physical, cognitive, and emotional symptoms for several months up to 15 years following injury (Bohnen and Jolles 1992; Gouvier, Cubic et al. 1992; Brown, Fann et al. 1994). Post concussive symptoms lasting for an extended period of time are often referred to as Postconcussion Syndrome (PCS) (Ryan and Warden 2003). The definition, etiology, and diagnostic criteria for PCS varies within the literature including the criteria within the International Classification of Diseases, 10^{th} edition (ICD-10) and the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DMS-IV) (Zasler, Katz et al. 2007). Physical postconcussive symptoms include headaches, dizziness, fatigue, visual disturbances, noise sensitivity, and light sensitivity. Cognitive postconcussive symptoms include memory deficits, attention and concentration deficits, and executive function deficits. Emotional postconcussive symptoms commonly include depression, anxiety, and heightened irritability (Ryan and Warden 2003). Impairments of neurocognitive functioning including attention, concentration, memory, problem solving, and decreases in measures of information processing, reasoning, and verbal learning have also been observed (Rimel, Giordani et al. 1981; Leininger, Gramling et al. 1990). These symptoms not only effect acts of daily living but also affect the dynamic tasks athletes are asked to perform on the playing field.

PCS has been treated using pharmacological intervention including the use of antidepressants, anti-anxiety, and non-steroidal anti-inflammatory medications with some success (Mittenberg and Burton 1994; Ryan and Warden 2003). Patient education, support, reassurance, and a graded increase in activity has also been observed as effective treatment strategies for individuals suffering from PCS (Mittenberg and Burton 1994). These intervention strategies are successful in the treatment of some PCS symptoms but athletes suffering from PCS may benefit from the addition of a rehabilitation program which extends beyond the standard cognitive rest period and gradual exertional return to play regiment. The effects of a concussion rehabilitation program on healthy athletes will provide the critical frame work for its future application to those athletes suffering from prolonged concussion deficits and PCS.

Concussion Rehabilitation

The effects following concussion can be extremely detrimental to the systems involved in sport and activities of daily living. If deficits following concussion include cognitive and balance impairment, clinicians should address these issues during the rehabilitation process to help athletes return to a pre-concussion performance level prior to returning to play. Clinicians need to address the functional capacity of systems affected by concussion to put the athlete in the best position for return to play (Johnston, Bloom et al. 2004).

Rehabilitation has been used for patients with moderate and severe traumatic brain injury, but has not been considered as a standard of care for mild traumatic brain injury such as sport related concussion with prolonged recover (Relander, Troupp et al. 1972; Ponsford 2005). Individuals suffering from moderate to severe traumatic brain injury have been shown to benefit from cognitive rehabilitation regardless of location in a hospital setting or at home with return to work and or fitness duties as required by the military (Salazar, Warden et al. 2000; Warden, Salazar et al. 2000). Following one year of rehabilitation in those that sustain a severe traumatic brain injury, independent living, employment, and or student status has been observed to rise to 58.9% and 37.2% regardless of rehabilitation strategy (Vanderploeg, Schwab et al. 2008). Improvements in cognitive functioning and reduction of subjective post-concussive symptoms have been observed in mild traumatic brain injury patients undergoing neuropsychological rehabilitation, particularly in areas of complex attention and information processing speed (Cicerone, Smith et al. 1996). The benefits of rehabilitation strategies for individuals suffering from traumatic brain injuries are evident, but concussion rehabilitation strategies need to become the standard of care, especially for those individuals who take longer than the average 7-10 day recovery window. Most information regarding concussion rehabilitation is composed of general guidelines and consensus statements with little evidence based justification. These recommendations heavily emphasize an exertional return to play progression to examine if signs and symptoms of concussion return with activity. These return to play progressions do not effectively target the systems affected by concussion. Current return to play protocols follow a step wise progression beginning with no activity as the first step followed by light aerobic exercise, sport-specific exercises, non-contact training drills, full-contact practice, and concluding with full return to play in a game situation. These progression protocols are not aimed at rehabilitating athletes following concussion, but rather serve as checkpoints for determining whether symptoms return with exertion. Objectives for each stage of return to play progression include recovery, increase in heart rate, the addition of movement and a cognitive load with exercise, and restoring an athlete's functional skill and confidence (Aubry, Cantu et al. 2002; Johnston, Bloom et al. 2004; McCrory, Johnston et al. 2005; McCrory, Meeuwisse et al. 2009).

Following some period of cognitive rest gradual transition back to acts of daily living, such as attending class or light exercises, may improve overall function and ability following concussion. Previously, a study observed that concussed individuals in an active treatment group, including daily visits by medical staff, repeated education of their injury, and encouragement to avoid bed rest and begin activities of daily living needed fewer days off from work when compared to those in a non-treatment group (Relander, Troupp et al. 1972). Simply educating a patient on common symptoms and coping strategies following a mild traumatic brain injury resulted in fewer symptoms reported and lower overall stress (Ponsford 2005). A later study observed student athletes with post injury activity level including school activity and participating in sports practice performed better on measures of verbal memory, visual memory, visual motor speed, and reaction time when compared to those student athletes restricted from all school and athletic activity and those with full participation in school activity and sports games (Majerske, Mihalik et al. 2008). Improved balance and decreased subjectively reported dizziness has been observed with vestibular rehabilitation intervention consisting of four visits over 33 days (Alsalaheen, Mucha et al. 2010). The results of these studies suggest that early return to light physical and cognitive activity is beneficial and may decrease recovery time following concussion.

Although the guidelines and research studies noted do serve their purpose in providing general strategies for return to play, they do not fully address the key component of rehabilitation which is addressing the systems affected by concussion, specifically cases of protracted recovery. Rehabilitation guidelines put forth in consensus statements are most often utilized when an athlete is asymptomatic following a period of cognitive rest period including limiting exertional activities, scholastic, and cognitive stressors (McCrory, Meeuwisse et al. 2009). These rehabilitation guidelines were developed for the athlete whose symptoms resolve within 7 to 10 days and often fail to address the issues of athletes who suffer impairment beyond that timeline. Vestibular rehabilitation following concussion has been shown to decrease patient reported dizziness and shows that rehabilitation strategies can be advantageous following the acute stage of injury (Alsalaheen, Mucha et al. 2010). Individuals suffering from traumatic brain injury are often subjected to holistic rehabilitation programs containing physical, occupational, and cognitive therapy (Mazaux and Richer 1998; Chua and Kong 1999; Nilsson, Bartfai et al. 2011). These same standards need to also be applied to mild traumatic brain injury as well. With single-task balance improvements observed during a dual-task paradigm, rehabilitation needs to continue its progression towards multifaceted rehabilitation techniques and away from traditional single-task rehabilitation strategies (Broglio, Tomporowski et al. 2005). There are few studies addressing concussion rehabilitation and a continued push in this area of research is needed.

Dual Task Paradigm

Although previous studies have given us insight into effects of early return to physical activity following concussion they fail to address specific impairments commonly seen following concussion and do not address intentionally intervening on concussion recovery through rehabilitation. As mentioned previously concussion effects cognition, balance, and over all sport performance ability, all important components to an athlete’s attention during competition (Posner and Boies 1971). Sports are not only made up of exertional motor tasks but also a complex paradigm involving cognitive skill combined with body movement.

In order to effectively complete a task an individual must be able to process information effectively and determine which systems involved in the task need increased resource investment. This concept is depicted by Wicken’s model which describes task performance (P) as an individual’s resources available (R) divided by the task difficulty (D):

$$\mathrm{P} = \frac{R}{D}$$

This model depicts how an individual’s performance is related to the resources available as well as the difficulty of the task at hand (Damos 1991). Within the dual-task paradigm individuals are asked to complete tasks with decreased resource availability. This is the case in athletics when athletes are constantly required to perform multiple tasks at once. Following concussion the functional capacities of resources available including balance and cognitive function are impaired making dual-task executions more difficult resulting in decreased performance. It may be important to incorporate a concussion rehabilitation program that would simultaneously exert an athlete physically and cognitively. This “dual-task” rehabilitation methodology would require a person to execute a secondary cognitive task while being physically exerted to address cognitive, balance, and or visual deficits following concussion. This condition of attention is unique because it forces an individual to connect the mental level of cognitive science with the anatomical level of neuroscience. The dual-task rehabilitation paradigm is the closest way to replicate sport performance in an effort to evaluate the multiple systems affected by concussion concurrently (Posner and Petersen 1990; Broglio, Tomporowski et al. 2005).

Creating a dual-task concussion rehabilitation protocol cannot be done without review of current literature and the effects of a dual-task environment on healthy and concussed people. With the addition of a secondary task various differences in biomechanics are seen. Some studies using healthy individuals under a dual-task have observed that performing a secondary task does not affect gait or stability yet improvements in postural sway have been observed (Shumway-Cook and Woollacott 2000; Hunter and Hoffman 2001; Swan, Otani et al. 2004; Broglio, Tomporowski et al. 2005; Siu, Catena et al. 2008). Elderly individuals suffering from balance impairment have displayed improvements in functional balance following a four week dual-task training session (Silsupadol, Siu et al. 2006). Improvements in dual-task performance over time has also been observed regardless of age which further demonstrates the positive benefits of a dual-task training intervention (Bherer, Kramer et al. 2005). Concussed individuals adapt a significantly shorter stride length, 42% increase in medio-lateral sway, and slower gait velocity with the addition of a cognitive task which has been attributed to adapting a safer walking and obstacle avoidance strategy due to impairment of the postural control system (Catena, van Donkelaar et al. 2011). Concussed individuals have been shown to display no difference in correct answers for dual-task situations when compared to healthy controls yet, healthy individuals have shown declines in secondary task performance including slower reaction time during auditory Stroop tasks (Catena, van Donkelaar et al. 2011). Concussed individuals subjected to various virtual reality environments not only recreated symptoms of concussion including nausea, dizziness, and disorientation but also induced postural destabilization (Cavanaugh, Guskiewicz et al. 2005; Parker, Osternig et al. 2005; Slobounov, Tutwiler et al. 2006; Parker, Osternig et al. 2008; Siu, Catena et al. 2008). Although balance has been shown to decrease onset latency of the gastrocnemius and tibialis anterior muscle, latency was not affected when a secondary math task was added to balance conditions (Rankin, Woollacott et al. 2000). This increase in muscle activation may explain the improved postural stability observed in some individuals while completing a dual-task. This increased muscle stiffness, practice effects leading to refinement of motor control, and the effect of voluntary eye movement have been postulated to improve an individual's balance with the addition of a cognitive task (Dault, Geurts et al. 2001; Broglio, Tomporowski et al. 2005).

Although the dual-task paradigm employs strategies which may improve areas where concussion deficits are often seen including balance and reaction time, current research does not center on intervention in which people may train under these circumstances for extended periods of time. Incorporating this intervention methodology may help demonstrate the positive effects of incorporating a dual-task intervention strategy with an athlete recovering from concussion. Athletes suffering from long term concussion impairment and post-concussion symptoms may require these dual-task rehabilitation strategies that go beyond a period of cognitive rest followed by an exertional return to play progression. These rehabilitation strategies will help athletes return to sport and improve their quality of activities of daily living which are rarely single-task in nature. Concussion intervention has been successful in some cases when administered to children slow to recover from sport related concussion (Gagnon, Galli et al. 2009). Continued research in this area would give clinicians insight into effective rehabilitation treatment and help determine if dual-task rehabilitation during concussion recovery should be the new standard in concussion rehabilitation and return to play progression.

Methodological Considerations

Previous literature on dual-task performance and clinical assessment of concussion varies in methodology. Accurate diagnosis of concussion includes a multifaceted approach investigating balance, cognitive, and various neurophysiological deficits. Current literature suggests that the BESS, SOT, and CNSVS are all reliable and valid tools sports medicine professionals can utilize in identifying deficits, such as balance and reaction time, and monitoring improvement following concussive injury (Riemann, Guskiewicz et al. 1999; Riemann and Guskiewicz 2000; Guskiewicz 2001; Guskiewicz, Ross et al. 2001; McCrea, Guskiewicz et al. 2003; Gualtieri and Johnson 2005; Gualtieri and Johnson 2006; Onate, Beck et al. 2007). Improvements in the outcome measures of these tests will help determine the feasibility and utility of a concussion rehabilitation strategy addressing all of the systems affected by concussion. This study will utilized these tools to make the results of this research more applicable to sports medicine professionals administering care to concussed athletes.

Summary

Concussion is a serious injury with short and long term complications. Although the average recovery window is between 7 to 10 days, some individuals may suffer from prolonged recovery and postconcussion syndrome which causes issues not only in the athletic setting but in all facets of daily living. As with any injury to the body, the systems involved or affected by injury often require rehabilitation strategies for a complete return to pre-injury state. Current recommendations for concussion rehabilitation are based primarily on the premises of cognitive rest followed by an exertional return to play progression. This current rehabilitation strategy fails to address deficits seen following concussion. Improvement in postural stability with secondary task completion has been demonstrated with the use of dual-task paradigms in healthy individuals. These findings support the need for further research in the application of a dual-task intervention for the rehabilitation of mild traumatic brain injury.

CHAPTER III

METHODOLOGY

Subjects

A sample of 33 healthy, physically active 18-25 year old males and females were recruited from the University of North Carolina at Chapel Hill. The sample consisted of 15 males and 15 females that reported participating in at least 30 minutes of self-reported physical activity at least 3 times per week. Demographic information is located in Table 1. Subjects were stratified by gender and then randomly assigned to either the dual-task (DT) intervention or single-task (ST) groups (15 DT, 15 ST). Each subject read and signed an IRB-approved informed consent and completed a brief general health history questionnaire. Subjects were excluded (n=3) from the study if they had been diagnosed with a concussion within the past three months, a history of two or more concussions, neurologic disorder, vestibular disorder, attention deficit hyperactive disorder, learning disorder, visual disorder not correctable by contact lenses or glasses, or a lower extremity injury within the past six months affecting balance.

Measurement and Instrumentation

Sensory Organization Test

The Sensory Organization Test (SOT) performed on the Smart Balance Master System (NeuroCom International, Clackamas, OR, USA) was utilized to assess balance (Figure 1). Sensory conflicts altered an individual’s visual, somatosensory, and vestibular information by distorting ones surroundings (Guskiewicz 2011). This was accomplished through sway referencing in regards to the participants sway as well as having an individual close their eyes in selected conditions. Sway referencing refers to changes in the orientation of the support surface or visual surroundings to follow the subject's center of gravity (Guskiewicz 2011). The SOT utilizes six conditions each 20 seconds and performed three times in random order. These conditions include (Figure 2): (1) fixed surface with a fixed visual field; (2) fixed surface with eyes closed; (3) fixed surface with sway referenced visual field; (4) sway referenced surface with fixed visual field; (5) sway referenced surface with eyes closed; (6) and a sway referenced surface with sway referenced vision. During sway referenced surface conditions the forceplate moved corresponding to the subjects' postural sway in the anterior-posterior direction. During sway referenced visual conditions the visual surrounding moved corresponding to the subjects' postural sway in the anterior-posterior direction.

