

DEVELOPMENT AND USE OF THE MULTI-TASK HEAD INJURY ASSESSMENT  
TEST IN ATHLETES WITH CONCUSSIONS

by

CONNIE LEE PETERSON

(Under the direction of Michael S. Ferrara)

ABSTRACT

Brief neuropsychological testing batteries and sophisticated balance assessment techniques have been identified as sensitive indicators for the identification of concussion. Typically, these tests are conducted independent of each other, yet sport participation demands the simultaneous performance of cognitive and motor tasks. The purpose of this study was to identify the viability of combining a common cognitive task with a simple balance task into a dual task testing paradigm for concussion assessment. Preseason, baseline data on 456 athletes were obtained. Participants counted backwards by 7s for 30 seconds from randomized starting points between 95 and 105. A rate of seconds to complete a correct subtraction was computed. A timed tandem walk (heel to toe) forward and backward on a standard 2"H X 4"W X 8'L board was performed. After performing the cognitive and motor tasks independent of each other (solo), participants performed the tasks concurrently. Performance of each task independently, always preceded the dual task with the independent tasks counterbalanced. Three trials of all tasks were performed. Paired sample t-tests comparing mean solo scores to mean dual scores revealed that serial 7s rate did not significantly differ ( $p = .892$ ) from the

independent performance of the task (S7s) to the dual performance of the task (D7s). However, beam walk time increased 43% ( $p < .001$ ) from the independent performance of the task (SBW) to the dual performance of the task (DBW). This suggests athletes compromised performance on the balance task to preserve cognitive performance. Subsequently, 23 athletes from the original sample suffered a concussion and were retested at days 1, 5, and 10 post-injury. An additional 17 athletes volunteered to complete testing as matched controls. Significant group differences were not identified on any of the four dependent variables, however, significant main effects for test day were noted. Planned comparisons suggest that injured athletes perform significantly worse 24 hours after the injury than baseline (SBW) and day 5 (D7s and DBW). It was concluded that cognitive task used in the Multi-Task Head Injury Assessment Test creates interference on the balance task and collectively reflects impaired neurological function immediately post-injury.

INDEX WORDS: Concussion in sport, Dual-task testing, Mild brain injury, Balance assessment

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## DEDICATION

This work is dedicated to my family and friends....

My parents taught me to dream big and gave me the tools and support to turn my dreams into reality.

My sister taught me that no matter what the challenge, find a positive and learn to laugh.

My brother with whom I am always competing.

My nieces and nephews who are a constant source of entertainment and joy.

My friends who do their part to remind me to enjoy life and challenge me to be the best I can.

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## CHAPTER 1

### INTRODUCTION

Participation in sports places an individual in a position of risk to suffer an injury. While most injuries occurring in sport are relatively minor, there is risk of significant and even catastrophic injury. Concussion, or mild traumatic brain injury (mTBI), follows this same pattern. In high school athletes, it is estimated that over 62,000 concussions occur annually accounting for 5.5% of all injuries<sup>75</sup>. At the collegiate level, the incidence of injury is 0.06-0.55 per 1,000 athlete exposures (games and practices)<sup>21</sup>. Football, ice hockey, boxing, wrestling, gymnastics, soccer, motor racing, cycling, alpine skiing and rugby are among the sports reporting higher incidences of mTBI<sup>92</sup>. Rarely are these injuries catastrophic, but a missed diagnosis or improperly managed head injury certainly has the potential for catastrophe.

Concussions do not present with easily measured, objective assessment criteria, such as a positive finding on an x-ray or pain with palpation, and often two similar presenting cases can result in two completely different outcomes<sup>56</sup>. Evaluation and subsequent return to play decisions are some of the most difficult challenges faced by sports medicine staffs. Concussions are commonly graded according to the presence or absence of symptoms and abnormal behavioral responses while return to play decisions are then based on the severity of the injury and persistence of these symptoms and behaviors. Currently, there are at least 25 published concussion grading scales<sup>45</sup>, each

with its own return to play guideline (see Appendix A for a summary of the most common). The biggest limitation to such grading scales and guidelines is that they are often based on personal and/or consensus opinion and experience rather than sound, objective, experimentally obtained data. None of the grading scales are followed with much consistency and none has emerged as a gold standard in the sports medicine community<sup>24;34;45</sup>.

Recently, experts in sport related head injury have advocated the inclusion of neuropsychological and sophisticated balance testing to determine injury severity which may assist in making return to play decisions. While the use of traditional neuropsychological testing following severe head injury had been utilized for years, it was not until the mid 1980s that it began surfacing in the athletic realm. One limitation to utilizing traditional, extensive neuropsychological test batteries to assess cognitive function in an athletic population is that these tests typically take between 4 -5 hours to administer. In an athletic environment, large numbers of athletes often need to be tested in a limited amount of time. Therefore, a limited number of tests are often selected from an extensive battery and typically include those which are easy and quick to administer, as well as those which measure aspects of function likely to be affected by concussion. It is now common practice to include immediate side-line evaluations<sup>48;49;63;64;70</sup> as well as limited test batteries<sup>1;9;18;53;55;95</sup> administered prior to the start of an athletic season (baseline measure) and at pre-determined times following injury to determine when an athlete has returned to normal by comparing to baseline measures or pre-established norms. As the inclusion of neuropsychological test batteries has emerged in concussion

management, researchers have also attempted to identify additional tests which might lend additional insight into neurological function.

Traditional balance testing of athletes following concussion has consisted of non-instrumented, often subjective, gross measures<sup>35-37;44;79;80</sup>. Technological advancements have resulted in the ability to precisely measure balance disturbances which often occur with concussion<sup>35;36</sup>. Guskiewicz, et al.<sup>37</sup> demonstrated the sensitivity of a Sensory Organization Test (SOT) in detecting differences between healthy, uninjured subjects and concussed athletes following injury. Injured athletes demonstrated significantly poorer postural control in the absence of significant cognitive differences<sup>37</sup>. Both neuropsychological assessments and sophisticated balance testing have been identified as being helpful to practitioners, yet clinical expertise of physicians remains the primary source for decision making<sup>23</sup>.

### **Statement of the Problem**

While the inclusion of neuropsychological testing and sophisticated balance testing has advanced our understanding of concussion in sport, it has left us with many challenges. Specifically, in what capacity can this information be of value in identifying if an athlete is injured and if injured, when is it “safe” for them to return to participation. Future answers to these questions may be philosophical at best, but the more empirical evidence available on which to base answers, continues to drive sport related head injury research. One concern is the time and equipment necessary to complete this testing, limiting the availability of it to those with extraordinary resources. Neuropsychologists advocate the need for their personal expertise in administering and subsequent

interpretation of cognitive testing<sup>8,31</sup>. Additional issues associated with the implementation of neuropsychological testing could include validity of the test battery, problems associated with repeated testing, age, gender, and the level of play<sup>31</sup>. Further, because concussion can injure different anatomic areas of the brain, it is unlikely that one single test will be effective in identifying concussion<sup>8,31</sup>. As neuropsychological testing advances to computer and web based models, it remains resource and financially limiting for most school based sport programs. Equipment for sophisticated balance testing can cost upwards of \$50,000 and be extremely time intensive to administer. Cost is certainly one problem associated with current concussion testing methods.

Another potential limitation to current testing procedures is that neuropsychological testing and balance testing have been conducted separate from each other, yet sport participation often demands the combination of cognitive function with physical activities. Athletic trainers have advocated the inclusion of sport specific activities into the testing, rehabilitation, and return to participation of orthopedic related injuries, yet have strayed from that model in the assessment of athletes with concussions. The athlete who is unable to perform normally both cognitively and physically is not only at risk of further injuring themselves, but will not likely be able to perform up to expectations. It appears that the next logical step in concussion assessment methodology is to progress to cognitive and motor tests which can be performed concurrently, thus assessing the ability of the athlete to multi-task and simulate the demands of their sport.

Specifically, the problem addressed by this study is the development and use of a cost effective concussion assessment tool which integrates cognitive and balance

function. Combining cognitive and balance tasks (dual task paradigm) has demonstrated marked decreases in the performance of both a mental task and a balance task while performing them concurrently in both normal and “dizzy” patients<sup>3</sup>, in amputees<sup>27;28</sup>, in older adults<sup>12;78;89;90</sup>, in those with Parkinsons disease<sup>69;85;91</sup>, and those with head injuries<sup>17;29</sup>.

### **Purpose and Objectives**

The purpose of this study was to address the utility of a dual task testing method in the assessment of concussed athletes and subsequent testing to assist in making return to play decisions. Specifically, the objectives were as follows:

1. To identify differences between injured athletes and healthy controls both at the time of injury and subsequent follow-up testing sessions utilizing the dual task.
2. To identify a point after injury at which there are no longer differences between the groups on the performance of the task.
3. To demonstrate the sensitivity of the test relative to previously demonstrated methods.

### **Rationale of the Study**

There are two primary concerns in the assessment of concussion in athletes. One is to determine when it is safe for an athlete to return to play following injury. Returning to play too soon after injury could result in second impact syndrome, a potentially catastrophic injury usually caused by relatively minor trauma to an unresolved concussed athlete. Athletes at risk for second-impact injuries are those who return to play while reporting post-concussion symptoms including visual, motor or sensory abnormalities

and difficulty with cognitive processing<sup>99</sup>. Postmortem scans on injured athletes have demonstrated extensive cerebral edema in five confirmed cases<sup>99</sup>. The second concern of concussion assessment in athletes is related to chronic cognitive deficits which have been attributed to repetitive sub-concussive blows in boxers and soccer players<sup>91;98</sup>. While the literature is inconclusive on these issues, it remains an important area of study<sup>77</sup>.

This study is most closely related to the first concern. That is, a test to assist the clinician in the identification of motor and cognitive deficits which may be present when an athlete has a concussion. The information from this test may then be used as a tool to assist clinical decision making concerning return to participation. Current concussion assessment typically consists of cognitive assessment independent of motor function, yet the demands of sport require that both be performed concurrently. The Multi-Task Head Assessment Test (MT-HAT), is proposed for a concurrent assessment of cognitive and motor function. It may be used to identify functional deficits and is proposed to simulate the readiness of an injured athlete to resume rigorous demands of sport activity.

### **Definition of Terms**

Concussion:	Trauma induced alteration in mental status that may or may not involve a loss of consciousness. See review of literature for clarification of definition.
Glasgow Coma Scale:	(GCS) Rating scale frequently utilized in hospital emergency rooms to classify brain injury. Utilizes best motor and verbal and eye opening response to verbal and painful stimuli. See Appendix B.

- Neuropsychological Tests: Various procedures designed to measure cognitive function, often combined into test batteries.
- Postural Control: A person's ability to maintain their center of pressure within their base of support. Often referred to as balance.
- Loss of Consciousness: LOC - abbreviation.
- Sway: Anterioroposterior and mediolateral oscillations used to control postural stance.

### **Delimitations of the Study**

Results from this study will be delimited to interpretation of concussions occurring from athletic participation in the college athlete.

### **Limitations of the Study**

1. Data collection occurred at various colleges and universities across the United States. Although measures were taken to adequately train the data collectors, it is possible that less than optimal data collection occurred.
2. Subjects were asked to participate voluntarily by the data collectors and were free to withdraw from participation at any time. Athletes may have felt pressured to participate because other team members were participating or because the athletic trainer at their school requested that they participate.

## CHAPTER 2

### REVIEW OF THE RELATED LITERATURE

#### **Definition of Injury and Concussion Grading Scales**

One of the greatest challenges facing researchers and clinicians alike is the multitude of definitions, terminology and published guidelines concerning injuries to the brain occurring from sport participation. While concussion is the term frequently mentioned in the athletic arena, other terms which may represent this same condition include mild head injury, mild brain injury, mild traumatic brain injury, closed head injury, post-concussion syndrome, and post-traumatic syndrome. Inconsistent terminology alone can create confusion in the definition of injury.

The Glasgow Coma Scale (GCS) has often been used to differentiate mild, moderate and severe brain injury. This scale is based on an injured person's current best motor and verbal response to stimuli as well as eye opening ability (see Appendix B). Scores of 13-15 are considered mild, 9-12 moderate and below nine, severe<sup>92</sup>. While this scale is commonly utilized in emergency room evaluations, it has limited use retrospectively<sup>84</sup> and in athletic related brain injuries<sup>45;92</sup>. Mild traumatic brain injury has also been defined as an injury with an initial GCS of 13-15, post-traumatic amnesia (PTA) lasting less than 24 hours, and loss of consciousness less than 20 minutes<sup>22</sup>. This definition excludes most athletic related brain trauma because less than 9% of these injuries are associated with LOC<sup>39</sup>. In 1991, the Mild Traumatic Brain Injury Committee

of the Head Injury Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine defined mild traumatic brain injury as one of the following, (1) LOC < 30 min with a GCS of 13-15 after this period, (2) any amnesia of < 24 hours, (3) any alteration in mental status at time of injury, and (4) focal neurological deficits that may or may not be transient<sup>22</sup>. Mild traumatic brain injuries occurring in sport are often classified as concussions which opens up another milieu of definitions.

The Committee of Head Injury Nomenclature of the Congress of Neurological Surgeons, defined concussion in 1966 as “a clinical syndrome characterized by immediate and transient post-traumatic impairment of neural functions, such as alteration of consciousness, disturbance of vision, equilibrium, etc. due to brain stem involvement.”

<sup>13</sup> In 1974, Ommaya and Gennarelli, proposed a brain injury grading scale that included three levels of mild brain injury. (See Appendix A) Because this scale is not based on LOC, many sport related researchers have embraced this model<sup>47;53;68</sup>. Their definition of concussion is “a graded set of clinical syndromes following head injury wherein increasing severity of disturbance in level and content of consciousness is caused by mechanically induced strains affecting the brain in a centripetal sequence of disruptive effect on function and structure.”<sup>73</sup> This work was considered groundbreaking in that it was one of the first to use an animal model and controlled amounts of trauma correlated to clinical and pathological observations to determine the various grades of injury. In 1986, Cantu proposed one of the first sport-based concussion severity grading scales. This grading scale was based on the presence and duration of LOC and/or retrograde or post-traumatic amnesia<sup>13;14</sup>.

In 1991, the Colorado Medical Society published Guidelines for the Management of Concussion in Sports as a response to team physicians' call for consistency in the management of concussion in young athletes<sup>49</sup>. This first attempt to build a consensus among experts with regard to sport concussion management was well received as these guidelines were endorsed by the American Academy of Pediatrics, the American Academy of Sports Physicians, and the American College of Surgeons Committee on Trauma<sup>49</sup>. However, the need for a broader consensus was identified and the involvement of the Quality Standards Subcommittee of the American Academy of Neurology emerged.

In 1996, a panel of experts responsible for the treatment of athletes who have sustained a concussion met twice to clarify issues regarding the identification and grading of concussions and criteria for return to play<sup>48</sup>. The result of these meetings was the development of the American Academy of Neurology practice parameter regarding the management of concussion in sport. Their definition of concussion, a traumatically induced alteration in mental status that may or may not involve loss of consciousness, is commonly utilized today. This model advocates the recognition of observable features of concussion and self-reportable symptoms that may present initially or develop days to weeks after the traumatic incident<sup>48</sup>.