Each of the six conditions was used to compute a weighted average of all the sensory conditions called the composite score. The composite score was computed as the average of the following 14 scores: the condition one average score, the condition two average score, and the three equilibrium scores from each of the trials in conditions three to six. A higher composite score was indicative of less postural sway and greater balance control. The composite score, composed of the weighted average of the scores of all sensory conditions, characterized the overall level of performance but does not give an accurate depiction of individual sensory systems and their effect on balance performance. Although an individual's balance may improve as hypothesized with the dual-task program, specific effects of the intervention are better depicted utilizing SOT sensory ratios. The data collected were used to calculate contributions of the visual, somatosensory, and vestibular system to each subjects overall balance. Contributions of these systems are represented by sensory ratios. The visual ratio was the ratio of the condition 4 equilibrium score to the condition 1 equilibrium score. The somatosensory ratio was the ratio of the condition 2 equilibrium score to the condition 1 equilibrium score. The vestibular ratio was the ratio of the condition 5 equilibrium score to the condition 1 equilibrium score. As with the composite score, higher ratio scores indicate improved ability to maintain postural stability while other systems are being simultaneously altered (Register-Mihalik, Mihalik et al. 2008; Sosnoff, Broglio et al. 2011).

Balance Error Scoring System

The Balance Error Scoring System (BESS) was developed for clinical use to assess postural stability following a concussion (Guskiewicz 2011). The BESS was composed of 20 second trials with three conditions including double leg, single leg on the non-dominant foot, and tandem (heel-to-toe) stances with the non-dominant foot behind the dominant foot (Figure 3). The dominant leg was defined as the leg the subject would use to kick a ball. Each condition was completed on a firm surface and repeated on a foam surface utilizing a medium density foam pad (Airex Balance Pad, Alcan Airex, Switzerland) with time kept on a standard stopwatch (Fisher Scientific, Pittsburgh, PA). Athletes were instructed to stand as quietly and as motionless as possible during each trial. Patients were instructed that upon losing their balance they were able to make any necessary adjustments and return to the appropriate testing position as quickly as possible. Each subjects performance was scored by adding one point (with a maximum of 10 points) for each of the following errors committed during each condition: lifting ones hands off the iliac crest, opening of the eyes, a step, stumble, or fall, moving the hip into greater than 30 degrees of abduction, lifting the forefoot or heel, and or remaining out of test position for greater than 5 seconds.

Neuropsychological Testing

CNS Vital Signs (CNS Vital Signs, Chapel Hill, NC) was utilized to administer a computerized neurocognitive test battery. CNSVS contained a battery of seven subtests. These CNSVS subtests included:

Verbal Memory Test

The verbal memory test (VBM) utilized words as target stimuli to test word list learning immediately after memorizing and following a period of approximately 20 minutes. For this test each subject was asked to remember a list of 15 target words, presented one by one every two seconds, on the computer screen. Subjects then immediately viewed a longer list of 30 words that contained all of the 15 target words and 15 additional words that were not contained in the original list. When a subject recognized one of the original target words they are instructed to press the space bar on the key board. Another list of 30 words containing all 15 of the original words was re-administered at the end of the test battery to test delayed recognition of the word list. Scoring for this section includes one point for each correct hit and correct pass during both the immediate and delayed testing. The maximum score is 120 and the minimum score is 60. A score below 60 suggests willful exaggeration.

Visual Memory Test

The visual memory test (VIM) was the same test as the VBM only it utilizes 15 geometric shapes drawn from a 60 shape reservoir. For this test each subject was asked to remember a list of 15 geometric shapes, presented one by one every two seconds, on the computer screen. After this was complete a list of 30 shapes was presented with the 15 target shapes mixed randomly among fifteen new shapes. When a subject recognized one of the original target shapes they were instructed to press the space bar on the key board. Each subject is also retested approximately 20 minutes later following the conclusion of the six remaining tests. Scoring for this section includes one point for each correct hit and correct pass for immediate and delayed testing. The maximum score is 120 and the minimum score is 60. A score below 60 suggests willful exaggeration.

Finger Tapping Test

The finger tapping test (FTT) measured an individual's fine motor control. For this test each subject was asked to press the space bar with their right index finger as many times as possible in 10 seconds. Each subject was allowed one practice run followed by three test trials. This was then repeated with the left hand. Scoring for this section was composed of the average number of taps of the right and left hand. This test is believed to be one of the most sensitive neuropsychological tests for determining brain impairment (Mitrushina, Boone et al. 1999).

Symbol-Digit Coding

The symbol-digit coding (SDC) test was a variation of the digit symbol substitution component of the Wechsler Intelligence Scale. During this test 8 symbols from a reservoir of 32 symbols are presented as a key. Each of the eight symbols was randomly matched with a digit, i.e. 1-#. These pairs were successively displayed on the computer screen. The subject must type in the correct number corresponding to the symbol presented using the keyboard. The number of correct responses in 2 minutes corresponded to an individual's score.

The Stroop Test

CNSVS utilized a version of the Stroop test developed by JR Stroop in 1935 (Strauss, Sherman et al. 2006). The CNSVS version utilized four color/color words including red, green, yellow, and blue. The test was broken down into three sections. During the first section the words red, green, yellow, and blue were flashed on the computer screen at random in black text. The subject was asked to click the space bar as soon as they see the word. This section tested simple reaction time. The second section randomly displays the words red, yellow, blue and green on the screen printed in color. The subject was asked to click the space bar if the text color matched the word displayed. For example, the participant would hit the spacebar if the word yellow was written in yellow text, but not if the word yellow was written in red text. This section tested complex reaction time. The third section also tested complex reaction time but the subject was asked to click the space bar if the color and the word do not match. For example, the participant would hit the spacebar if the word blue was written in green text, but not if the word blue was written in blue text. Information processing speed was quantified by averaging the two complex reaction scores from this portion of the test.

The Shifting Attention Test

The Shifting Attention Test (SAT) was a 90 second test which tests one's ability to shift attention from one set of instructions to another as accurately and as fast as possible. Subjects were presented with one top figure (either a red or blue square or circle) and two bottom figures (either a red or blue square or circle). Instructions appeared just above the top figure that declared either "Match to shape" or "Match to color". Based on instruction the subject selected the lower figure that matched the top figure based on the instruction given by either striking the right or left arrow key. The score from the SAT included the number of correct responses, the number of incorrect responses, and response time in milliseconds.

The Continuous Performance Test

The Continuous Performance Test (CPT) measured attention over time. The CPT is sensitive to CNS dysfunction and the ability to maintain attention (Schein 1962). During this test each subject were asked to click the space bar only when the letter “B” appeared on the monitor. The letter “B” appeared randomly throughout the 5 minute presentation of 200 letters. Of the 200 letters 40 are “B”. Scoring for this test was composed of the correct responses, impulsive responses, and the number of times a subject does not click the space bar when presented with the letter “B”.

Non-verbal Reasoning Test

The Non-verbal reasoning test (NVRT) was a 5 minute test in which the subject was presented with a series of 15 – 4x4 square puzzles or visual analogies. Within each 4x4 square, one block was empty. The subject was asked to identify the correct response from four possible answers by selecting the number that matches the answer that makes most sense within the empty block within 14 seconds. Scoring was composed of the number of correct and incorrect responses as well as reaction time.

CNSVS Scoring

From these subtests listed above CNSVS computed raw domain scores, standard, and percentile scores. The raw scores were used as the outcomes measures for all analyses. To ensure test validity CNSVS validity indicators were used to identify possible invalid test or domain scores for each of the domains. These domains include:

Verbal Memory

Verbal memory was calculated by adding VBM correct hits immediate with VBM correct passes immediate, VBM correct hits delay, and VBM correct passes delay. A higher verbal memory score indicated better performance. A verbal memory raw score greater than 30 was required to qualify as a valid test score.

Visual Memory

Visual memory was calculated by adding VIM correct hits immediate with VIM correct passes immediate, VIM correct hits delay, and VIM correct passes delay. A higher visual memory score indicated better performance. A visual memory raw score greater than 30 was required to qualify as a valid test score.

Processing Speed

Processing speed was calculated by subtracting SDC errors from SDC correct responses. A higher processing speed score indicated better performance. More than 20 correct responses during the symbol digit coding test were required to ensure test validity.

Executive Function

Executive function was calculated by subtracting SAT errors from SAT correct responses. A higher processing speed score indicated better performance. Shifting attention test correct responses was required to be greater than shifting attention test errors in order to ensure test validity.

Psychomotor Speed

Psychomotor speed was calculated by adding FTT right taps average with FTT left taps average, and SDC correct responses. A higher psychomotor speed score indicated better performance. Total taps during the finger tapping test must have been greater than 40 or one must have achieved greater than 20 correct responses during the symbol digit coding test to ensure test validity.

Reaction Time

Reaction time was calculated by dividing the sum of ST complex reaction time correct with Stroop reaction time correct by 2. A lower reaction time score indicated better performance. To ensure valid reaction time domain scores simple reaction time must have been less than complex reaction time and less than stroop reaction time.

Complex Attention

Complex attention was calculated by adding Stroop commission errors with SAT errors, CPT commission errors, and CPT omission errors. A lower complex attention score indicated better performance. Correct responses must have been greater than incorrect responses for the stroop test, continuous performance test, and shifting attention test to ensure test validity.

Cognitive Flexibility

Cognitive flexibility was calculated by subtracting SAT errors and Stroop commission errors from SAT correct responses. A higher cognitive function score indicated better performance. Correct responses must have been greater than incorrect responses for the stroop test and shifting attention test to ensure test validity.

Reasoning

Reasoning was calculated by subtracting NVRT commission errors from NVRT correct responses. A higher reasoning score indicated better performance. A non-verbal reasoning test score must have been greater than four and correct responses must have been greater than incorrect responses to ensure test validity.

Procedure

All subjects reported to the Matthew Gfeller Sport-Related Traumatic Brain Injury Research Center for testing and intervention sessions. Prior to the beginning of the testing session all inclusion/exclusion criteria were reviewed with each subject.

Assessments

All subjects reported for pre- and post- intervention testing including two balance performance measures: SOT, BESS; and a neurocognitive test battery: CNSVS. Subjects were also administered a General Health History Questionnaire (Appendix A) to obtain demographic information, physical activity level, and injury/medical history. BESS trials were captured using video analysis and independently scored, blinding for BESS Total Error Score throughout the intervention. A paper-pencil battery was also included in the testing order but was not part of the objective measures of this study. Subjects repeated the same testing order during their post testing. The SOT conditions were always completed in a randomized order, no matter the task. SOT screen scores were covered to assure test administrator blinding.

Two groups composed of 15 single-task intervention and 15 dual-task intervention subjects were matched based on age and sex. All 30 subjects in the groups were required to report to the Gfeller Center twice a week to complete their specified intervention training program and completed an additional training session each week on their own at home. Once participants agreed to participate following an initial phone screening, a randomly generated number and group list was used to randomly assign participants to groups based on the gender stratification. If a participant withdrew or could not complete the study a replacement of the same gender was recruited. Subjects completed the single-task or dual-task progression over 4 weeks for a total of 12 training sessions (8 in person and 4 at home). Subjects were required to complete at least one observed or home session per week and twelve sessions overall to be included in study analysis. All observed sessions were mandatory to be included in study analysis. Subjects were allowed a fifth week of intervention progression to account for missed observed sessions due to academic breaks and scheduling issues (n=16). Subjects were asked to log their home training sessions and outside activities completed during the intervention period. Two sets of each designated exercises, unless specified, was performed regardless of group. All subjects regardless of group and task proficiency completed a mass progression of four weeks. A detailed explanation of the single-task and dual-task intervention and difficulty progression is provided in Appendix A.

Intervention Progression

All subjects in the single-task intervention group (ST) completed activities broken down into balance and cognitive exercises of varying degrees of difficulty. Each subject began at the entry level of both balance and cognitive exercises and progressed to the advanced level based on the mass progression. The single-task progression was composed of a four-week progression of altering balance and cognitive training. Week one incorporated cognitive and balance tasks composed of difficulty levels 1-2. Week two incorporated entry level cognitive and balance tasks composed of difficulty level 3 and advanced level cognitive and balance tasks composed of difficulty level 4. Week three incorporated advanced level cognitive and balance tasks composed of difficulty level 5. The single-task intervention concluded during week 4 which incorporated advanced level cognitive and balance tasks composed of difficulty level 6. A detailed explanation of the single-task intervention progression is provided in Appendix A.

All subjects in the dual-task intervention group (DT) completed activities from all four progressive dual-task levels broken down into the Entry Level, Moderate Level, Advanced Level, and the Activity Specific Level. The progression began with one week of Entry Level tasks. The entry level is composed of difficulty levels 1-3 and focused on concurrently completing basic balance exercises level 1-3 and cognitive exercises level 1-3. Following week one subjects were progressed to the moderate level. The moderate level was composed of difficulty levels 4-6 utilizing balance levels 4-6 and cognitive exercises level 1-4. The moderate level also incorporated Wii Fit (Nintendo, Redmond, WA, USA) activities at each level including soccer heading and running with memory tasks. Following the second week the subject was progressed to the advanced level. This level was composed of difficulty levels 7-9 utilizing balance levels 1-6 and cognitive exercises from level 4-6 along with ball throwing activities. Wii Fit including obstacle courses and table tilt games were again used for each difficulty level. The final week consisted of the activity specific level and was composed of difficulty levels 10-12. These levels incorporated balance activities combined with ball or object response, movement decisions, and obstacle avoidance. A detailed explanation of the dual-task and single-task weekly exercise task progression is provided in Appendix A.

Progression for both the single-task and dual-task intervention groups utilized a mass progression. Following each week each subject completed an intervention progression check point. This checkpoint included a BESS total error score, cognitive test score, subjective task average score, and objective balance and cognitive task progression achievement score. The subjective task score incorporated asking each subject to answer the subjective difficulty scale question based on the difficulty of each task. Each question was scaled to the Borg CR10 Rating of Perceived Exertion Scale. Each subject was asked to identify the number that most closely corresponded to the difficulty of tasks completed at each tier. The subjective scores from each task were averaged across the week and recorded. A detailed explanation of the subjective task difficulty scale is provided in Appendix A. Along with the subjective questionnaire each subject was videotaped to be objectively scored each week proceeding intervention progression. If subjects are able to achieve the specified objective score the yes box would be checked for future analysis. If subjects were not able to achieve the specified objective score the no box would be checked for future analysis. Weekly checkpoints allowed for future analysis of individual rate of progression. A detailed explanation of the intervention progression weekly check point is provided in Appendix A.