The American Orthopedic Society of Sports Medicine (AOSSM) sponsored a Concussion Workshop in December 1997 which resulted in yet another definition of concussion. Their definition includes “any alteration in cerebral function caused by a direct or indirect (rotation) force transmitted to the head resulting in one or more of the

following acute signs or symptoms: a brief loss of consciousness, light headedness, vertigo, cognitive and memory dysfunction, tinnitus, blurred vision, difficulty concentrating, amnesia, headache, nausea, vomiting, photophobia, or a balance disturbance. Delayed signs and symptoms may also include sleep irregularities, fatigue, personality changes, an inability to perform usual daily activities, depression, or lethargy”<sup>97</sup>. While another grading scale was not devised from this workshop, recognizing differences in clinical practice and the importance of consistent definitions, assessment tools and terminology for future research were presented.

The primary concern with current grading scales is that they are frequently based on subjectively assessed symptomology<sup>39;65;84;92;100</sup> and time periods of LOC and PTA<sup>22;68</sup>. However, while these are recognizable signs of concussion, they do not need to be present in order for an injury to be classified a concussion. Guskiewicz et al., reporting on 1003 injuries, found only 8.9% of concussions are associated with a LOC and 27.7% with amnesia<sup>39</sup>. Interestingly, many national and international sport governing bodies have adopted their own concussion grading scales which are primarily based on LOC<sup>45</sup>. The symptoms of headache, dizziness, confusion, disorientation and blurred vision actually occur more often with concussion than do LOC or PTA<sup>34;39</sup>. Lovell et al. demonstrated that LOC is not an important predictor of cognitive impairment following injury<sup>54</sup>. Limited research on the importance of PTA following mild injury indicates that it is not as important of a prognostic measure in mild brain injury as it is in severe brain injury<sup>65</sup>. Many athletes demonstrate motor and cognitive impairment as well as confusion in a concussed state, but do not demonstrate PTA<sup>39</sup>. Johnston<sup>45</sup> makes an

argument that the presence of an attention deficit or attention dysfunction should be essential for the diagnosis and recognition of concussion rather than the symptoms described above.

Following five years of data collection including symptomology, neurocognitive function, and postural stability, Guskiewicz<sup>34</sup> proposed yet another grading scale and return to play model which appears to diminish some of the problems associated with previous models. This model utilizes consciousness, three C's (assessment of cranial nerves II, III, IV, VII and VIII, cognition - memory and concentration, and coordination), and the presences or absence of a headache to grade injuries as mild, moderate or severe. The return to play guidelines emphasize the importance of serial follow-up testing on objective measures as well as a return to participation in a slow and progressive manner. This is the first model that describes a progressive return to participation which is consistent with how athletes are returned to play following orthopedic injuries.

Most recently, an international panel of expert representing the International Ice Hockey Federation (IIHF), the Federation Internationale de Football Association (FIFA), and the International Olympic Committee (IOC) provided a summary agreement statement on concussion in sport. Their lengthy definition reflects: 1) that the injury mechanisms are traumatic forces which could be direct or indirect, 2) these mechanisms may result in neuropathological changes which are functional in nature rather than structural and are rarely seen on neuroimaging studies, and finally, 3) impaired neurological functional disturbances (not necessarily a LOC) resolve in a short period of time along a predictable and sequential course<sup>6,7</sup>. The strength of this grading scale is its

recognition that a concussion results in impaired neurological function. This should guide researchers and clinicians to develop assessment tools which measure functional changes. Further, despite at least 3 of the panel members previously publishing concussion grading scales, they hesitated to endorse any particular one thus reflecting current understanding of the strengths and weaknesses of these scales. Instead, the group recommended combined measures of recovery with individual consideration regarding return to play decisions<sup>6,7</sup>.

Does the perfect definition or grading scale exist? Probably not. The published literature has contributed significantly to the understanding of injury mechanisms, epidemiology, symptomology, and immediate care of sport related concussions, yet it is limited in its ability to substantiate the definition of concussion, recommend grading scales and agree on return to play guidelines used by clinicians<sup>19;39;45;82</sup>. The lack of scientific data to support current grading scales and guidelines has led to controversy and confusion in the research literature and in clinical application. Guskiewicz<sup>34</sup> proposes that “the primary purposes of grading scales are to a) provide a tool for triaging the injury and eventually placing it into a management algorithm based on injury severity, b) assist in predicting outcome, and c) prevent catastrophic outcomes of acute structural brain injury, second impact syndrome, or cumulative brain injury caused by repetitive trauma.”<sup>34</sup> The practical need for grading scales does not lie in the classification of severity, but rather in the identification of when it is safe to return to participation. An emphasis on serial testing of measurable signs and symptoms following injury can be far more valuable in decision making than the presence or absence of any individual

symptom. No athlete should be returned to participation while still symptomatic and when in doubt, erring on the side of caution is advisable to a catastrophic outcome.

### **Cognitive testing**

Neuropsychological testing of cognitive ability following brain injury has been commonly used since the early 1900's. Typically, this testing has been conducted retrospectively on moderate and severe head trauma cases and was neglected in the mild injury. Mild injuries were thought to “heal” on their own without long term or permanent disability. In 1974, Gronwell and Wrightson demonstrated deficits on the Paced Auditory Serial Addition task (PASAT) by mildly injured subjects for about 30-35 days when compared to non-head injured controls<sup>33</sup>. Since that time, numerous other researchers have demonstrated that mild brain injuries result in post-injury cognitive deficits<sup>4;9;11;25;41;42;46;76</sup>. The biggest limitation to most of these studies is the lack of precision in determining if the injured and control groups had similar levels of function prior to injury. While many attempts were made to match groups based on level of education, socioeconomic standards, and life styles, none of these studies compare pre-injury levels of cognitive function to post-injury levels of function. In addition to definition of injury inconsistencies, most of these studies were conducted using only patients who had sought professional assistance for recovery from their injury. Many mild concussions are never reported to medical authorities and often go untreated without significant repercussions. Finally, many of these studies tested individuals at 1, 3 and 6 month intervals following injury and often the injuries did not occur from athletic participation. In an athletic population, 3-6 months may constitute an entire competitive

season, and the type of injury may be different. While much of this research seemed to be at odds with what was typically observed in athletic induced concussions, it did serve as the basis for the development of sport relevant testing batteries<sup>2;9;21;55;58;60;93</sup>.

The first large scale, prospective, neuropsychological assessment of concussed football players began in 1982 with 10 Division I Universities and 2350 athletes participating<sup>2;9</sup>. The purpose of this study was to identify neuropsychological deficits associated with concussed football players, to determine a recovery curve and return to play guidelines based on these results, and to evaluate the long-term consequences of multiple injuries during a college career<sup>2;9;59</sup>. Preseason, baseline tests and post injury testing within 24 hours, at days 5 and 10, and week 12 post injury were obtained. During the study, 200 players met the study's criteria for having sustained a concussion. In addition, 60 orthopedically injured teammates and 50 male college students were recruited to serve as controls. Neuropsychological test measures included the Paced Auditory Serial Addition Task, Digit Symbol Test, and Trail Making Test as well as a symptom checklist. Injured athletes and controls both reportedly demonstrated significant improved performance from pre to post testing scores ( $p < 0.001$ ), although the statistical technique to determine this significance was not reported<sup>55</sup>. Change scores revealed injured athletes gains were significantly less than the control group 24 hours after injury, but by day 5 had reversed this trend to demonstrate significantly greater gains when compared to controls. Comparison of raw scores of injured players to controls 10 days after injury revealed no significant differences between groups<sup>55</sup>. The authors concluded that head injured players demonstrated impaired neuropsychological

test performance, especially in the domains that demonstrated speed of information processing, the day after injury, but were essentially equivalent to the control group by the fifth day after injury and thus able to return to play. These conclusions are suspect because the authors chose to use change scores rather than raw scores. A perusal of their published results would indicate that injured players performance did not significantly decrease from baseline, but simply did not demonstrate learning effects consistent with the control group. The two groups were essentially equivalent at baseline testing and the injured subjects demonstrate a slowed learning curve for approximately 5 days post injury relative to non-injured control subjects. This analysis would question the value of obtaining a baseline score as a marker for “return to normal.” Nonetheless, this study is considered a landmark study for research concerning head injured athletes and has provided the theoretical model for which most recent testing has been conducted.

Using the same data base, Macciocchi et al.<sup>55</sup> compared the neuropsychological test scores of the 183 injured athletes and 60 controls to the symptoms they experienced. His conclusions indicate that athletes with concussion demonstrate impaired cognitive performance as well as increased symptoms in comparison to controls, and that these impairments typically resolve within five days post injury<sup>1;55</sup>.

Lovell, et al.<sup>53</sup> reported similar results to those of Barth, Alves and Macchiocci on a pilot study utilizing 500 high school football players and a slightly different testing protocol. In this study, injured athletes demonstrated limited or no neuropsychological impairments and a rapid resolution of symptoms. Results from this study led to the development of the Pittsburgh Steelers test battery and protocol which has been widely

used by the National Football League and the National Hockey League since the early 1990's<sup>59</sup>. Unfortunately, results utilizing this test battery with these athletes are largely unavailable due to legal restrictions within these leagues.

Maddocks and Selig<sup>58</sup> tested players from three Australian Rules Football teams prior to the start of the season and again five days post injury for those subsequently injured on three neuropsychological tests. The 5-day post injury follow-up test period was chosen because this was when most subjects reported resolution of symptoms associated with their concussion. League umpires matched for age, years of education, and health history served as controls. Results from 10 concussed players found their performance on post injury measures significantly worse than the control group on a Digit Symbol Substitution Task (DSST) and decision time of a choice reaction time measure when their baseline measure of these tasks was used as a covariate in the statistical analysis. PASAT and movement time on the choice reaction time test were not found to be significant between groups post injury. The authors concluded that the DSST and decision time tasks were sensitive measures of persisting neuropsychological deficits in light of resolution of symptoms. Limitations to this study were that players were only tested at five days post-injury. While there was evidence that the two groups differed at this time on two of their tests, there is not an indication as to when these two groups are no longer significantly different thus potentially indicating when it might be “safe” to return to participation. One strength of this study however is the use of the baseline measure as a covariate in the statistical analysis. Performance on many neuropsychological tests is highly varied and individual. Utilizing the baseline as a

covariate removes part of the error variance associated with individual variability<sup>58</sup>.

Continuing research with Australian footballers has used the DSST to demonstrate the effectiveness of this test in confirming return to normal cognitive function upon full resolution of postconcussive symptoms<sup>66</sup>.

McCrary, et al.<sup>66</sup> followed up this study by comparing the symptoms experienced by 23 concussed Australian rules football players relative to their performance on the DSST. Researchers reported that both the number and duration of symptoms correlated significantly with each other as well as with poor performance on the DSST and can be used as a guide for making return to play decisions<sup>66</sup>.

Echemendia et al.<sup>21</sup> prospectively studied 29 injured college athletes and 20 control subjects 2 hours, 48 hours, 1 week and 1 month post injury on a brief neuropsychological test battery. Prior to all analysis, a MANCOVA analysis using Scholastic Aptitude Test (SAT) scores as a covariate was conducted to determine group differences on baseline measures. No significance was found thus eliminating the use of this covariate in all further analysis. Independent day MANOVA analysis indicated that control subjects performed significantly better than concussed athletes at two hours and 48 hours. At one week, the control subjects continued to perform better on 20 of 23 neuropsychological indices than concussed subjects, but the MANOVA analysis was no longer significant. Two important issues are derived from this study. First, this is the first study to include an immediate (2 hours) assessment compared to baseline scores on a brief neuropsychological test battery. McCrea et al.<sup>62,63</sup> used the SAC for immediate sideline assessment, but did not follow-up those studies with an extensive

neuropsychological test battery. Second, this study demonstrates the limitations of using SAT scores as a covariate. While it is well accepted that native intelligence contributes to performance on neuropsychological tests, SAT scores may not be an appropriate score for comparison.

Much of the literature concerning concussion in athletics describes the importance of a baseline measure for comparison purposes post injury to assist in determining when an athlete has returned to normal<sup>21;31;59;72</sup>. However, stability of test scores over multiple administrations is one potential source of error in repeat testing. Lovell and Collins<sup>53</sup> addressed this issue by administering the Pittsburgh Steelers Test Battery to a Division IA college football team prior to the start of contact sessions during the 1996-1997 football season and again following the last game of the regular season. Athletes suffering concussions (N=4) during the season were not included in the final analysis. Alternative forms were used with tests when possible to minimize practice effects. Minimal changes in tests scores were reported from preseason to post-season. Trail A, Trail B, Grooved Pegboard, and Digit Span scores increased slightly, while COWAT and Symbol Digit Modalities scores decreased slightly. Only Trails A and COWAT demonstrated statistically significant changes. The authors concluded that the test battery they utilized demonstrated adequate stability over time and that the utilization of a baseline measure as a determinant for return to play is sufficient. While the authors demonstrated the stability of testing from pre to post season, they failed to identify practice and learning effects which may occur with multiple testing sessions throughout the season. The four athletes who suffered concussions in this study were tested an

additional time at 24 hours post injury. Other studies have tested athletes up to 5 times post injury, often with fewer than 48 hours between testing sessions<sup>2;37;40;79</sup>. To minimize learning effects with repeated testing, it is recommended that retesting of athletes be kept to a minimum and equivalent test forms, when available, be selected<sup>31</sup>.

How many concussions are too many? The effect of repeated trauma on the brain has been studied, with little consensus amongst the experts<sup>57;77</sup>. Boxing, football, and soccer have all been identified as sports where frequent sub-concussive blows may contribute to long-term and permanent cognitive deficits. Tysvaer and Lochen<sup>93</sup> examined thirty-seven former Norwegian National Soccer players and found 81% demonstrated mild to severe deficits in measures of attention, concentration, memory and judgement. It should be noted that this same study found similar deficits in 40% of its control group<sup>93</sup>. Additional research by these authors has supported the notion that permanent deficits occur in soccer players.

Matser et al.<sup>60</sup> compared 33 amateur soccer players to 27 amateur athletes on 16 different neuropsychological tests to determine if participation in amateur soccer resulted in chronic traumatic brain injury. While the amateur soccer players in the study demonstrated impaired planning and memory measures, this study was rife with methodological concerns. First, both the control group and the soccer players were heavy alcohol users limiting the generalization of the results to other populations. Second, 83% of the soccer players had experienced a prior concussion NOT due to soccer participation. The severity of these prior concussions was not discussed and the potential exists that these prior injuries could significantly be lowering the group means.

Finally, some experts have questioned the scoring methods used indicating limitations to the drawn inferences {Letter to JAMA, February 16, 2000}.

Casto et al.<sup>16</sup> compared baseline scores of 17 soccer, 17 softball and 20 football athletes on 5 neuropsychological tests, a Sensory Organization Test, and a Limits of Stability balance test. No significant differences were found between the athletes in their different sports on any of the balance measures. Football athletes demonstrated significantly different results from the soccer players on one neuropsychological variable (COWAT) and from the softball players on another neuropsychological variable (Symbol Digit) when SAT performance was used as a covariate. In both cases the football athletes scored lower than the athletes in the other sports thus suggesting soccer players are not at increased risk for developing long term deficits as a consequence of repetitive minor blows to the head.