Data Analysis

All data analyses were conducted using SPSS 19.0 (Chicago, IL). An a priori alpha level set at 0.05 was utilized for each dependent variable. This alpha level was adjusted for the four SOT variables, as the composite score is not independent of the three ratio scores. Alpha level for SOT Composite score was set at .0167 and SOT ratios utilized and alpha level of .025. Statistical analyses for each research question were as follows:

Balance Performance

Research Question 1

To address our first research question, we utilized four separate 2 (group) x 2 (session) mixed model ANOVAs. These analyses compared between the two groups and across the two assessment sessions for the following dependent variables: SOT composite score, somatosensory ratio, vestibular ratio, and visual ratio.

Research Question 2

To address our second research question we utilized a single 2 (group) x 2 (session) mixed model ANOVAs. This analysis addressed BESS balance performance (total error score) between the two groups and across the two assessment sessions.

Neurocognitive Performance

Research Question 3

To address our third research question we utilized nine separate 2 (group) x 2 (session) mixed model ANOVAs. These analyses addressed the comparisons between both groups and across sessions for each of the nine outcome measures assessed by CNSVS.

Research Question	Comparison	Data Source	Methods
1. Are there significant differences in balance performance, as measured by the SOT, prior to and following intervention between collegiate recreational athletes completing a four-week dual-task training program and a group of single-task control participants?	Dual-Task Group vs Single-Task Group Balance Performance (SOT)	IV: ▪ Intervention Groups – o Dual-Task o Single-Task ▪ Time – o Pre- o Post- DV: SOT Outcomes ▪ Composite score ▪ Visual Ratio ▪ Vestibular Ratio ▪ Somatosensory Ratio	4 separate 2x2 mixed model subjects ANOVAs
2. Are there significant differences in balance performance, as measured by the BESS, prior to and following intervention between collegiate recreational athletes completing a four-week dual-task training program and a group of single-task control participants?	Dual-Task Group vs Single-Task Group Balance Performance (BESS)	IV: ▪ Intervention Groups – o Dual-Task o Single-Task ▪ Time – Pre- Post- DV: ▪ BESS Total Error Score	A single 2x2 mixed model subjects ANOVAs
3. Are there significant differences in neurocognitive performance, as measured by components of CNS Vital Signs, prior to and following intervention between collegiate recreational athletes completing a four-week dual-task training program and a group of single-task participants?	Dual-Task Group vs Single-Task Neurocognitive Performance (CNSVS)	IV: ▪ Intervention Groups – o Dual-Task o Single-Task ▪ Time – Pre- Post- DV: CNSVS Domain Scores: ▪ Verbal Memory ▪ Visual Memory ▪ Processing Speed ▪ Executive Function ▪ Psychomotor Speed ▪ Reaction Time ▪ Complex Attention ▪ Cognitive Flexibility ▪ Reasoning	9 separate 2x2 Mixed Model Subjects ANOVAs

CHAPTER IV

RESULTS AND DISCUSSION

Concussions are the most frequent form of traumatic brain injury that occur in sport (Guskiewicz, Weaver et al. 2000). Along with the continuing push for concussion prevention there is also a need to turn attention to management, recovery, and current concepts in concussion rehabilitation (Ponsford 2005). Previously, the focus of concussion research has been on prevention, evaluation and acute management. Although much more is to be understood in these areas, further research is necessary to determine how rehabilitation may play a role in recovery following a concussion. The brain may return to normal function more quickly with rehabilitation just as other injuries sports medicine professionals are faced with daily, especially in cases where symptoms following concussion are prolonged in duration. Although the majority of concussion symptoms resolve within a 7 to 10 day window (Guskiewicz, McCrea et al. 2003), some individuals may suffer from Post Concussion Syndrome (PCS) where physical, cognitive, and emotional symptoms may not resolve for several months to years following injury (Bohnen and Jolles 1992; Gouvier, Cubic et al. 1992; Brown, Fann et al. 1994). Research has demonstrated that individuals suffering from dizziness, headache at time of injury, loss of consciousness, sensitivity to noise, anxiety, and post-traumatic amnesia are good predictors of developing PCS (Bazarian, Wong et al. 1999; Savola and Hillbom 2003; Dischinger, Ryb et al. 2009). It is also now understood that athletes who have suffered multiple concussions have a 7.4 to 30% greater chance of experiencing protracted recovery and symptoms consistent with PCS (Guskiewicz, McCrea et al. 2003).

If concussion symptoms include, but are not exclusive to, cognitive and balance impairment then why not address these issues during the rehabilitation process to facilitate recovery? Sports medicine professionals need to address the functional capacity of systems affected by concussion to put injured athletes in the best position for return to play (Johnston, Bloom et al. 2004). Rehabilitation has been used for patients with moderate and severe traumatic brain injury, but has not been considered as a standard of care for mild traumatic brain injury such as sport related concussion with prolonged recovery (Relander, Troupp et al. 1972; Ponsford 2005). The current standard of care for sports related concussion centers around cognitive rest followed by gradual return to activity (Guskiewicz, Bruce et al. 2004).

Sports are not only made up of exertional motor tasks but also a complex paradigm involving cognitive skill combined with body movement. Following concussion the functional capacities of resources available including balance and cognitive function are impaired making dual-task executions more difficult. This “dual-task” rehabilitation methodology would require a person to execute a secondary cognitive task while being physically exerted to address cognitive, balance, and or visual deficits following concussion. A study by Broglio *et al.* (Broglio, Tomporowski et al. 2005) observed that normal healthy young adults showed improvements in postural control when balance and cognitive tasks were performed concurrently in a dual-task paradigm. Therefore, the purpose of this study was to examine dual-task neurocognitive and balance performance in healthy collegiate recreational athletes, prior to and following a dual-task training intervention compared to matched single-task controls. The intent of this research was to determine the utility and feasibility of a dual-task training program to potentially be applied following concussion.

Methods

Participants

Thirty-one, physically active males and females were recruited to participate in the study. One subject was dropped due to lack of intervention compliance. The final study sample consisted of 15 males and 15 females that reported participating in at least 30 minutes of self-reported physical activity at least 3 times per week. Demographic information is located in Table 1. Subjects were stratified by gender and then randomly assigned to either the ***dual-task (DT)*** intervention or ***single-task (ST)*** intervention group (15 DT, 15 ST).

Instrumentation

All subjects reported for pre- and post- intervention testing including two balance performance measures: Sensory Organization Test (SOT), Balance Error Scoring System (BESS); and a neurocognitive test battery: CNS Vital Signs (CNSVS). Subjects were also administered a General Health History Questionnaire to obtain demographic information, physical activity level, and injury/medical history.

Sensory Organization Test

The Sensory Organization Test (SOT) performed on the Smart Balance Master System (NeuroCom International, Clackamas, OR, USA) was utilized to assess balance. Sensory conflicts alter an individual’s visual, somatosensory, and vestibular information by distorting ones surroundings (Guskiewicz 2011). This was accomplished through sway referencing in regards to the participants sway as well as having an individual close their eyes in selected conditions. Sway referencing refers to changes in the orientation of the support surface or visual surroundings to follow the subject's center of gravity (Guskiewicz 2011). The SOT utilizes six conditions each 20 seconds and performed three times in random order. These conditions include (Figure 2): (1) fixed surface with a fixed visual field; (2) fixed surface with eyes closed; (3) fixed surface with sway referenced visual field; (4) sway referenced surface with fixed visual field; (5) sway referenced surface with eyes closed; (6) and a sway referenced surface with sway referenced vision (Figure 1). During sway referenced surface conditions the forceplate moved corresponding to the subjects' postural sway in the anterior-posterior direction. During sway referenced visual conditions the visual surround moved corresponding to the subjects' postural sway in the anterior-posterior direction.

Each of the six conditions was used to compute a weighted average of all the sensory conditions called the composite score. The composite score was computed as the average of the following 14 scores: the condition one average score, the condition two average score, and the three equilibrium scores from each of the trials in conditions three to six. A higher composite score is indicative of less postural sway and greater balance control. The data collected were used to calculate contributions of the visual, somatosensory, and vestibular system to each subjects overall balance. Contributions of these systems were represented by sensory ratios. The visual ratio is the ratio of the condition 4 equilibrium score to the condition 1 equilibrium score. The somatosensory ratio is the ratio of the condition 2 equilibrium score to the condition 1 equilibrium score. The vestibular ratio is the ratio of the condition 5 equilibrium score to the condition 1 equilibrium score. As with the composite score, higher ratio scores indicate improved ability to maintain postural control while other systems are being simultaneously altered. (Register-Mihalik, Mihalik et al. 2008; Sosnoff, Broglio et al. 2011)

Balance Error Scoring System

The BESS was composed of 20 second trials with three conditions including double leg, single leg on the non-dominant foot, and tandem (heel-to-toe) stances with the non-dominant foot behind the dominant foot (Figure 3). The dominant leg was defined as the leg the subject would use to kick a ball. Each condition was completed on a firm surface and repeated on a foam surface utilizing a medium density foam pad (Airex Balance Pad, Alcan Airex, Switzerland) with time kept on a standard stopwatch (Fisher Scientific, Pittsburgh, PA). Athletes were instructed to stand as quietly and as motionless as possible during each trial. Patients were instructed that upon losing their balance they were able to make any necessary adjustments and return to the appropriate testing position as quickly as possible. Each subject's performance was scored by adding one (with a maximum of 10 points) point for each of the following error committed during each condition: lifting ones hands off the iliac crest, opening of the eyes, a step, stumble, or fall, moving the hip into greater than 30 degrees of abduction, lifting the forefoot or heel, and or remaining out of test position for greater than 5 seconds.

Neurocognitive Testing

CNS Vital Signs (CNS Vital Signs, Chapel Hill, NC) was utilized to administer a computerized neurocognitive test battery. CNSVS contained a battery of seven subtests. These CNSVS subtests include: verbal memory test (VBM); visual memory test (VIM); finger tapping test (FTT); symbol-digit coding (SDC); the Stroop test; the shifting attention test (SAT); the continuous performance test (CPT); and the non-verbal reasoning test

(NVRT). From these subtests CNSVS computed raw domain scores, standard, and percentile scores. The raw scores were used as the outcomes measures for all analyses. These domains included: verbal memory; visual memory; processing speed; executive function; psychomotor speed; reaction time; complex attention; cognitive flexibility; and reasoning. A detailed explanation of each clinical domain along with its description and domain score calculations are presented in Table 1.

Procedures

Group Assignment

Once participants agreed to participate following an initial phone screening, an excel random number generator and gender grouping list were used to randomly assign participants to groups based on the gender stratification so that there were an equal number of males and females included in the sample. If a participant withdrew or could not complete the study a replacement of the same gender was recruited (n=1). As mentioned earlier one subject was dropped due to lack of compliance with observed intervention sessions.

Assessment

All subjects reported for pre- and post- intervention testing including SOT, BESS, and CNSVS tests. Subjects were also administered a General Health History Questionnaire to obtain demographic information, physical activity level, and injury/medical history. BESS trials were captured using video analysis and independently scored, blinding for BESS Total Error Score throughout the intervention. The SOT conditions were always completed in a randomized order, no matter the task. SOT screen scores were covered during test administration to assure test administrator blinding. Subjects repeated the same testing order during their post testing.

Intervention

All 30 subjects were required to report to the Gfeller Center twice a week to complete their specified intervention training program and completed an additional training session each week on their own at home. Subjects completed the single-task or dual-task progression over 4 weeks for a total of 12 training sessions (8 in person and 4 at home). Average days between pre- to post- test was 34.03±4.22 days. Subjects were required to complete at least one observed session per week and twelve sessions overall to be included in study analysis. All observed sessions were mandatory to be included in study analysis. Subjects were allowed a fifth week of intervention progression to account for missed observed sessions due to academic breaks and scheduling issues (n=16; average days pre-test to post-test: 34.03±4.22 days). Subjects were asked to log their home training sessions and outside activities completed during the intervention period. All subjects regardless of group and task proficiency completed a mass progression over the course of the four weeks intervention period. A detailed explanation of the single-task and dual-task intervention and difficulty progression is provided in Figure 1 and Figure 2.

Intervention Progression

All subjects in the single-task intervention group (ST) completed activities broken down into balance and cognitive exercises of varying degrees of difficulty. These exercises were completed separately. Each subject began at the entry level of both balance and cognitive exercises and progressed to the advanced level based on the mass progression. The single-task progression was composed of a four-week progression of altering balance and cognitive training. Week one incorporated cognitive and balance tasks composed of difficulty levels 1-2. Week two incorporated entry level cognitive and balance tasks composed of difficulty level 3 and advanced level cognitive and balance tasks composed of difficulty level 4. Week three incorporated advanced level cognitive and balance tasks composed of difficulty level 5. The single-task intervention concluded during week 4 which incorporated advanced level cognitive and balance tasks composed of difficulty level 6. A detailed explanation of the single-task intervention progression is provided in Figure 1.

All subjects in the dual-task intervention group (DT) completed activities from all four progressive dual-task levels broken down into the Entry Level, Moderate Level, Advanced Level, and the Activity Specific Level. The balance and cognitive activities were always complete concurrently to divide attention. The progression began with one week of Entry Level tasks. The entry level is composed of difficulty levels 1-3 and focused on concurrently completing basic balance exercises level 1-3 and cognitive exercises level 1-3. Following week one, subjects were progressed to the moderate level. The moderate level was composed of difficulty levels 4-6 utilizing balance levels 4-6 and cognitive exercises level 1-4. The moderate level also incorporated Wii Fit (Nintendo, Redmond, WA, USA) activities at each level including soccer heading, and running with memory tasks. Following the second week the subject was progressed to the advanced level. This tier was composed of difficulty levels 7-9 utilizing balance levels 1-6 and cognitive exercises from level 4-6 along with ball throwing activities. Wii Fit including obstacle courses and table tilt games were again used for each difficulty level. The final week consisted of the activity specific tier and was composed of difficulty levels 10-12. These levels incorporated balance activities combined with ball or object response, movement decisions, and obstacle avoidance. A detailed explanation of the dual-task intervention progression is provided in Figure 2.

Progression for both the single-task and dual-task intervention groups utilized a mass progression. Following each week each subject completed an intervention progression check point. This checkpoint included a BESS total error score, cognitive test score, subjective task average score, and objective balance and cognitive task progression achievement score. The subjective task score incorporated asking each subject to answer the subjective difficulty scale question based on the difficulty of each task. Each question was scaled to the Borg CR10 Rating of Perceived Exertion Scale. Each subject was asked to identify the number that most closely corresponded to the difficulty of tasks completed at each level. The subjective scores from each task were averaged across the week and recorded.