Macciocchi et al.<sup>57</sup> reported performance on a brief neuropsychological test battery and symptoms of 12 athletes who sustained multiple concussions within 1 or 2 years of baseline testing. Athletes who sustained two injuries did not perform significantly worse than athletes who sustained only a single injury, nor did they perform worse than after their first concussion or than preseason baseline measures. Analyses of the symptoms revealed that the frequency of symptoms after the second injury did not significantly increase relative to the first injury. The authors concluded that two concussions do not result in significant deficits in cognitive function nor in an increased presence of symptoms<sup>57</sup>.

An objective, quantifiable initial assessment of concussion immediately after injury is a critical step in preventing a more serious or catastrophic injury. The American Academy of Neurology and the Colorado Medical Society Guidelines for the management of concussion both recommend the inclusion of tests assessing orientation, concentration, and memory as paramount in the initial assessment of athletes suspected of having a concussion. In 1995, McCrea et al.<sup>64</sup> established a Standardized Assessment of Concussion (SAC) to be utilized for “documenting the presence and severity of neurocognitive impairment associated with concussion, thereby providing information to athletic trainers and other medical personnel responsible for clinical decision making in the care of athletes.” This test is easily administered in a short period of time (~5 min.) and includes measures of orientation, immediate memory, concentration, and delayed recall as well as a brief neurological assessment of coordination, recall of the event, and performance of sport specific exertional activities. Three different forms have been developed and found to be equivalent<sup>63</sup> with each having a maximal score of 30 points. Initial research with this instrument consisted of baseline testing 141 high school football players during either a game or practice environment. During the season in which the study was conducted, six athletes were identified as suffering a mild concussion (AAN and Colorado Guidelines). These six athletes were retested immediately after injury. One-way ANOVA’s found no significant differences between the group tested during practice and the group tested during game situations. Additionally, there was no significant correlation between score and age indicating that freshman do not score significantly different from seniors. Concussed players scored significantly lower than

non-concussed players on total score ( $F_{(1,145)} = 18.4, p < 0.0001$ ), immediate memory ( $p < 0.0001$ ), and delayed recall ( $p < 0.025$ ). When concussed players post injury scores were compared to their pre-injury baselines, their total scores were significantly lower<sup>63</sup>.

Follow-up research utilizing the SAC consisted of 353 high school (this sample included the 141 previously evaluated) and 215 college non-concussed football players. All subjects performed a baseline evaluation prior to the start of contact practice sessions. Of the 568 subjects, 33 players were identified by medical staffs as having suffered a mild concussion (brief confusion, no LOC). Injured players were tested immediately following injury, and 48 hours after injury. One-way ANOVA found no significant differences between high school and college athletes performance on the SAC ( $F = .01, p = .91$ )<sup>64</sup>. With the larger sample, marginal differences were identified among the three forms ( $F = 3.2, p < 0.04$ ). Concussed players scored significantly lower than non-concussed players on total score, orientation, immediate memory, concentration and delayed memory sections. Using matched t-tests of the injured players immediate post injury score to their baseline score revealed that mean total score was significantly lower post injury ( $t = 4.6, p < 0.0001$ ). At 48 hours post injury, injured athletes' performance had returned to their baseline preinjury measure. Injured players dropped an average of 3.5 points below their preinjury baseline which was 1.48 standard deviations below their own mean. The authors offer two suggestions for clinical use of their data. One is to compare post-injury scores to previously obtained baseline measures. However, in lieu of a baseline score, comparison to normative data to established cutoff points may be possible. Normative data on over 2500 male and female athletes from junior high school

to professional levels of participation, indicate that the instrument is reliable over repeated administrations, free of significant gender effects, and acceptable for all competitive and educational levels<sup>61</sup>. The clinician is warned however, that the SAC does not evaluate all domains of cognitive function (speed of information processing and reaction time specifically) which could be impacted by concussion and should not be used as a stand-alone method for returning an athlete to play following concussion<sup>62</sup>.

One challenge in concussion research is that human subjects have to sustain an injury to be included in the study. Identification of and access to injured individuals can be limited. Experimental animal models have been used but the inferences to human concussion must be cautioned<sup>67</sup>. Beaumont et al.<sup>10</sup> conducted research examining neuropsychological dysfunction after various injury severities in adult rats. Their methodology consisted of dropping a brass weight of known mass onto a stainless steel cap secured to a rodent's skull. Severity of injury was controlled and modified to create five subgroups. After insult, motor and behavioral function was assessed daily for 31 days at which time the animals were sacrificed. Results from this study lead the authors to conclude that neurological reflexes were suppressed longer in the more severely injured animals and that balance beam walking (dynamic) was found to be more sensitive to differences in less severely injured groups while the beam balance test (static stance) was sensitive to differences between the more severely injured groups. The Morris Water Maze and inclined plane test were less sensitive<sup>10</sup>. The impact of this study was that it demonstrated a correlation between injury severity and performance on different motor and cognitive tasks after trauma. This information is valuable in identifying motor

tasks which may be valuable for identifying subtle differences associated with mild brain trauma.

### **Balance Testing**

The evidence supporting the inclusion of sophisticated balance testing during concussion assessment in athletes is less extensive than that of neuropsychological assessment. While it is well documented for more severe injuries<sup>43;44;51;71;96</sup>, it is less prevalent in the mild injury assessment associated with athletic related injuries. Wojtyts et al.<sup>97</sup> state that “newer tools, such as balance testing, cannot be recommended for clinical decision-making after concussion at this time...however, further data collection is encouraged...and...may prove a useful tool for identifying impairment associated with concussion.”

Under normal circumstances, human beings maintain balance by monitoring the feedback control circuit between the brain and the musculoskeletal system. Balance, or postural control, requires the central nervous system to process and integrate afferent information from the somatosensory, visual, and vestibular systems into an appropriate selection and execution of musculoskeletal responses. Deficiency in one of these peripheral systems is usually compensated for by the other systems. However, deficits in the central processing (brain) mechanism may not sufficiently be compensated. The goal of these integrated systems, is to maintain the body's center of pressure within it's base of support. The base of support is all points of the body which are in contact with an object such as the floor, a crutch or cane, or even a railing or wall. The more narrow the base of support, the more challenging it is to maintain postural control. Lehamn et al.<sup>51</sup>

demonstrated this by testing traumatically brain injured (TBI) subjects on multiple balance and beam walking tasks. Fewer subjects were able to maintain the required stance position independently for 22 seconds as the tasks progressed from a comfortable stance to a narrow stance to a tandem stance. Additionally, in all stances, an eyes closed condition presented greater difficulty than eyes open thus demonstrating the influence of the visual system on postural stability. Balance tasks are also classified as static or dynamic. When performing a static task, the goal is to remain as stationary as possible within a predetermined base of support while dynamic tasks challenge the person to maintain upright posture as the base of support is changing<sup>43;79;81;88</sup>. Lehmann et al.<sup>51</sup> also reported a significant correlation between sway on the static tasks with self selected walking speed and distance walked without falling on a balance beam.

The Romberg test, introduced in 1853, is one of the first balance tests to be implemented for the assessment of postural control<sup>81</sup>. This static test is performed by having a person stand with their heels and toes together for approximately 30 seconds with their eyes closed. Without neurological or vestibular dysfunction, this task is easily performed with little to no sway. Closing the eyes eliminates vision as a sensory source and creates a significant increase in sway in patients with cerebral or vestibular dysfunction<sup>5;44</sup>. However, this test only subjectively assesses impairment. Therefore, researchers have attempted to quantitatively and qualitative assess postural stability using criteria such as time to first compensatory event, general assessment of ability, or number of compensatory events per unit of time<sup>43;44</sup>. Regardless of the stance or measurement

criteria, this test is still criticized as overly subjective, difficult to interpret, and insensitive to subtle alterations associated with concussion<sup>37,43,81</sup>.

In 1986, Shumway-Cook, proposed the foam and dome test to examine postural control under altered sensory conditions<sup>87,88</sup>. This technique utilizes a Japanese lantern and a piece of medium density foam to create six different sensory conditions. During the first three conditions, the subject stands on a firm surface. In the first condition, the subjects eyes are open and all sensory modalities have full and accurate input. In the second condition, subjects are blind folded thus eliminating any visual contribution to postural control. During the third condition, a Japanese lantern, attached to a head band and lined with vertical stripes on the interior, is placed over the head. This creates abnormal visual inputs. The same three conditions are then repeated on a foam surface which acts to alter the somatosensory input. Subjects are observed for changes in the amount and direction of sway over the six conditions. If unable to stand for 30 seconds, a second trial is given. Neurologically intact adults are able to maintain balance for 30 seconds in each condition with a minimal amount of body sway<sup>88</sup>. As technological advancements have integrated the use of force platform systems into the study of human balance, this test has become more sophisticated.

Force platforms have allowed quantitative assessment of force production under both static and dynamic conditions. Measuring vertical forces at three or more points on the platform or by measuring torque around the horizontal axis quantifies parameters such as center of pressure and postural sway<sup>30</sup>. Center of pressure is the distribution pattern of the resultant forces and corresponds to the vertical projection of the center of

gravity of the body<sup>30</sup>. Postural sway can be reported as the total excursion (displacement) from the starting position or mean center of pressure in any given direction, or as a percentage of degrees moved from a start position relative to the theoretical maximal degrees of movement possible before a fall would occur.

Using Shumway-Cook's foam and dome model of postural control assessment, Ingersoll and Armstrong<sup>44</sup> tested 48 individuals with varying levels of brain injury (control, mild, moderate and severe based on length of LOC) on a force platform. Total displacement, anterior-posterior displacement, and medial-lateral displacement were measured from the mean position of the center of pressure. The most severely injured group demonstrated significant differences from the control and mild groups, especially as sensory modalities were altered. The authors argue that loss of sensory modality communication potentially predisposes head injured subjects to orthopaedic injuries<sup>44</sup>. While there is some logic to draw these conclusions, testing was conducted on average eight years post injury on a sample that was not necessarily consisting of athletes. Therefore, this study's main contribution to understanding the utility of balance testing in head injured individuals is the inclusion of quantitative measures from the force platform.

Rubin et al.<sup>83</sup> measured postural stability using a foam and dome test on a force platform in mild head injured subject complaining of dizziness post injury. Eighty-one subjects were divided into a control group and a mild head injured and/or whiplash group. The magnitude of deviation in a medial-lateral (ML) direction, an anterior-posterior (AP) direction, and total movement displacement (TMD) were computed from

the mean location of the center of pressure over a 30-second trial. Sensory ratios were then computed. Significant group differences were reported for magnitude of AP sway on all firm surface measures, and the visually inaccurate condition on the foam surface as well as the TMD during the dome/foam condition with the head injured group exhibiting higher magnitudes of sway than the normal control group. Analysis of the ratio scores did not result in statistical significance on ML or AP sway, but the head injured group demonstrated a trend to perform worse when visual inputs were absent or inaccurate. Significant differences were observed in the TMD ratio scores between the groups. Again, the head injured group's performance was worse when visual inputs were inaccurate. It was concluded that the mildly head injured subjects in the study exhibited a reliance on accurate visual inputs to maintain postural stability<sup>83</sup>. While these authors demonstrate the potential use of such testing with head injured individuals, it should be noted the injured participants in this study ranged in age from 16-92 years and had been referred for assessment due to continuing symptomatic dizziness. Also, the authors did not indicate how their injuries occurred nor how long after injury they were tested.

Nashner and colleagues integrated the foam and dome test assessment with force plate technology and created the Clinical Test for Sensory Interaction in Balance (CTSIB). This test uses only four conditions (eyes open and eyes closed both on a firm surface and a foam surface) on a force platform. The lack of a visual conflict condition soon led to the development of the Sensory Organization Test. The Sensory Organization Test (SOT) assesses a person's ability to use inputs from the various sensory modalities which contribute to balance. It consists of three, 20-second trials

under six different sensory conditions: normal vision and normal support surface (condition 1), eyes closed with normal support surface (condition 2), sway-referenced visual input with normal support surface (condition 3), normal vision and sway-referenced support surface (condition 4), eyes closed and sway-referenced support surface (condition 5), and sway-referenced visual and support surface (condition 6). In the sway-referencing conditions, inputs provided by that particular sensory modality are not consistent with information from the other senses thus requiring subjects to suppress the inaccurate information and rely on the remaining sensory systems to maintain quiet upright posture.

Guskiewicz et al.<sup>37</sup> are credited with demonstrating the utility of postural stability testing in the assessment and subsequent clinical decision making (establishment of MHI guidelines) of mild head injuries in athletes. Using a SOT to assess postural stability in eleven concussed athletes and eleven matched controls at days 1, 3, 5, and 10 post injury, along with cognitive assessment on four neuropsychological tests, this study was the first to integrate sophisticated balance assessment into the earlier identified methodological model of serial testing following injury. At day one post injury, concussed athletes demonstrated decreased composite postural stability scores relative to controls and relative to their own baseline scores. Additionally, the injured subjects' day one scores were significantly worse compared to their own day 3 scores. This same pattern held true for the visual ratio, but did not hold for vestibular or somatosensory ratios. Interestingly, all subjects demonstrated a practice effect on the neuropsychological tests, but no significant differences were found between groups. By day three, no significant

differences were identified, but it appears from the day 5 and 10 data that additional recovery is occurring in the concussed athletes. The authors conclude that perhaps, objective and quantifiable measures of balance are sensitive indicators of concussion and thus should be considered an asset in the assessment and return to play guidelines.

Despite the landmark findings, this study was limited in that baseline measures were not included in the model. The utility of such measures was later supported in a case report<sup>79</sup> and on follow-up manuscripts of this ongoing research<sup>35,38</sup>.

Unpublished research conducted at the University of Georgia used similar testing methods as Guskiewicz et al.<sup>37</sup> except the researchers tested athletes as days 1, 2, 3, and 10 post injury. Additionally, this study included baseline measures in the statistical analysis as a covariate. Mixed-model (group by test), repeated measure ANCOVA's for each neuropsychological and SOT test, found significant differences between groups across a ten-day test period on a symptom severity scale, composite balance, Trails B, and Symbol Digit tests. Not significant differences were found on Trails A, COWAT, Hopkins Verbal Learning Total Score, Hopkins Verbal Learning Delayed Score, Digit Span Forward, and Digit Span Backward. These results indicate that injured athletes' symptoms, balance performance, and various neuropsychological tests differ across days from uninjured athletes tested on the same schedule. Separate day ANCOVA's were conducted on all significant between group tests to identify at which days the groups differed. Generally, injured athletes performed worse than control athletes for three days post injury with a recovery to not significant differences by day 10 post injury.

Force plate equipment and assessment tend to be expensive, time consuming, and in many cases very bulky, thus limiting its use in a sports medicine setting. Riemann, Guskiewicz, and Shields<sup>81</sup> proposed the Balance Error Scoring System (BESS) as an alternative balance assessment technique. The BESS test requires subjects to stand as steady as possible during three different variations of the Romberg test (double leg, single leg, and tandem stance) both on a firm surface and a foam surface. Evaluators count the number of errors occurring during each 20-second trial. Errors include lifting hands off iliac crests, opening the eyes, stepping, stumbling or falling, remaining out of the test position for more than 5 seconds, moving hip into more than 30° of flexion or abduction, and lifting forefoot or heel off the floor. Significant correlations between force platform measures of sway and the BESS have been reported for single leg firm, tandem firm, and all foam conditions for 111 male athletes<sup>81</sup>. Interestingly, the original version of the Romberg test, feet together on a firm surface, was the only condition which did not significantly correlate to force plate measures. Additionally, high (.78 to .96) intertester reliability coefficients were found for three evaluators (only for 18 subjects) indicating that the BESS may offer a reliable alternative method of assessing postural stability<sup>81</sup>.