Data Analysis

Mixed model analyses of variance (ANOVA) were used to analyze all outcome measures. All data analyses were conducted using SPSS 19.0 (Chicago, IL). An a priori alpha level set at 0.05 was utilized for each dependent variable. This alpha level was adjusted for the four SOT variables, as the composite score is not independent of the three ratio scores. Alpha level for SOT Composite score was set at 0.0167 and for SOT ratio scores was set at 0.0250.

Results

Research Questions 1 & 2: Effect of Intervention Assignment on Balance Performance

All subjects achieved a higher SOT Vestibular ratio pre- (0.76 ± 0.11) to post- (0.82 ± 0.11) test session ($F_{1,28} = 6.550$, p= 0.016) and exhibited fewer BESS total error score pre- (8.50 ± 2.95) to post- (4.46 ± 2.50) test session ($F_{1,26} = 42.342$, p < .000). No significant session by group interaction effects for SOT Composite Score ($F_{1,28} = 0.285$, p= 0.598), SOT Visual ratio ($F_{1,28} = 0.004$, p= 0.951), SOT Vestibular ratio ($F_{1,28} = 1.471$, p= 0.235), or SOT Somatosensory ratio ($F_{1,28} = 0.019$, p= 0.891), and BESS total error score ($F_{1\ 26} = 1.507$, p= 0.231) were observed. No significant main effects of pre- to post- test session for SOT Composite Score ($F_{1,28} = 2.838$, p= 0.103), SOT Visual ratio ($F_{1,28} = 3.945$, p= 0.057), or SOT Somatosensory ratio ($F_{1,28} = 2.749$, p= 0.108) were observed. No significant main effects of intervention group for SOT Composite Score ($F_{1,28} = 0.285$, p= 0.598), SOT Visual ratio ($F_{1,28} = 0.975$, p= 0.332), SOT Vestibular ratio ($F_{1,28} = 1.037$, p= 0.317), SOT Somatosensory ratio ($F_{1,28} = 0.127$, p= 0.724), or BESS total error score ($F_{1,26} = 0.086$, p= 0.771) were observed. Descriptive statistics for balance measures are located in Table 3.

Research Question 3: Effect of Intervention Assignment on Neurocognitive Performance

The single task group showed significantly greater improvement following their four-week training period for the domain of complex attention pre- (7.36 ± 3.18) to post- test (4.57 ± 2.17) than the dual-task group from pre- (6.86 ± 2.93) to post- (6.17 ± 2.73) test ($F_{1,26} = 5.478$, p= 0.027). Significant main effects were observed for domains of executive function pre- (50.67 ± 0.7.52) to post- (53.00 ± 6.65) test session ($F_{1,28} = 4.968$, p= 0.034), complex attention pre- (7.11 ± 3.01) to post- (5.64 ± 2.66) test session ($F_{1,26} = 6.726$, p=

0.015), and cognitive flexibility pre- (49.27 ± 0.7.51) to post- (52.00 ± 6.64) test session ($F_{1,28}$ = 6.707, p= 0.015). No significant session by group interaction effects for domains including verbal memory ($F_{1,28}$ = 0.394, p= 0.535), visual memory ($F_{1,28}$ = 0.006, p= 0.937), processing speed ($F_{1,28}$ = 0.001, p= 0.978), executive function ($F_{1,28}$ = 1.038, p= 0.371), psychomotor speed ($F_{1,28}$ = 0.280, p= 0.601), reaction time ($F_{1,21}$ = 0.033, p= 0.858), cognitive flexibility ($F_{1,28}$ = 1.440, p= 0.240), and reasoning ($F_{1,27}$ = 1.001, p= 0.326) were observed. No significant main effects of pre- to post- test session for domains including verbal memory ($F_{1,28}$ = 0.804, p= 0.377), visual memory ($F_{1,28}$ = 0.025, p= 0.875), processing speed ($F_{1,28}$ = 2.241, p= 0.146), psychomotor speed ($F_{1,28}$ = 3.233, p= 0.083), reaction time ($F_{1,21}$ = 0.102, p= 0.753), and reasoning ($F_{1,27}$ = 1.001, p= 0.326) were observed. No significant main effects of intervention group for domains including verbal memory ($F_{1,28}$ = 1.046, p= 0.315), visual memory ($F_{1,28}$ = 0.008, p= 0.929), processing speed ($F_{1,28}$ = 3.003, p= 0.094), executive function ($F_{1,28}$ = 0.250, p= 0.621), psychomotor speed ($F_{1,28}$ = 2.159, p= 0.153), reaction time ($F_{1,21}$ < .000, p= 0.998), cognitive flexibility ($F_{1,28}$ = 0.225, p= 0.639), complex attention ($F_{1,26}$ = 0.861, p= 0.362), or reasoning ($F_{1,27}$ = 0.004, p= 0.952) were observed. Descriptive statistics for all neurocognitive domains are located in Table 4. Also reference to relative effect size for all balance and neurocognitive measures can be found in Table 5.

Subjective Task Difficulty Descriptives

Variations within subjective task difficulty, scaled to the Borg CR10 Rating of Perceived Exertion Scale, were observed throughout the intervention. Subjective task weekly difficulty descriptive means and standard deviations can be found in Table 6.

Discussion

This study aimed to examine dual-task neurocognitive and balance performance in healthy collegiate recreational athletes, prior to and following a dual-task training intervention compared to matched single-task controls. The primary findings of this study indicate that regardless of training type, participants significantly improved following both the dual- and single-task intervention on measures of executive function, complex attention, cognitive flexibility, and some measures of balance performance. Single-task controls had greater neurocognitive improvements in the domain of complex attention from pre- to post-test than the dual-task subjects. These findings suggest that regardless of group, healthy subjects did improve in measures of cognition and balance. This may implicate the use of cognitive and balance rehabilitation paradigms for those suffering from a mild traumatic brain injury and protracted recovery; particularly in sport, where input from these systems are paramount. This study was also found to be very feasible and may provide important framework for future application within an injured population as it mimicked weekly participation in rehabilitation under the care of sports medicine professionals.

Our findings refute our hypothesis regarding balance performance. Athletes that completed the dual-task training intervention did not exhibit significantly better balance performance, as measured by the SOT compared to those in the single-task group. Although there was no difference between groups subjects as a whole achieved better scores from pre- to post- test for SOT vestibular and somatosensory ratios. Improvements in SOT vestibular ratios were similar to previous findings with individuals completing extensive balance training (Tsang and Hui-Chan 2004; Tsang, Wong et al. 2004). Previous literature has also shown that vestibular deficits and symptoms of dizziness may be associated with a greater risk of protracted recovery (Chamelian and Feinstein 2004; Lau, Kontos et al. 2011). If these vestibular system improvements were seen regardless of group in our healthy sample then the intervention may prove beneficial to injured athletes suffering protracted recovery and vestibular complications due to mild traumatic brain injury. Training techniques utilized may gradually stress these systems affected by concussion with potential benefits of decreased recovery time (Alsalaheen, Mucha et al. 2010). Although improvements in balance performance as measured by the SOT were expected, subjects who completed the dual-task training were hypothesized to have greater gains in postural stability due to training in an environment where performance was related to resource availability and task difficulty as proposed by Wicken (Damos 1991).

As discussed previously in order to maintain equilibrium the central nervous system must integrate afferent information from the vestibular, somatosensory, and visual systems to effectively execute a musculoskeletal task (Guskiewicz 2011). The challenge of completing concurrent balance and cognitive tasks were presumed to place greater stress on these sensory systems, facilitating greater performance gains compared to the single-task intervention exercises. Although some studies suggest that healthy individuals under a dual-task conditions do not exhibit improved gait or stability some studies do suggest improvements in postural sway (Shumway-Cook and Woollacott 2000; Hunter and Hoffman 2001; Swan, Otani et al. 2004; Broglio, Tomporowski et al. 2005; Siu, Catena et al. 2008). Broglio et al. utilized the SOT to evaluate the acute effect of a concurrent cognitive task on balance performance. It was found that this dual-task scenario resulted in greater postural control as measured by the SOT (Broglio, Tomporowski et al. 2005). The dual-task scenario performed utilizing the SOT required divided attention in which sensory input to maintain equilibrium was challenged. Broglio *et al.* (Broglio, Tomporowski et al. 2005) hypothesized that this improvement in balance performance may have been attributed to increased vestibular and somatosensory input when the visual system was compromised. Although this study showed improved postural control utilizing a dual-task paradigm it does not mimic the intervention utilized in our study. As the methodology utilized by Broglio and colleagues may have served as a measurement of divided attention, our study aimed to continually train athletes in this divided attention, or dual-task environment. The imposed stressors of the dual-task environment were thought to provide a greater challenge to the afferent information required for maintaining balance then the single-task environment thus resulting in greater improvement in balance measures. The issue with comparing previous dual-task research to our study is that most balance measures, for instance SOT measures, are taken while individuals are concurrently completing a secondary task during an assessment. This does not mimic the nature of our study in which individuals were trained in a dual-task setting yet were tested using a single-task assessment, balance and cognitive tasks completed separately.

Similarly, athletes that completed the dual-task training intervention did not exhibit significantly better balance performance as measured by the BESS. Both groups committed fewer errors during the BESS total error scores following the interventions, yet there was no significant group interaction effect between groups. Throughout the intervention athletes were asked to perform various balance tasks on various unstable surfaces including the use of foam pad (Airex Balance Pad, Alcan Airex, Switzerland) used to administer the BESS test. The ability for subjects regardless of group to train regularly on the foam pad not only challenged each individuals balance but may have also contributed a practice effect. Practice effects have been previously observed for serial testing using the BESS resulting in decreases in total error score when compared to baseline measures in healthy individuals which may have attributed to the significant main effect seen from pre- to post- test (Valovich, Perrin et al. 2003; Broglio, Zhu et al. 2009). Balance improvement following training has been shown extensively in previous literature citing improved proprioception and increase in muscular strength (Hoffman and Payne 1995; Heitkamp, Horstmann et al. 2001; Hale, Hertel et al. 2007; McLeod, Armstrong et al. 2009), however we did suspect that individuals completing the dual-task progression would show greater improvements. Although the dual-task group completed concurrent balance and cognitive tasks, this group did complete the same balance tasks as the single-task group. Week 1 and 2 cognitive exercises may not have been difficult enough to compromise afferent input further stressing balance and thus providing greater opportunity for improvement. Although cognitive exercises did increase in difficulty for weeks 3 and 4 causing increased difficulty in maintaining balance, athletes may not have been exposed to these exercises long enough to elicit any group interaction effect when compared to the single-task group. In addition to the observed training sessions all subjects regardless of group were administered the BESS test during weekly checkpoints which may have further contributed to improvements in balance seen across both groups. Although balance improves with balance training (Valovich, Perrin et al. 2003) BESS scores have been shown to level out after three administrations of the test (Broglio, Zhu et al. 2009). Although the continued decrease in total error score may indicate balance improvements due to intervention sessions it cannot be ruled out that improvements were due to repeated exposure, six administrations in total, to the BESS test. With this global improvement balance training should be an integral part of the rehabilitation process to treat prolonged balance deficits seen following concussion (Guskiewicz, Riemann et al. 1997; Riemann and Guskiewicz 2000;

Guskiewicz, Ross et al. 2001; McCrea, Guskiewicz et al. 2003; Register-Mihalik, Mihalik et al. 2008).

Athletes that completed the dual-task training program were also not found to have significantly improved on neurocognitive performance compared to the single-task group. We found that the single-task group significantly improved from pre- to post- test in the domain of complex attention as measured by CNSVS when compared to the dual-task group. Although this was not hypothesized it is reasonable in that complex attention as measured by CNSVS measures the ability to track and respond to information over extended periods of time and to perform cognitive tasks as quickly and accurately as possible. Single-task subjects were asked to complete cognitive exercises separate from balance exercises requiring sustained attention, for example completing a 10 word immediate and delayed recall, which may have resulted in greater gains in complex attention. Subjects, regardless of group, improved in neurocognitive domains of executive function and cognitive flexibility as well. Although improvements were seen for the domain of complex attention regardless of group it is possible that the significant findings were driven by overall improvements within the single-task group alone. Previous research has shown that individuals suffering from a mild traumatic brain injury suffer from cognitive deficits in the domains of complex attention, executive function, and cognitive flexibility (Brooks, Fos et al. 1999; Millis, Rosenthal et al. 2001; Mathias, Bigler et al. 2004; Vanderploeg, Curtiss et al. 2005).

Although significant findings were observed it cannot be ignored that many findings were also deemed not significant. No significant findings were seen with respect to balance components including SOT composite score, SOT visual ratio, along with neurocognitive domains including visual memory, verbal memory, processing speed, psychomotor speed, reaction time, and reasoning. Since subjects were excluded from the study if they had any type of visual disorder not correctable by glasses or contact lenses and all subjects were healthy and not suffering any visual impairment which have been documented with individuals suffering from mild traumatic brain injury (Sabates, Gonce et al. 1991; Ponsford, Willmott et al. 2000; Ciuffreda, Rutner et al. 2008). Due to the extent of the visual innervation and the complexity of the visual pathways within the brain it is highly susceptible to impact and diffuse axonal injury (Ciuffreda, Kapoor et al. 2007). The visual, somatosensory, and vestibular systems work together and are heavily dependent on the state, input, and information available from each system utilized (Redfern, Yardley et al. 2001). It can be hypothesized without visual impairment due to injury subjects may have increased their reliance on the vestibular system because the visual system was operating at its maximum capacity to maintain equilibrium. This system dependence may explain why improvement was seen for SOT vestibular ratio but not the SOT visual ratio. Subjects may have had greater room for improvement of the vestibular system as the visual and somatosensory systems are often taxed first in a healthy population. With regards to neurocognitive domains it is possible that the cognitive exercises each subject completed during observed and home training sessions were not broad enough to foster improvement in multiple neurocognitive domains. Greater variance in exercise type and purpose may need to be further investigated to target specific cognitive domains and to determine the effects on multiple domains following an intervention. With reference to Table 5 we can also see that effect size was extremely low for the dependent variables measured. This can also contribute to the multitude of non-significant findings indicating that drastic increases in our total number of subjects would have been needed for any statistical difference to be observed.

If completion of the intervention, regardless of group, resulted in improvements within these cognitive domains then the developed single- or dual-task training methodology may prove beneficial to those suffering from protracted recover following concussion. Although our study is unique to healthy subjects completing a training intervention, previous research with individuals suffering a mild traumatic brain injury have also shown improvements in complex attention with administered neuropsychological rehabilitation strategies including paper-and-pencil test batteries and “real-life” activities (Cicerone, Smith et al. 1996). Future research should continue to bridge the gap utilizing cognitive exercises with increasing level of difficulty to help address the deficits seen following concussion regardless of if they are performed with concurrent balance tasks. This combined approach of single-task and dual-task exercises may prove more beneficial for individuals suffering from deficits in these areas following concussion.

Overall subjects were extremely compliant with reporting for observed sessions as well as self-recording their at home sessions. All of the observed sessions (8 in total) were completed by each subject. This study was very feasible for the subjects as all training sessions were based around the subject’s schedule. The overall compliance and feasibility suggests this model can easily be applied to an injured population and is clinically applicable for sports medicine professionals as it mimicked participation in weekly rehabilitation sessions that athletes typically complete for various musculoskeletal injuries. The feasibility of this study may serve as a guideline or pilot study for future research within and injured population and individuals suffering protracted recovery following concussion.

Limitations

Although efforts were made to increase compliance and motivation, the current study is not without limitation. Although subjects did receive a small compensation for completion of the study some subjects were notably mentally taxed and pre-occupied with other academic or life stressors and may have had a decrease in motivation during pre- post- test sessions and or intervention training sessions effecting scores (Hunt, Ferrara et al. 2007). A second limitation of this study was compliance of individuals completing the weekly at home sessions. Along with being required to report to the Gfeller research lab twice a week to complete observed training sessions, individuals were also required to complete one at home session each week to be completed with the help of a friend. Some individuals did not return their home session sheets (n= 6) as requested so completion of these sessions is unclear. Compliance with completing all of the exercises along with completing them correctly is also unknown although the at home exercises were directly explained to each athlete at the conclusion of their preceding observed session. Training frequency was also a limitation within this study. Although all of the subjects completed all of the observed training sessions the times at which they completed them were completely structured based on subject availability. At times, this resulted in subjects performing two training sessions early in the week with the athletes not returning for their next observed training session for several days. The frequency and duration of training in the dual-task group may actually have not been enough to influence a significant change. In retrospect subjects were most likely completing a maximum of one hour of training each week which is four hours total throughout the entire intervention. This training frequency and duration may not have been enough to challenge balance and neurocognitive systems to elicit optimum performance adaptations consistent with the overload principle (Clark, Lucett et al. 2012). Previous training literature has shown that the human body will only respond if continually challenged to meet higher physiological demands and it can be hypothesized that exercises completed were not challenging enough to create these demands within a healthy population (Morrissey, Harman et al. 1995; Hass, Feigenbaum et al. 2001; Kraemer and Ratamess 2004). Although this may have not been enough time to evoke more substantial significant neurocognitive and balance interaction affects in the dual-task group this may more closely resemble how rehabilitation would be structured with a sports medicine clinician. Also with the use of a mass progression individuals may not have been adequately challenged to stimulate improvement during the first two weeks of training. This is especially evident with reference to the weekly subjective difficulty ratings provided by each subject. Although our outcome measures did not include analysis of subjective task weekly difficulty questions this is important to mention. Within the weeks regarded by the subjects as the most difficult they were only rating completed tasks as moderately hard. This demonstrates that perhaps subjects were not challenged enough to see significant improvements from pre- to post- test. With specific reference to the dual-task group we also see that week four was actually rated as easier than the previous week even though exercises difficulty was increased. Future research should investigate multiple starting points based upon baseline measures as well as subjective and objective task difficulty measures to ensure exercises remain challenging to stimulate balance and neurocognitive gains. This may also be a reason why we did not see any significant group interaction effects with the dual-task group performing better than the single-task group. Future research should also investigate intervention paradigms in an injured population as healthy individuals are already functioning maximally and may have contributed to the lack of significant effects observed within our study. As discussed previously, balance improvements, specifically decrease in BESS total error score, may have been attributed to a training effect and serial evaluation utilizing the BESS test during weekly checkpoints.

Conclusion

Concussion is a serious injury in athletics with both short term and long term complications. Although individuals who have suffered a mild traumatic brain injury usually recover within 7 to 10 days, some individuals may suffer from prolonged concussion recovery and postconcussion syndrome. Deficits following concussion include balance and cognitive impairments which may benefit from rehabilitation targeting these systems. Current recommendations for concussion rehabilitation are based primarily on the premises of cognitive rest followed by an exertional return to play progression without fully addressing individuals suffering protracted recovery or deficits which may linger following return to play.

Our study was designed to examine the feasibility and potential use of a dual-task training intervention to address these balance and cognitive deficits seen following individuals suffering prolonged recovery form concussion. Our findings suggest that combining a cognitive task with a balance task as performed by the dual-task group does not have any additional benefits to performing these tasks independently as with the single-task group. Both groups regardless of intervention improved on balance methods as measured by the SOT and the BESS. Subjects within the single-task group were found to improve within the domain of complex attention as measured by CNSVS. Although dual-task subjects did not improve in respect to cognitive domains there are potential benefits to a single-task progression which may be beneficial to an injured population. We believe balance improvements along with neurocognitive improvements in the domain of complex attention were two clinically significant findings for sports medicine professionals working with athletes suffering protracted recovery following concussion. Our intervention progression may prove beneficial to these individuals who experience neurocognitive and balance deficits outside of the normal recovery window. In the sports medicine setting musculoskeletal injury rehabilitation and goals are often compartmentalized before progression towards a combined approach. For instance range of motion deficits are often addressed before strength gains. This combined approach beginning with a single-task intervention progression followed by dual-task exercises may provide potential benefits for concussed individuals. Future research should examine a combined approach of single-task and dual-task exercises within an intervention progression for an injured population.

TABLES

Table 1. Neurocognitive Domain Descriptions, Score Calculations, and Validity Indicators

Clinical Domain	Domain Description	Doman Score Calculation	Validity Indicators
Verbal Memory	Measures how well subjects can recognize, remember, and retrieve words.	VBM Correct Hits Immediate + VBM Correct Passes Immediate + VBM Correct Hits Delay + VBM Correct Passes Delay	Raw score greater than 30.
Visual Memory	Measures how well subjects can recognize, remember, and retrieve shapes.	VIM Correct Hits Immediate + VIM Correct Passes Immediate + VIM Correct Hits Delay + VIM Correct Passes Delay	Raw score greater than 30.
Processing Speed	Measures how well a subject recognizes and processes information.	SDC Correct Responses - SDC Errors	More than 20 correct responses during the symbol digit coding test.
Executive Function	Measures how well a subject recognizes rules, categories, and manages their ability to manage rapid decision making.	SAT Correct Responses - SAT Errors	Shifting attention test correct responses was required to be greater than shifting attention test errors,
Psychomotor Speed	Measures how well a subject perceives, attends, responds to visual- perceptual information, and performs motor speed and fine motor coordination.	FTT Right Taps Average + FTT Left Taps Average + SDC Correct Responses	Total taps during the finger tapping test must have been greater than 40 or one must have achieved greater than 20 correct responses during the symbol digit coding test.
Reaction Time	Measures how quickly each subject can react to simple and increasingly complex directions.	(ST Complex Reaction Time Correct + Stroop Reaction Time Correct) / 2	Simple reaction time must have been less than complex reaction time and less than stroop reaction time.
Complex Attention	Measures a subject's ability to track and respond to information over an extended period of time.	Stroop Commission Errors + SAT Errors + CPT Commission Errors + CPT Omission Errors	Correct responses must have been greater than incorrect responses for the stroop test, continuous performance test, and shifting attention test.
Cognitive Flexibility	Measures how well a subject is able to rapidly changing and increasingly complex directions.	SAT Correct Responses - SAT Errors - Stroop Commission Errors	Correct responses must have been greater than incorrect responses for the stroop test and shifting attention test.
Reasoning	Measures how well a subject is able to recognize, reason, and respond to non-verbal visual abstract stimuli.	NVRT Correct Responses – NVRT Commission Errors	A non-verbal reasoning test score must have been greater than four and correct responses must have been greater than incorrect responses.

VBM – Verbal Memory Test; VIM – Visual Memory Test; SDC – Symbol Digit Coding Test; SAT – Shifting Attention Test; FTT – Finger Tapping Test; ST – Stroop Test; CPT – Continuous Performance Test; NVR – Non-verbal Reasoning Test

Table 2. Demographic Information Means and Standard Deviations (SD)

	ST (*n=15*)	**DT (*n=15*)**	**Total Sample (*n=30*)**
Age	20.87 (2.23)	19.73 (1.33)	20.30 (1.90)
Height (m)	1.68 (.11)	1.62 (.18)	1.65 (.15)
Mass (kg)	70.65 (14.71)	65.86 (12.81)	68.25 (13.77)
Days Between Pre- Post-Test	33.27 (5.02)	34.80 (3.23)	34.03 (4.22)

Table 3. Descriptive and Statistical Results for Balance Measures

Balance Variable	Pre-Test Mean (SD)	Post-Test Mean (SD)	Collapsed Group Means Mean (SD)
SOT Composite Score			
Single-Task	78.87 (4.81)	81.68 (5.77)	80.27 (9.23)
Dual-Task	77.96 (8.89)	79.42 (9.12)	78.69 (9.23)
Entire Sample	78.41 (7.04)	80.55 (7.58)	-----
SOT Vestibular Ratio			
Single-Task	.77 (.10)	.85 (.07)	.810 (.13)
Dual-Task	.76 (.13)	.79 (.14)	.775 (.13)
Entire Sample	.76 (.11)	.82 (.11)†	-----
SOT Somatosensory Ratio			
Single-Task	.98 (.08)	1.00 (.05)	.991 (.07)
Dual-Task	.97 (.05)	1.00 (.07)	.985 (.07)
Entire Sample	.98 (.06)	1.00 (.06)	-----
SOT Visual Ratio			
Single-Task	.90(.11)	.92 (.07)	.911 (.10)
Dual-Task	.87 (.08)	.90 (.07)	.884 (.10)
Entire Sample	.88 (.09)	.91 (.07)	-----
BESS Total Error Score*			
Single-Task	8.23 (1.79)	5.00 (2.86)	6.62 (3.28)
Dual-Task	8.73 (3.73)	4.00 (2.12)	6.37 (3.05)
Entire Sample	8.50 (2.95)	4.46 (2.50)†	-----

*Total n = 28 (ST =13, DT = 15) due to BESS total error score recording error.
† Significant main effect observed.

Table 4. Descriptive and Statistical Results for Neurocognitive Domains

Domain Raw Scores	**Pre-Test Mean (SD)**	**Post-Test Mean (SD)**	**Collapsed Group Means Mean (SD)**
Verbal Memory			
Single-Task	54.80 (3.51)	54.60 (3.48)	54.70 (6.31)
Dual-Task	53.60 (6.26)	52.47 (5.71)	53.03 (6.31)
Entire Sample	54.20 (5.03)	53.53 (4.77)	-----
Visual Memory			
Single-Task	50.53 (3.87)	50.73 (4.20)	50.63 (5.58)
Dual-Task	50.73 (5.95)	50.80 (4.48)	50.77 (5.58)
Entire Sample	50.63 (4.93)	50.77 (4.26)	-----
Processing Speed			
Single-Task	73.60 (13.70)	77.20 (10.33)	75.40 (13.41)
Dual-Task	67.67 (11.57)	71.13 (9.94)	69.40 (13.41)
Entire Sample	70.63 (12.82)	74.17 (10.43)	-----
Executive Function			
Single-Task	50.73 (7.29)	54.13 (6.20)	52.43 (9.30)
Dual-Task	50.06 (7.99)	51.87 (7.10)	51.23 (9.30)
Entire Sample	50.67 (7.52)	53.00 (6.65)†	-----
Psychomotor Speed			
Single-Task	200.27 (20.89)	205.40 (16.63)	202.83 (26.44)
Dual-Task	191.40 (20.26)	194.20 (20.53)	192.80 (26.44)
Entire Sample	195.83 (20.715)	199.80 (19.22)	-----
Reaction Time*			
Single-Task	602.55 (55.61)	608.91 (78.12)	605.73 (115.38)
Dual-Task	604.75 (102.94)	606.50 (88.73)	605.625 (110.46)
Entire Sample	603.70 (81.89)	607.65 (81.93)	-----
Complex Attention*			
Single-Task	7.36 (3.18)	4.57 (2.17)‡	5.96 (3.31)
Dual-Task	6.86 (2.93)	6.71 (2.73)	6.79 (3.31)
Entire Sample	7.11 (3.01)	5.64 (2.66)†	-----
Cognitive Flexibility			
Single-Task	49.20 (7.35)	53.20 (6.67)	51.20 (9.26)
Dual-Task	49.33 (7.92)	50.80 (6.63)	50.07 (9.26)
Entire Sample	49.27 (7.51)	52.00 (6.64)†	-----

*Invalid data resulted in decreased n for domains of Reaction time (total n = 23, ST = 11, DT = 12) and Complex Attention (total n = 28, ST = 14, DT = 14).

† Significant main effect observed.

‡ Significant session by group interaction.

Table 5. Balance and Neurocognitive Effect Sizes (Partial Eta Squared)

Variable	**Interaction**	**Group Comparisons**	**Session Comparisons**
Verbal Memory	.014	.036	.028
Visual Memory	.000	.000	.001
Processing Speed	.000	.097	.074
Executive Functioning	.036	.009	.151
Psychomotor Speed	.010	.072	.104
Reaction Time	.002	.000	.005
Complex Attention	.174	.032	.206
Cognitive Flexibility	.049	.008	.193
Reasoning	.036	.000	.022
BESS Total Error Score	.055	.003	.620
SOT Composite Score	.010	.015	.092
SOT Vestibular Ratio	.050	.036	.190
SOT Somatosensory Ratio	.001	.005	.089
SOT Visual Ratio	.000	.034	.123

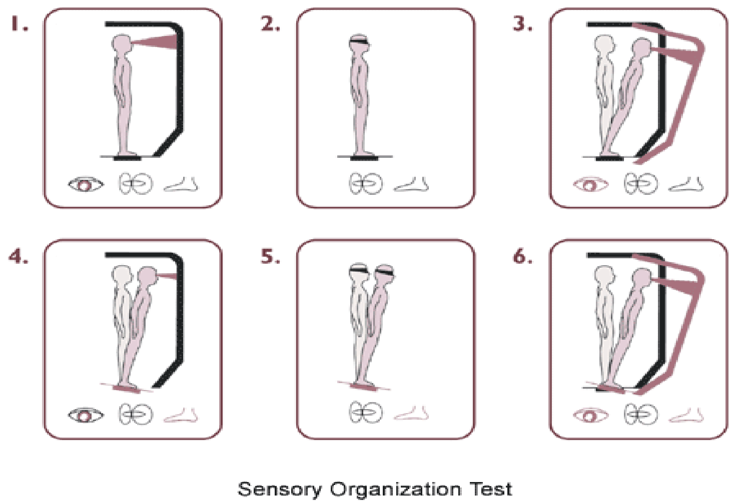
Table 6. Subjective Task Weekly Difficulty Descriptive Means and Standard Deviations (SD)

Week	*ST (n=15)*	*DT (n=15)*
1	2.05 (.90)	2.47 (.77)
2	3.58 (.88)	3.07 (.88)
3	4.46 (1.71)	4.40 (1.36)
4	4.89 (1.68)	3.32 (1.32)

FIGURES

Figure 1: Sensory Organization Test Booth

Figure 2: SOT conditions



SOT conditions (1) fixed surface with a fixed visual field; (2) fixed surface with eyes closed; (3) fixed surface with sway referenced visual field; (4) sway referenced surface with fixed visual field; (5) sway referenced surface with eyes closed; (6) and a sway referenced surface with sway referenced vision.