### **Attention, Balance and Dual Task Theory**

Attention is a multifaceted construct closely related to memory, visual and mental tracking, and concentration. Its components, as identified by Lezak<sup>52</sup>, include vigilance, working memory, mental tracking and complex attention. Vigilance is the ability to repeatedly perform tasks over time. This requires sustained focus on a given task. Tests

with widely accepted psychometric properties believed to measure vigilance typically require subjects to scan a list of random numbers or letters and cancel out all of a given number or letter (two and seven test, CPT)<sup>52</sup>. Working memory, also known as short-term storage capacity, is related to how fast and how much information the information processing system can handle at one time. Speed and quantity are directly related in that the faster one can process information, the greater the quantity of information processed. Tests used to measure working memory require subjects to encode increasingly larger amounts of information and repeat them back immediately. Examples would include digit span forward, silly sentences, and sentence repetition<sup>52</sup>. Mental tracking refers to the number of pieces of information a person can attend to at a given time. Normal adults are capable of remembering one thing while doing another. Examples would be reciting the months in reverse, serial addition or subtraction tests, and repetition of digits in the reverse order in which they were presented<sup>52</sup>. Complex attention is the brain's ability to visually search and scan the environment for relevant information with the intent of selecting the appropriate cues and successfully responding to the stimuli according to a set of previously provided rules. These tests rely on sustained, focused attention and directed visual shifting along with adequate visual, motor and agility capacity. Examples include the symbol digit modalities test, trail making test, and digit symbol test<sup>52</sup>.

According to Gronwall, mild head injury produces diffuse damage in the brain which “affects how much and how rapidly information can be processed.” (p. 153)<sup>32</sup>. Information processing capacity is a term that refers to “the number of operations a brain

can carry out at the same time” (p. 154)<sup>32</sup>. Normal adults can walk, chew gum, manipulate a small object and carry on a simple conversation all at the same time. However, when faced with a difficult question, these same individuals are observed to slow down or even stop to think about the answer indicating a need to focus attention on the most complex task. Mild head injured subjects encounter similar difficulties when faced with multiple items of information to be analyzed. When the amount of information presented exceeds the individual capacity, subjects present as inattentive because they are unable to process all of the information<sup>32</sup>. After observing a number of patients who displayed reduced information processing capacity, Gronwall and Wrightson<sup>33</sup> developed The Paced Auditory Serial Addition Task (PASAT). This task requires subjects to add a series of single digits such that the first number is added to the second, the second is added to the third, and so on at increasingly faster rates of presentation. Early research utilizing the PASAT test comparing a head-injured group to a control group found ninety-nine percent of the injured samples scores fell significantly below the control’s scores on initial testing. The head injured group was tested with the PASAT “as soon as the patient had recovered from the “early confused disoriented stage of concussion” and at weekly intervals until their scores had improved to within one standard deviation of the normative sample. This usually occurred within 10-20 days<sup>33</sup>.

Attentional capacity is often measured using a dual task methodology as well. Dual task studies typically present the subject with two tasks to perform concurrently. Dual task methodology can take on different forms. One is to present the first task as the primary task with a secondary task being presented intermittently (probe technique).

Other models do not identify either task as primary or secondary, expecting persons to attempt to perform both tasks equally well and leaving the decision of how to allocate attention resources to the individual. This is often the method chosen when investigating a motor task with a cognitive task. Balance literature in particular does not instruct subjects to maintain their balance first and perform a cognitive task second to the best of their ability, it is left to the subject to decide and determine how to distribute attentional resources.

Dual task method research studies of attention are based on three assumptions: a) that there is a limit of attention in the central processing system, b) performance of the chosen tasks demand part of the limited processing capacity of the central nervous system, and c) two tasks sharing the same processing capacity will result in decreased performance of one or both of the tasks if the capacity is exceeded<sup>50;52;74;86</sup>. If the performance of one activity requires attention, some or all attention resources must be allocated to perform that task. The introduction of a second attention demanding task could a) interfere with the first task, b) interfere with the second task, c) interfere with both tasks equally, or d) completely prevent either task from occurring. Different patterns of interference may tell researchers about where within the information processing system, limitations in attention capacity occur.

Researchers must also address whether the interference of adding a second task is limited by structural interference or capacity interference. Structural interference occurs when physical structures are responsible for decreases in performance and capacity interference occurs when there is a limitation to the central allocation of attention<sup>86</sup>.

Structural interference would be differentiated from capacity interference by looking at driving abilities when using cellular telephones. Driving with a hands free telephone should not create as much structural interference as a hand-held telephone, yet both should create equal capacity interference.

Preservation of balance, whether static or dynamic, requires the integration of visual, vestibular and somatosensory inputs through a complex network of neural connections and information processing centers. A systematic hierarchy linking the spinal cord, brainstem, cerebellum, basal ganglia and cerebral cortex exists. The lowest level of the hierarchy consists of the spinal cord. There, sensory receptors transmit somatosensory information to higher cortical levels and receive information via descending pathways concerning muscle firing patterns and tension. The middle level of the hierarchy consists of the brainstem and the cerebellum. These structures receive information from the spinal cord, somatosensory, visual and vestibular systems. The received information is compared to the intended output and modulated when necessary. The highest level of the perception/action hierarchy is the cerebral cortex and the basal ganglia where movement programs are selected and motor strategies are planned. High order cortices are also responsible for memory, learning, and attention<sup>15</sup>. It is within this perception/action hierarchy that the cognitive aspects of motor control emerge.

Perception is modulated by the sensory neurons and spinal cord. This information is transmitted via afferent pathways to the brainstem and cerebellum where it is interpreted and conceptualized and sent to the cerebral cortex. The cortex selects an appropriate action or strategy and sends this information back to the brainstem and cerebellum. The

brainstem and cerebellum put into action the selected strategy and send this information via descending pathways back down the spinal cord and to the muscle effectors. Higher brain centers, therefore, are responsible for interpreting and integrating inputs from the sensory system, forming motor plans, and developing strategies for muscle actions<sup>88</sup>.

It has been suggested that in a predictable environment, muscle synergies responsible for locomotion and postural control can operate at low spinal levels requiring little cognitive input<sup>50</sup>. However, when postural control and locomotor tasks require adaptive and anticipatory responses, higher cortical inputs are necessary to successfully complete the action<sup>88</sup>. Using a classical information processing framework and dual task methodology, this notion was supported by Lajoie et al.<sup>50</sup>. Subjects reaction times to a verbal stimulus increased as balance and locomotor tasks increased in complexity from sitting, standing with a broad base of support, standing with a narrow base of support, to walking. Thus, the authors concluded that balance control may require “continuous regulation and integration of sensory inputs” and that balance control within the gait cycle is not automatic and loads on the higher cognitive levels. Applying these results to the perception/action hierarchy previously described, initiation of the walking task loaded the highest level of the system in selection of appropriate actions to carry out the task loaded the middle levels for continuous modulation of the activity with the intended performance.