Figure 3: Balance Error Scoring System

FIRM / GROUND TESTING POSITIONS

Double leg stance: Standing on a firm surface with feet side by side (touching), hands on the hips and eyes closed

Single leg stance: Standing on a firm surface on the non-dominant foot (defined below), the hip is flexed to approximately 30° and knee flexed to approximately 45°. Hands are on the hips and eyes closed.

> *Non-Dominant Leg*: The non-dominant leg is defined as the opposite leg of the preferred kicking leg

Tandem Stance: Standing heel to toe on a firm surface with the non-dominate foot (defined above) in the back. Heel of the dominant foot should be touching the toe of the non-dominant foot. Hands are on the hips and their eyes are closed.

FOAM TESTING POSITIONS

Double leg stance: Standing on a foam surface with feet side by side (touching), with hands on the hips and eyes closed

Single leg stance: Standing on a foam surface on the non-dominant foot (defined below), with hip flexed to approximately 30° and knee flexed to approximately 45°. Hands are on the hips and eyes closed.

> *Non-Dominant Leg*: The non-dominant leg is defined as the leg opposite of the preferred kicking leg

Tandem Stance: Standing heel to toe on a foam surface with the non-dominant foot (defined above) in the back. Heel of the dominant foot should be touching the toe of the non-dominant foot. Hands are on the hips and their eyes are closed.

WARNING: Trained personnel should always be present when administering the BESS protocol. Improper use of the foam could result in injury to the test subject.

Score Card

Balance Error Scoring System (BESS)
(Guskiewicz)

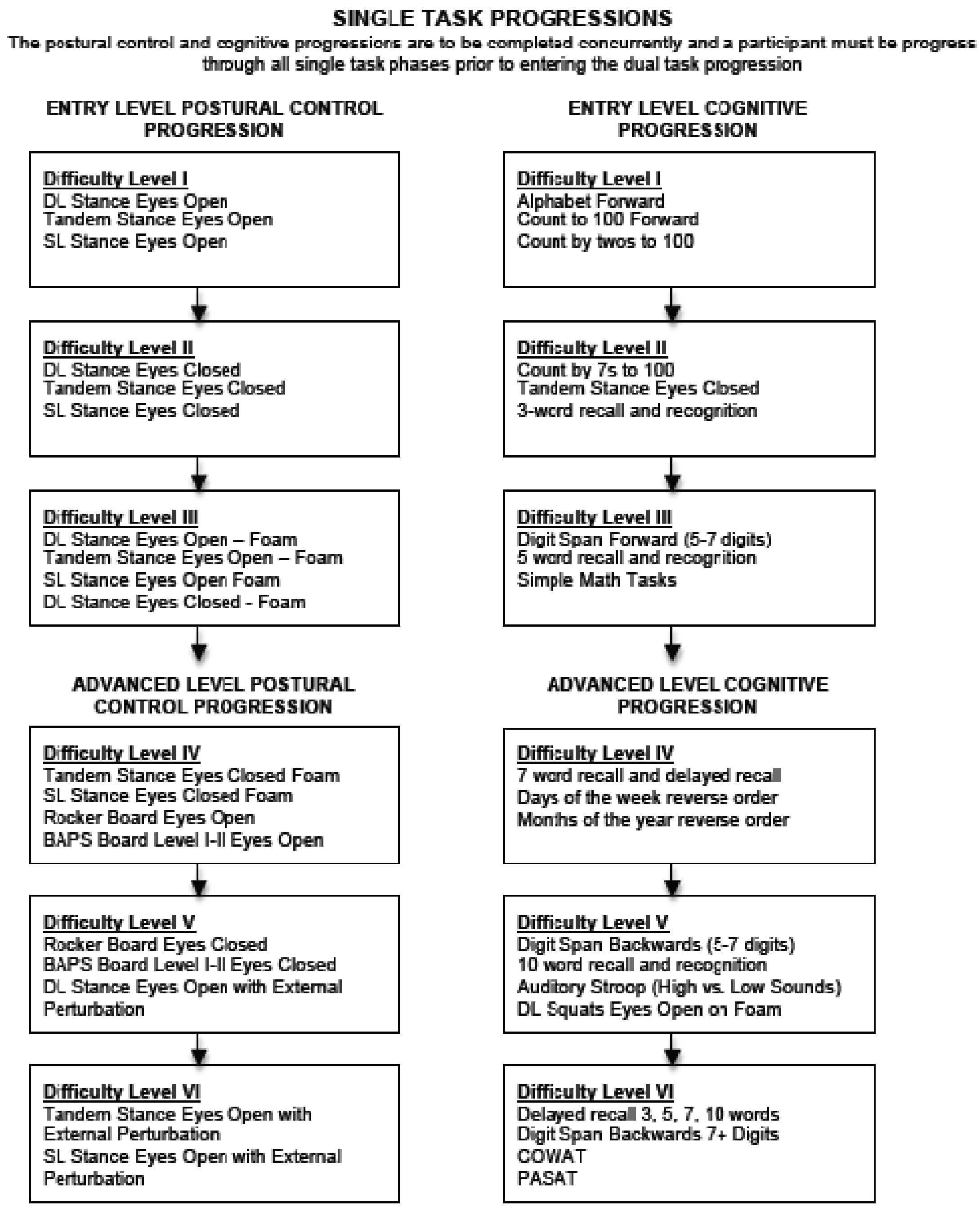
Balance Error Scoring System – Types of Errors
1. Hands lifted off iliac crest 2. Opening eyes 3. Step, stumble, or fall 4. Moving hip into > 30 degrees abduction 5. Lifting forefoot or heel 6. Remaining out of test position >5 sec
The BESS is calculated by adding one error point for each error during the 6 20-second tests.

SCORE CARD: **(# errors)**	FIRM Surface	FOAM Surface
Double Leg Stance (feet together)		
Single Leg Stance (non-dominant foot)		
Tandem Stance (non-dom foot in back)		
Total Scores:		
BESS TOTAL:		

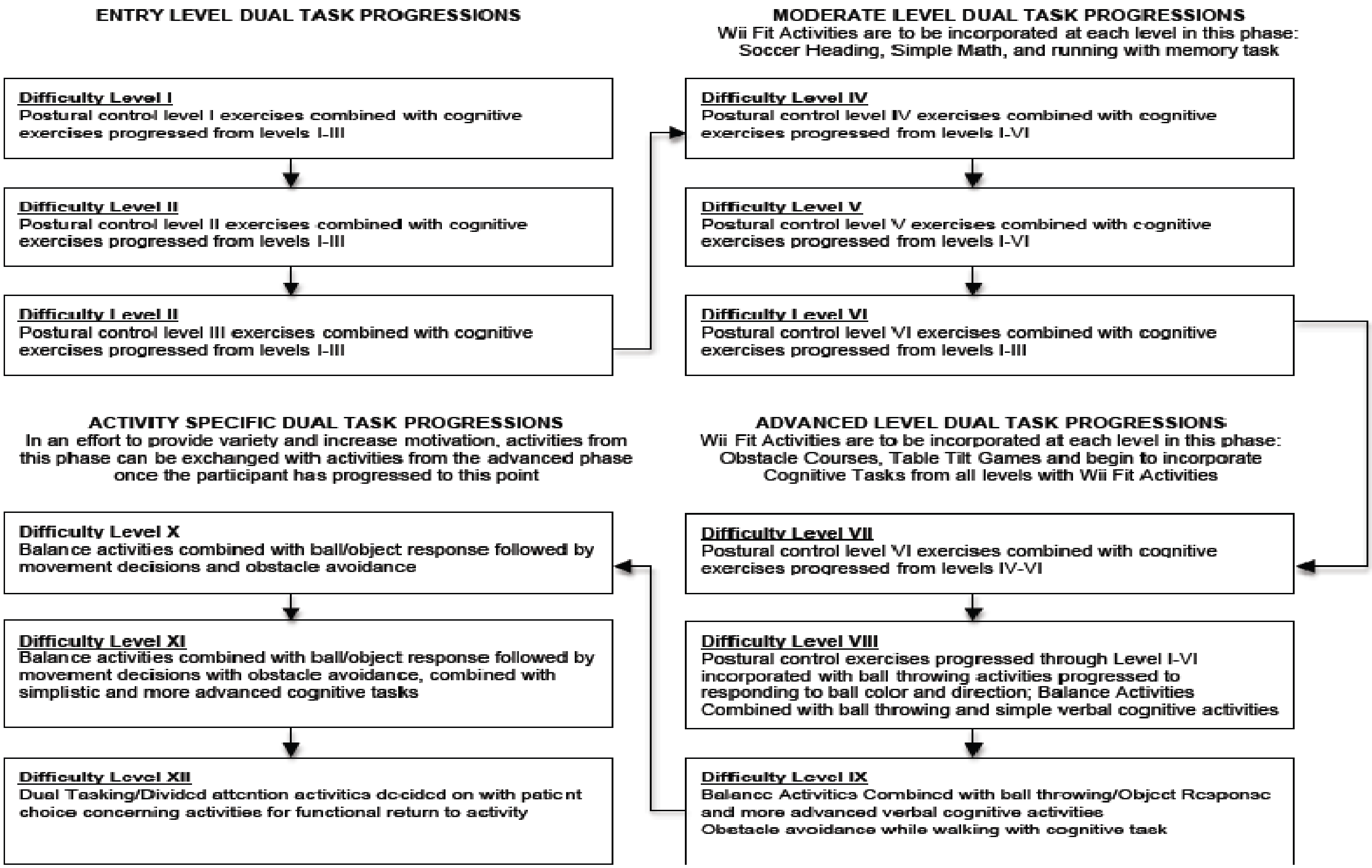
Which **foot** was tested: ☐ Left ☐ Right
(i.e. which is the **non-dominant** foot)

APPENDICES

Appendix 1: Single-Task Progression



Appendix 2: Dual-Task Progression



Appendix 3: Weekly Exercise Progression

Dual-Task Weekly Check List

Week 1 Observed Session 1:

DL Stance EO with Alphabet Forward ☐

DL Stance EO with Count to 100 Forward by 3 ☐

Tan EO with Count Down from 100 by 2 ☐

Tan EO with Count by 7s to 100 ☐

Tan EO with 3-Word Recall and Recognition ☐

Apple Sandwich Wagon

SL EO with 5-Word Recall and Recognition ☐

Bubble Paper Elbow Sugar Saddle

SL EO with Digit Span Forward (5-7) ☐

71384 92847 548126 327598 7543129 8456315

SL EO with Simple Math Tasks (Addition) ☐

21: (4+18)Y, (9+8)N, (22+9)Y, (11+11)Y, (8+10)N, (6+17)Y, (14+12)Y, (17+5)Y, (2+14)N, (17+2)N, (15+4)N, (6+13)N, (18+7)Y, (3+19)Y, (15+15)Y, (6+18)Y, (12+7)N, (13+16)Y, (19+6)Y, (9+17)Y

DL Stance EC with Alphabet Forward ☐

DL Stance EC with Count to 100 Forward by 3 ☐

Tan EC with Count Down from 100 by 2 ☐

Tan EC with Count by 7s to 100 ☐

Tan EC with 3-Word Recall and Recognition ☐

Perfume Sunset Iron

SL EC with 5-Word Recall and Recognition ☐

Roof Salmon Storm Ceiling Snow

SL EC with Digit Span Forward (5-7) ☐

62458 97512 364918 563419 7438124 8462315

SL EC with Simple Math Tasks (Addition) ☐

30: (14+17)Y, (19+8)N, (22+9)Y, (17+12)N, (8+18)N, (6+17)N, (14+15)N, (17+5)N, (12+14)N, (17+16)Y, (15+14)N, (6+13)N, (18+17)Y, (3+25)N, (15+16)Y, (6+18)N, (12+7)N, (13+16)N, (21+6)N, (9+17)N

Week 1 Observed Session 2:

DL Stance EO on Foam with Alphabet Forward ☐

DL Stance EO on Foam with Count to 100 Forward by 3 ☐

Tan EO on Foam with Count Down from 100 by 2 ☐

Tan EO with Count by 7s to 100 ☐

SL EO on Foam with 3-Word Recall and Recognition ☐

Apple   Sandwich   Wagon

SL EO on Foam with 5-Word Recall and Recognition ☐

Baby   Monkey   Insect Sunset Iron

DL EC on Foam with Digit Span Forward (5-7) ☐

68495 21354 684932 9356147 8965243

DL EC on Foam with Simple Math Tasks (Addition) ☐

29: (14+18)Y, (9+18)N, (22+9)Y, (11+17)N, (8+15)N, (6+17)N, (14+16)Y, (17+5)N, (22+8)Y, (19+21)Y, (15+16)Y, (16+14)Y, (18+17)Y, (3+25)N, (15+15)Y, (6+18)N, (11+20)Y, (14+16)Y, (21+6)N, (9+17)N

Week 1 Home Session:

DL Stance EC with Alphabet Forward ☐

DL Stance EC with Count to 100 Forward by 3 ☐

Tan EC with Count Down to 100 by 2 ☐

Tan EC with Count by 7s to 100 ☐

Tan EC with 3-Word Recall and Recognition ☐

Perfume Sunset Iron

SL EC with 5-Word Recall and Recognition ☐

Bubble Paper Elbow Sugar Saddle

SL EC with Digit Span Forward (5-7) ☐

56892 61289 542789 143267 9587123 1456829

SL EO with Simple Math Tasks (Addition) ☐

25: (14+18)Y, (9+8)N, (22+9)N, (11+12)N, (8+13)N, (6+17)N, (14+12)Y, (17+5)N, (12+14)Y, (17+21)Y, (15+14)Y, (6+13)N, (13+7)N, (3+21)N, (15+15)Y, (6+18)N, (14+7)N, (13+16)Y, (21+6)Y, (9+17)Y

Week 2 Observed Session 1:

SL EC on Foam with Digit Span Forward (5-7) ☐

68134 26751 786235 129734 9815432 8715342

Rocker Board EO Antero-Posterior and Medio-Lateral Direction

with Simple Math Tasks (Addition) ☐

31: (14+16)N, (19+8)N, (22+10)Y, (15+12)N, (8+13)N, (6+17)N, (14+18)Y, (17+5)N, (19+14)Y, (17+21)Y, (11+14)N, (16+13)N, (18+17)Y, (3+25)N, (15+15)N, (17+18)Y, (12+17)N, (13+16)N, (21+6)N, (9+17)N

BAPS Board Level I-II EC with Days of the Week Reverse Order ☐

DL EO Ext Pert with Simple Math Tasks (Subtraction) ☐

9: (27-16)Y, (19-8)Y, (22-9)Y, (15-12)N, (18-11)N, (26-19)N, (19-8)Y, (17-5)Y, (19-14)N, (27-21)N, (18-4)Y, (16-3)Y, (18-7)Y, (33-25)N, (19-15)N, (19-18)N, (22-7)Y, (19-16)N, (21-6)Y, (39-17)Y

SL EO Ext Pert with Count by 7s to 100 ☐

BAPS LI-II EO Ext Pert with Count to 100 by 3 ☐

Wii Fit Soccer Heading ☐

Wii Fit Running with Digit Span Forward (5-7) ☐

73291 87254 894672 897351 3547612 9812743

Week 2 Observed Session 2:

SL EC on Foam with Digit Span Forward (5-7) ☐

74691 87254 394672 567351 2157612 4582743

Rocker Board EO Antero-Posterior and Medio-Lateral Direction

with Simple Math Tasks (Addition) ☐

32: (14+16)N, (19+8)N, (22+11)Y, (15+12)N, (8+13)N, (6+17)N, (14+19)Y, (17+5)N, (19+14)Y, (17+21)Y, (11+14)N, (16+13)N, (18+17)Y, (3+25)N, (15+15)N, (16+18)Y, (12+17)N, (13+16)N, (21+6)N, (9+17)N

BAPS Board Level I-II EC with Days of the Week Reverse Order ☐

DL EO Ext Pert with Simple Math Tasks (Subtraction) ☐

14: (27-16)N, (19-8)N, (22-9)Y, (15-12)N, (18-3)Y, (26-5)Y, (19-3)Y, (17-2)Y, (19-4)Y, (27-21)N, (18-14)N, (16-3)N, (18-17)N, (33-5)Y, (19-15)N, (19-18)N, (22-7)Y, (19-16)N, (21-6)Y, (39-17)Y

SL EO Ext Pert with Count by 7s to 100 ☐

BAPS LI-II EO Ext Pert with Count to 100 by 3 ☐

Wii Fit Soccer Heading ☐

Wii Fit Running with Digit Span Forward (5-7) ☐

78314 87129 234659 714359 8173549 1435798

Week 2 Home Session:

SL EC Foam with 3-Word Recognition and Recall ☐

Paper Elbow Saddle

Tan EC Foam with Count by 7s to 100 ☐

DL EO Ext Pert with Digit Span Forward (5-7) ☐

73546 31298 687342 192765 9143562 8245672

DL EC Ext Pert with Simple Math Tasks (Addition) ☐

31: (14+18)Y, (9+8)N, (24+9)Y, (11+12)N, (8+13)N, (6+17)N, (14+12)N, (17+15)Y, (12+14)N, (17+21)Y, (15+14)N, (6+13)N, (18+17)Y, (3+25)N, (15+15)N, (6+18)N, (12+7)N, (13+16)N, (21+16)Y, (9+17)N

Tan EO Ext Pert with Count Backwards from 100 by 2s ☐

SL EO Ext Pert with Count to 100 by 3 ☐

<u>Week 3 Observed Session 1:</u>

Rocker Board EO (Antpost/Medlat) with Simple Math Tasks (Subtraction) ☐

17: (27-6)Y, (19-1)Y, (22-9)N, (20-2)Y, (18-3)N, (26-8)Y, (19-3)N, (19-5)N, (19-14)N, (27-6)Y, (18-14)N, (16-13)N, (18-17)N, (33-15)Y, (19-5)N, (19-8)N, (22-7)N, (19-3)N, (21-6)N, (39-17)Y

BAPS Board LI-II EO with Stroop ☐

Rocker Board EO (Antpost/Medlat) with Ball Toss Response to Color Direction ☐

TD EO Foam with Digit Span Backwards (5-7) ☐

12985 23756 984652 125673 9812735 5679821

BAPS Board LI-II EO with Ball Toss and 10-Word Recall ☐

Canary Shoes Eagle Blouse Nails Crow Bluebird Screwdriver

Obstacle Avoidance with Digit Span Backwards (7-9) ☐

1347932 7851439 89147523 34217865 978635241 193845267

Wii Fit Obstacle Course ☐

Wii Fit Table Tilt Games ☐

<u>Week 3 Observed Session 2:</u>

Rocker Board EO (Antpost/Medlat) with Simple Math Tasks (Subtraction) ☐

20: (27-6)Y, (29-8)Y, (22-9)N, (30-12)N, (31-13)N, (36-9)Y, (19-18)N, (27-5)Y, (19-14)N, (27-5)Y, (28-14)N, (26-13)N, (28-17)N, (33-11)Y, (29-15)N, (31-8)Y, (22-7)N, (29-16)N, (21-6)N, (39-17)Y

BAPS Board LI-II EO with Stroop ☐

Rocker Board EO (Antpost/Medlat) with Ball Toss Response to Color Direction ☐

TD EO Foam with Digit Span Backwards (5-7) ☐

43752 67891 239814 897651 513429 9765214 1293758

BAPS Board LI-II EO with Ball Toss and 10-Word Recall ☐

Shark Wall Herring Rain Floor Hail Catfish Roof Salmon Storm

Obstacle Avoidance with Digit Span Backwards (7-9) ☐

1358632 8751439 89147253 24317865 678935241 193846725

Wii Fit Obstacle Course ☐

Wii Fit Table Tilt Games ☐

Week 3 Home Session:

DL EO Ext Pert with Months of the Year in Reverse Order ☐

DL EC Ext Pert with Days of the Week in Reverse Order ☐

SL EO Ext Pert with Digit Span Backwards (5-7) ☐

78923 85642 123645 875489 1245978 9124735

SL EC Ext Pert with COWAT ☐

Tan EO Ext Pert with Digit Span Backwards (7-9) ☐

3158632 8571439 87194253 24713865 678935241 193846725

Tan EC Ext Pert with PASAT ☐

Week 4 Observed Session 1:

Rocker Board Balance EO (Antpost/MedLat) with

Ball Toss Response to Color and Direction ☐

Rocker Board EO and Ball Toss with PASAT ☐

SL Balance EC with COWAT ☐

Obstacle Avoidance with PASAT ☐

Subject Selection ☐

Subject Selection ☐

Week 4 Observed Session 2:

Rocker Board Balance EO (Antpost/MedLat) with

Ball Toss Response to Color and Direction ☐

Rocker Board EO and Ball Toss with PASAT ☐

SL Balance EC with COWAT ☐

Obstacle Avoidance with PASAT ☐

Subject Selection ☐

Subject Selection ☐

<u>Week 4 Home Session:</u>

DL EO Ext Pert with Months of the Year in Reverse Order ☐

DL EC Ext Pert with Days of the Week in Reverse Order ☐

SL EO Ext Pert with Digit Span Backwards (5-7) ☐

67891 23147 981246 349256 1237286 9134568

SL EC Ext Pert with COWAT ☐

Tan EO Ext Pert with Digit Span Backwards (7-9) ☐

5267891 2398147 98123546 13492856 123728946 913427568

Tan EC Ext Pert with PASAT ☐

Single Task Week 1 Observed Task Check List

Observed Session 1

DL Stance EO: Touch Down Errors	Trial 1: _____Trial 2:
Count to 100 Forward by 3:	Counting Errors:
TD Stance EO: Touch Down Errors	Trial 1: _____Trial 2:
Count down from 100 by 2:	Counting Errors:
SL Stance EO: Touch Down Errors	Trial 1: _____Trial 2:
Alphabet Backwards:	Errors:
DL Stance EC: Touch Down Errors	Trial 1: _____Trial 2:
Count by 7s to 100:	Counting Errors:
TD Stance EC: Touch Down Errors	Trial 1: _____Trial 2:
3-Word Recall and Recognition: Recall – Recognition	
Apple Sandwich Wagon	
SL Stance EC: Touch Down Errors	Trial 1: _____Trial 2:____
3-Word Recall and Recognition: Recall – Recognition	
Perfume Sunset Iron	

Observed Session 2

DL Stance EO: Touch Down Errors	Trial 1: _____Trial 2:
Count to 100 Forward by 3:	Counting Errors:
TD Stance EO: Touch Down Errors	Trial 1: _____Trial 2:
Count down from 100 by 2:	Counting Errors:
SL Stance EO: Touch Down Errors	Trial 1: _____Trial 2:____
Alphabet Backwards:	Errors:
DL Stance EC: Touch Down Errors	Trial 1: _____Trial 2:____
Count by 7s to 100:	Counting Errors:
TD Stance EC: Touch Down Errors	Trial 1: _____Trial 2:
3-Word Recall and Recognition: Recall – Recognition	

Baby   Monkey   Insect

SL Stance EC: Touch Down Errors   Trial 1: _____Trial 2:

3-Word Recall and Recognition: Recall – Recognition

Penny   Blanket   Lemon

<u>Week 1 Home Session:</u>

DL Stance EO: Touch Down Errors   Trial 1: _____Trial 2:

Count to 100 Forward by 3:   Counting Errors:

TD Stance EO: Touch Down Errors   Trial 1: _____Trial 2:

Count down from 100 by 2:   Counting Errors:

SL Stance EO: Touch Down Errors   Trial 1: _____Trial 2:____

Alphabet Backwards: Errors:

DL Stance EC: Touch Down Errors   Trial 1: _____Trial 2:____

Count by 7s to 100:   Counting Errors:

TD Stance EC: Touch Down Errors   Trial 1: _____Trial 2:

Count by 7s to 100:   Counting Errors:

SL Stance EC: Touch Down Errors   Trial 1: _____Trial 2:____

Count by 7s to 100:   Counting Errors:

Single Task Week 2 Observed Task Check List

<u>Observed Session 1</u>

DL Stance EO Foam: Touch Down Errors   Trial 1: _____Trial 2:_____

5-Word Recall and Recognition: Recall

Bubble   Paper   Elbow   Sugar   Saddle

TD Stance EO Foam: Touch Down Errors   Trial 1: _____Trial 2:_____

Digit Span Forward (5-7) :

12647   98762   346385 175394 659382   7592836   2134597

SL Stance EO Foam: Touch Down Errors   Trial 1: _____Trial 2:_____

Simple Math Choice Tasks (Addition):

21: (4+18)Y, (9+8)N, (22+9)Y, (11+11)Y, (8+10)N, (6+17)Y, (14+12)Y, (17+5)Y, (2+14)N, (17+2)N, (15+4)N, (6+13)N, (18+7)Y, (3+19)Y, (15+15)Y, (6+18)Y, (12+7)N, (13+16)Y, (19+6)Y, (9+17)Y

DL Stance EC Foam: Touch Down Errors Trial 1: _____Trial 2:_____

7-Word Immediate/Delayed Recall:

Shark Wall Herring Rain Floor Hail Catfish

TD Stance EC Foam: Touch Down Errors Trial 1: _____Trial 2:_____

Days of the Week in Reverse Order: Errors:_____

SL Stance EC Foam: Touch Down Errors Trial 1: _____Trial 2:_____

Months of the Year in Reverse Order: Errors:_____

Rocker Board EO – Antero-Posterior and Medio-Lateral Direction:

Touch Down Errors Trial 1: _____Trial 2: ______

Simple Math Choice Tasks (Subtraction):

9: (27-16)Y, (19-8)Y, (22-9)Y, (15-12)N, (18-11)N, (26-19)N, (19-8)Y, (17-5)Y, (19-14)N, (27-21)N, (18-4)Y, (16-3)Y, (18-7)Y, (33-25)N, (19-15)N, (19-18)N, (22-7)Y, (19-16)N, (21-6)Y, (39-17)Y

BAPS Board Level I-II EO: Touch Down Errors Trial 1: _____Trial 2:_____

Simple Math Choice Tasks (Subtraction):

14: (27-16)N, (19-8)N, (22-9)Y, (15-12)N, (18-3)Y, (26-5)Y, (19-3)Y, (17-2)Y, (19-4)Y, (27-21)N, (18-14)N, (16-3)N, (18-17)N, (33-5)Y, (19-15)N, (19-18)N, (22-7)Y, (19-16)N, (21-6)Y, (39-17)Y

Observed Session 2:

DL Stance EO Foam: Touch Down Errors Trial 1: _____Trial 2:_____

5-Word Recall and Recognition: Recall

Roof Salmon Storm Ceiling Snow

TD Stance EO Foam: Touch Down Errors Trial 1: _____Trial 2:_____

Digit Span Forward (5-7) :

12647 98762 346385 175394 659382 7592836 2134597

SL Stance EO Foam: Touch Down Errors Trial 1: _____Trial 2:_____

Simple Math Choice Tasks (Addition):

30: (14+17)Y, (19+8)N, (22+9)Y, (17+12)N, (8+18)N, (6+17)N, (14+15)N, (17+5)N, (12+14)N, (17+16)Y, (15+14)N, (6+13)N, (18+17)Y, (3+25)N, (15+16)Y, (6+18)N, (12+7)N, (13+16)N, (21+6)N, (9+17)N

DL Stance EC Foam: Touch Down Errors Trial 1: _____Trial 2:_____

7-Word Immediate/Delayed Recall:

Canary Shoes Pants Blouse Nails Crow Bluebird

TD Stance EC Foam: Touch Down Errors Trial 1: _____Trial 2:_____

Days of the Week in Reverse Order: Errors:_____

SL Stance EC Foam: Touch Down Errors Trial 1: _____Trial 2:_____

Months of the Year in Reverse Order: Errors:_____

Rocker Board EO – Antero-Posterior and Medio-Lateral Direction:

Touch Down Errors Trial 1: ____Trial 2:______

Simple Math Choice Tasks (Subtraction):

20: (27-6)Y, (29-8)Y, (22-9)N, (30-12)N, (31-13)N, (36-9)Y, (19-18)N, (27-5)Y, (19-14)N, (27-5)Y, (28-14)N, (26-13)N, (28-17)N, (33-11)Y, (29-15)N, (31-8)Y, (22-7)N, (29-16)N, (21-6)N, (39-17)Y

BAPS Board Level I-II EO: Touch Down Errors Trial 1: _____Trial 2:_____

Simple Math Choice Tasks (Subtraction):

14: (27-16)N, (19-8)N, (22-9)Y, (15-12)N, (18-3)Y, (26-5)Y, (19-3)Y, (17-2)Y, (19-4)Y, (27-21)N, (18-14)N, (16-3)N, (18-17)N, (33-5)Y, (19-15)N, (19-18)N, (22-7)Y, (19-16)N, (21-6)Y, (39-17)Y

Week 2 Home Session

DL Stance EO Foam: Touch Down Errors Trial 1: _____Trial 2:_____

5-Word Recall and Recognition: Recall

Screwdriver Eagle Chisel Skirt Wrench

TD Stance EO Foam: Touch Down Errors Trial 1: _____Trial 2:_____

Digit Span Forward (5-7) :

12647 98762 346385 175394 659382 7592836 2134597

SL Stance EO Foam: Touch Down Errors Trial 1: _____Trial 2:_____

Simple Math Choice Tasks (Addition):

29: (14+18)Y, (9+18)N, (22+9)Y, (11+17)N, (8+15)N, (6+17)N, (14+16)Y, (17+5)N, (22+8)Y, (19+21)Y, (15+16)Y, (16+14)Y, (18+17)Y, (3+25)N, (15+15)Y, (6+18)N, (11+20)Y, (14+16)Y, (21+6)N, (9+17)N

DL Stance EC Foam: Touch Down Errors Trial 1: _____Trial 2:_____

7-Word Immediate/Delayed Recall:

Snow Salmon Catfish Floor Rain Herring Wall

TD Stance EC Foam: Touch Down Errors Trial 1: _____Trial 2:_____

Days of the Week in Reverse Order: Errors:_____

SL Stance EC Foam: Touch Down Errors Trial 1: _____Trial 2:_____

Months of the Year in Reverse Order: Errors:_____

SL Stance EO Foam: Touch Down Errors Trial 1: _____Trial 2:_____

Simple Math Choice Tasks (Subtraction):

9: (27-16)Y, (19-8)Y, (22-9)Y, (15-12)N, (18-11)N, (26-19)N, (19-8)Y, (17-5)Y, (19-14)N, (27-21)N, (18-4)Y, (16-3)Y, (18-7)Y, (33-25)N, (19-15)N, (19-18)N, (22-7)Y, (19-16)N, (21-6)Y, (39-17)Y

SL Stance EC Foam: Touch Down Errors Trial 1: _____Trial 2:_____

Simple Math Choice Tasks (Subtraction):

17: (27-6)Y, (19-1)Y, (22-9)N, (20-2)Y, (18-3)N, (26-8)Y, (19-3)N, (19-5)N, (19-14)N, (27-6)Y, (18-14)N, (16-13)N, (18-17)N, (33-15)Y, (19-5)N, (19-8)N, (22-7)N, (19-3)N, (21-6)N, (39-17)Y

Single Task Week 3 Observed Task Check List

Observed Session 1:

Rocker Board EC – Antero-Posterior and Medio-Lateral Direction:

Touch Down Errors Trial 1: ____Trial 2:______

10 Word Recall:

Canary Shoes Eagle Blouse Nails Crow Bluebird Screwdriver Pants Chisel Skirt Wrench

BAPS Board Level I-II EC: Touch Down Errors Trial 1: _____Trial 2:_____

Digit Span Backwards (5-7) Digits:

38612   46879   985614   543987   2973654   1968435

DL Stance EO with Ext Pert: Touch Down Errors   Trial 1: _____Trial 2:_____

Stroop: Errors:_____

DL Stance EC with Ext Pert: Touch Down Errors   Trial 1: _____Trial 2:_____

Stroop: Errors:_____

Observed Session 2:

Rocker Board EC – Antero-Posterior and Medio-Lateral Direction:

Touch Down Errors   Trial 1: ____Trial 2:_____

10 Word Recall:

Shark   Wall   Herring   Rain   Floor   Hail   Catfish   Roof   Salmon   Storm   Ceiling   Snow

BAPS Board Level I-II EC: Touch Down Errors   Trial 1: _____Trial 2:_____

Digit Span Backwards (5-7) Digits:

38612   46879   985614   543987   2973654   1968435

DL Stance EO with Ext Pert: Touch Down Errors   Trial 1: _____Trial 2:_____

Stroop: Errors:_____

DL Stance EC with Ext Pert: Touch Down Errors   Trial 1: _____Trial 2:_____

Stroop: Errors:_____

Week 3 Home Session:

DL Stance EO with Ext Pert: Touch Down Errors   Trial 1: _____Trial 2:_____

10 Word Recall:

Shark   Wall   Herring   Rain   Floor   Hail   Catfish   Roof   Salmon   Storm   Ceiling   Snow

DL Stance EC with Ext Pert: Touch Down Errors   Trial 1: _____Trial 2:

Digit Span Backwards (5-7)

34672   21897   564793 132465   9687451   4578561

Single Task Week 4 Observed Task Check List

Observed Session 1:

TD Stance EO with Ext Pert: Touch Down Errors   Trial 1: _____Trial 2:_____

10 Word Delayed Recall:

Canary Shoes Eagle Blouse Nails Crow Bluebird Screwdriver Pants Chisel Skirt Wrench

SL Stance EO Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

Digit Span Backwards (7-9) ea. string length

2358169 3591487 45829613 85412937 873946512 289673514

TD Stance EO Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

COWAT (2 letters): Raw Score:

SL Stance EO Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

PASAT (2” stimulus): Raw Score:

BAPS Board Level I-II EO with Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

PASAT (2” stimulus): Raw Score

Observed Session 2:

TD Stance EO with Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

10 Word Delayed Recall:

Roof Salmon Storm Ceiling Snow Bubble Paper Elbow Sugar Saddle

SL Stance EO Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

Digit Span Backwards (7-9) ea. string length

7421986 5623981 81254739 96745132 759863241 418923675

TD Stance EO Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

COWAT (2 letters): Raw Score:

SL Stance EO Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

PASAT (2” stimulus): Raw Score:

BAPS Board Level I-II EO with Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

PASAT (2” stimulus): Raw Score

Week 4 Home Session:

TD Stance EO with Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

10 Word Delayed Recall:

Perfume Sunset Iron Apple Sandwich Wagon Canary Nails Screwdriver

SL Stance EO Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

Digit Span Backwards (7-9) ea. string length

5683941 2193865 92515368 14983756 2318654 792134658 893467521

TD Stance EO Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

COWAT (2 letters): Raw Score:

SL Stance EO Ext Pert: Touch Down Errors Trial 1: _____Trial 2:_____

PASAT (2” stimulus): Raw Score:

Appendix 4: Subjective with Objective Task Difficulty Scale

Rating	Definition
0	Nothing at all
0.5	Very, very easy
1	Very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	Very, very hard
10	Impossible

SUBJECTIVE BALANCE TASK DIFFICULTY SCALE

Please answer the following questions to the best of your ability based on the difficulty of each task. Please use the above Borg CR10 Ratings of Perceived Exertion Scale and record your perceived exertion for each question on the line provided.

ENTRY LEVEL

1. Please rate the difficulty of the balance tasks completed during *Difficulty Level I* (ie. DL Stance Eyes Open, Tandem Stance Eyes Open, SL stance Eyes Open):

Difficulty:_______

Objective Measure to be used by Clinician: Subject within ***1 standard deviation*** of age normative values DL stance, tandem stance and SL stance (***eyes open***) from the ***FIRM*** BESS values.

2. Please rate the difficulty of the balance tasks completed during *Difficulty Level II* (ie. DL Stance Eyes Closed, Tandem Stance Eyes Closed, SL Stance Eyes Closed):

Difficulty:_______

Objective Measure to be used by Clinician: Subject within ***2 standard deviations*** of the age normative values for ***FIRM*** DL stance, tandem stance, and SL stance (***eyes closed***) from the BESS values.

3. Please rate the difficulty of the balance tasks completed during *Difficulty Level III* (ie. DL Stance Eyes Open, Tandem Stance Eyes Open, SL Stance Eyes Open, DL Stance Eyes Closed – all conditions on foam):

Difficulty:_______

Objective Measure to be used by Clinician: Subject within ***1.5 standard deviations*** of the age normative values for ***FOAM*** DL stance, tandem stance, and SL stance (***eyes open***) from the BESS values.

ADVANCED LEVEL

1. Please rate the difficulty of the balance tasks completed during *Difficulty Level IV* (ie. Tandem Stance Eyes Closed Foam, SL Stance Eyes Closed Foam, Rocker Board Eyes Open, BAPS Board Level I-II Eyes Open):

Difficulty:_______

Objective Measure to be used by Clinician: Subject within ***2 standard deviations*** of the age normative values for ***FOAM*** DL stance, tandem stance, and SL stance (***eyes closed***) from the BESS values.

2. Please rate the difficulty of the balance tasks completed during *Difficulty Level V* (ie. Rocker Board Eyes Closed, BAPS Board Level I-II Eyes Closed, DL Stance Eyes Open with External Perturbation):

Difficulty:_______

Objective Measure to be used by Clinician: Subject able to complete a ***rocker board eyes closed task*** for at least ***5 seconds*** without stepping off the board and able to maintain a ***10 second double leg stance eyes closed*** with ***external perturbation***.

3. Please rate the difficulty of the balance tasks completed during *Difficulty Level VI* (ie. Tandem Stance Eyes Open with External Perturbation, SL Stance Eyes Open with External Perturbation):

   Difficulty:______

   Objective Measure to be used by Clinician: Work within to add to similar activities at this Step (more sport/activity specific/Wii balance, etc.)

SUBJECTIVE COGNITIVE TASK DIFFICULTY SCALE

Please answer the following questions to the best of your ability based on the difficulty of each task. Please use the above Borg CR10 Ratings of Perceived Exertion Scale and record your perceived exertion for each question on the line provided.

ENTRY LEVEL

1. Please rate the difficulty of the cognitive tasks completed during *Difficulty Level I* (ie. Alphabet Forward, Count to 100 Forward, Count by Twos to 100):

   Difficulty:______

   Objective Measure to be used by Clinician: Subject able to recite the ***alphabet forward*** in its entirety and ***count by twos to 100*** with ***no errors***.

2. Please rate the difficulty of the cognitive tasks completed during *Difficulty Level II* (ie. Count by 7s to 100, 3-word Recall and Recognition):

   Difficulty:______

   Objective Measure to be used by Clinician: Subject able to ***count by 7s to 100*** and complete a ***3-word recall with a 3-minute delay*** with ***no errors***.

3. Please rate the difficulty of the cognitive tasks completed during *Difficulty Level III* (ie. Digit Span Forward (5-7 digits), 5-word Recall and Recognition, Simple Math Tasks):

   Difficulty:______

   Objective Measure to be used by Clinician: Subject able to complete at least a ***5 number BACKWARD digit span task*** and ***5-word recall word recall with a 3-minute delay*** with ***no errors***.

ADVANCED LEVEL

1. Please rate the difficulty of the cognitive tasks completed during *Difficulty Level IV* (ie. 7-word Recall and Delayed Recall, Days of the Week Reverse Order, Months of the Year Reverse Order):

   Difficulty:______

   Objective Measure to be used by Clinician: Subject able to complete at least a ***7 number FORWARD digit span task*** and ***7 word recall word recall with a 3-minute delay*** with ***no errors***.

2. Please rate the difficulty of the cognitive tasks completed during *Difficulty Level V* (ie. Digit Span Backwards (5-7 digits), 10-word Recall and Recognition, Auditory Stroop):

   Difficulty:______

   Objective Measure to be used by Clinician: Subject able to complete at least a ***5 number BACKWARD digit span task*** and ***10-word recall within a 3-minute delay*** with ***no errors***.

3. Please rate the difficulty of the cognitive tasks completed during *Difficulty Level VI* (ie. Delayed Recall 3, 5, 7, 10-words, Digit Span Backwards 7+ Digits, COWAT, PASAT):

   Difficulty:______

   Objective Measure to be used by Clinician: Work within to add to similar activities and even more difficult and challenging cognitive task related to activities and cognitive processes.

Appendix 5: General Health History Questionnaire

ID No.____________ **Page 1**

General Health History Questionnaire
(All information is fully confidential and will not be shared with anyone outside of the research team.)

Section I: Demographic Information

Height:_________ Weight:__________ Age:_______ Sex: ☐ Male ☐ Female

Academic Year: ☐FR ☐SO ☐JR ☐SR ☐GRADUATE STUDENT ☐ OTHER

Hours of sleep last night:_______________________

Section II: Physical Activity. *Complete this section for all sports you compete in at the college level*

Please check how many days per week (on average) you ***participate in physical activity for at least 30 minutes:***

☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7

Please list the 3 most common types of physical activity you participate in on a regular basis:
1.__________________________________
2.__________________________________
3.__________________________________

Please list any Intramural of Club Sports you have participated in during your college years:

Section III: Injury/Medical History. *Please check the appropriate box*

If you are female: Are you knowingly pregnant? YES NO
**You should only complete one box of questions. The researcher will check the box beside the questions you should answer and will instruct you on which set of questions to complete.*

HEALTHY PARTICIPANT ______

Do/have you had…	**Yes**	**No**
1. Exercise 3 times per week for 30 minutes or more each time		
2. Vestibular or neurological dysfunction		
3. Lower extremity injury within past 6 months		
4. A history more than 2 concussions		
5. A history of concussion in the past 3 months		
5. ADHD		
6. Learning disability		
7. Color blindness		

Appendix 6: Intervention Progression Check Point Sheet

Week 1:

BESS Total Error Score:______

Cognitive Test Score:______

Objective Balance Score Achieved: ☐YES ☐NO

Objective Cognitive Score Achieved: ☐YES ☐NO

Subjective Task Average Score:_____

Week 2:

BESS Total Error Score:______

Cognitive Test Score:______

Objective Balance Score Achieved: ☐YES ☐NO

Objective Cognitive Score Achieved: ☐YES ☐NO

Subjective Task Average Score:_____

Week 3:

BESS Total Error Score:______

Cognitive Test Score:______

Objective Balance Score Achieved: ☐YES ☐NO

Objective Cognitive Score Achieved: ☐YES ☐NO

Subjective Task Average Score:_____

Week 4:

BESS Total Error Score:______

Cognitive Test Score:______

Objective Balance Score Achieved: ☐YES ☐NO

Objective Cognitive Score Achieved: ☐YES ☐NO

Subjective Task Average Score:_____

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