Andersson and colleagues<sup>3</sup>, conducted a dual task study of vertigo patients compared to healthy controls on the performance of a balance task and a visuospatial cognitive task. A Sensory Organization Test (SOT) was used to assess balance. Both the

healthy controls and vertigo patients demonstrated decreased cognitive task performance while they were simultaneously performing the balance tasks. Interestingly, subjects who had normal balance prior to testing (healthy controls) demonstrated increased sway when the cognitive task was added to the balance task, yet dizzy patients who had failed the balance test initially, demonstrated less sway when adding the mental task. The authors explained this last result as occurring possibly because the demanding balance tasks increased arousal level (also considered an executive control resource) or possibly that the addition of the cognitive task served as a mental distractor preventing maladaptive postural strategies from occurring or more specifically responding to misleading proprioceptive information for balance control.

Shumway-Cook and associates<sup>90</sup> conducted interesting research assessing the effect of two different cognitive tasks on the postural stability of older adults with and without a history of falls. Using a dual-task paradigm, they compared performance on two different balance tasks (firm and foam surfaces) while performing a visual-spatial task and while performing a verbal task. Previous research had suggested that performance of a balance task on a foam surface with the eyes open will increase the demands placed on the visual and vestibular systems to compensate for inaccurate information entering the system from the somatosensory system. The authors hypothesized that the greatest interference in their dual task study would result when the subjects performed the balance task on foam with the visual-spatial task because these two tasks are potentially sharing the same information processing pathway. This theory is consistent with the multiple channels of processing theorists who argue that processing

occurs in parallel for tasks which are different resulting in less interference than when tasks are similar and demand processing from a similar channel. Shumway-Cook<sup>90</sup> found that simultaneous performance of cognitive and postural tasks did result in decrements in postural control performance for all three groups, but not cognitive tasks. Additionally, comparisons of the effect of the two cognitive tasks on stability indicate that the sentence completion task resulted in greater disturbances to balance than did the visual-spatial. These differences were greater in older adults with a history of falls than older adults without a history of falls which were greater than younger healthy adult control subjects. While these results did not support the author's hypotheses, they do indicate that even performing simple cognitive tasks effect balance activity and may contribute to increased fall rates in the elderly. Additionally, these results suggest that information processing of balance sensory inputs may take precedent over cognitive tasks when subjects are free to choose the task on which to expend their attentional resources. Guerts et al.<sup>29</sup> used a dual task paradigm to assess static and dynamic postural instability in a sample of traumatic brain injured subjects. Subjects demonstrated no sensorimotor impairment as demonstrated by standard clinical examination, but complained of postural instability and gross motor "clumsiness." Using the GCS, 13 subjects had sustained mild injuries, 2 moderate injuries, and three severe injuries. Quiet standing with eyes open and while wearing dark goggles, as well as a weight shifting task with visual feedback were used as the postural control measures. The cognitive task consisted of a verbal presentation of eight single digit additions to which the subject identified correctness of the problem, presented spatially across each 30-second trial. Injured subjects

demonstrate more than a 50% increase in sway in AP and ML directions when compared to normal controls. Further, the injured group demonstrated significantly more difficulty when visual inputs were deprived thus suggesting sensory integration deficits.

Interesting, dual task interference was not found for the balance data or the arithmetic task. Potential explanations for the lack of interference found included the possibility that the arithmetic task was too easy to induce dual task effects and that static balance tasks are often relegated to automatic processing at the subcortical level, thus bypassing the central processing component often required for more challenging postural control tasks. This conclusion was supported by Vuillerme<sup>94</sup> who theorized that the addition of a 2<sup>nd</sup> task to static postural control tasks, actually may facilitate the automatic processes at a sensory-motor level<sup>94</sup>.

Guerts et al.<sup>26</sup> built on their previous study by adding three neuropsychological tests to their dual task testing. The Symbol-Digit Substitution Test (SDST) was used to assess visuomotor processing and working memory. A15 Word Test was included to assess verbal learning and memory, and a Symptom Checklist - 90 to assess emotional distress. Fifteen mild head injured subjects (GCS>13) who had been referred to an outpatient rehabilitation department for post concussion symptoms at least 3 months post-injury served as participants in the study. Balance and dual task results were similar to those from their previous study. Multiple regression analysis was used to identify the relationship between the balance scores and the neuropsychological test scores. A positive association between the SDST and both the static and dynamic balance tasks

were identified, suggesting that postural instability may not be related exclusively to the postural control systems, but also to the more general systems for visuomotor control<sup>26</sup>.

Attention deficits are common following mild traumatic brain injury<sup>1;9;20</sup>. Head injured patients not only report a multitude of physical symptoms (headache, dizziness, nausea, difficulty sleeping) but also numerous neuropsychological symptoms including difficulties concentrating, remembering, returning to task after being distracted and most important, slow processing of information. Cicerone<sup>17</sup> suggests that most of the attention deficits experienced by this patient population can be accounted for by slowness of information processing. This was supported with evidence from a study in which mild traumatic brain injured patients perform similarly to healthy controls on dual tasks where the secondary task was irrelevant and they were instructed to ignore that stimulus (fairly automatic and less demanding processing). However, when required to respond to the secondary task (controlled processing which is more demanding), head injured subjects performed significantly worse than healthy controls indicating difficulty switching between tasks and inability to sustain effective processing. Performance on both tasks correlated significantly with patient subjective complaints of slowed processing.

Despite the fast growing body of literature regarding the definition, identification and management of concussion, the most important aspect of concussion management remains the education of physicians and health care providers responsible for athletic care. It remains doubtful that a single test (cognitive or balance assessment) will be the gold standard assessment tool, but the more that is understood about the interaction of the cognitive and motor systems, the more complete the puzzle will become.

## CHAPTER 3

### DEVELOPMENT OF THE MULTI-TASK HEAD INJURY ASSESSMENT TEST<sup>1</sup>

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<sup>1</sup>Peterson, C.L., Ferrara, M.S., Casto, S.R., Piland, S.G. *To be submitted to Journal of Sport Rehabilitation*

## ABSTRACT

**Context:** Experts recommend the inclusion of neuropsychological testing and balance assessment for the assessment of concussion. While these tests are conducted independent of each other, sport participation demands simultaneous performance.

**Objective:** Identify the viability of combining cognitive and balance tasks into a dual task paradigm for the assessment of concussed athletes.

**Design:** Participants performed 3 trials of a cognitive and balance task, first independently then concurrently.

**Setting:** College athletic training facilities.

**Participants:** College athletes.

**Main Outcome Measures:** The cognitive task consisted of a rate of completion for serial 7s subtraction while the balance task consisted of seconds to complete a tandem beam walking in both a solo and dual task condition.

**Results:** Cognitive rate did not significantly differ ( $p = .952$ ) from the independent ( $\bar{x} = 4.79$  sec./word) to the concurrent task ( $\bar{x} = 4.77$  sec./word) however, beam walk time significantly increased ( $p < .001$ ) from the independent ( $\bar{x} = 11.52$  sec.) to the concurrent task ( $\bar{x} = 20.04$  sec.). Learning effects were noted across trials.

**Conclusions:** The Multi-Task, Head Assessment Test (MT-HAT) warrants further investigation as an assessment tool for concussed athletes. Despite significant learning effects across trials, the test demonstrates dual-task interference and can be administered with little intertester error.

## INTRODUCTION

Experts in sport related concussion management advocate the inclusion of neuropsychological and sophisticated balance testing to determine injury severity and to assist in making return to play decisions. While the use of traditional neuropsychological testing following severe head injury has been utilized for years, it was not until the mid 1980s that it began surfacing in the athletic realm. One limitation to utilizing traditional, extensive neuropsychological test batteries to assess cognitive function in an athletic population is that these tests typically take between 4 -5 hours to administer. In an athletic environment, large numbers of athletes often need to be tested in a limited amount of time. Therefore, a limited number of tests are often selected from an extensive battery and typically include those which are easy and quick to administer, as well as those which measure aspects of function likely to be affected by concussion. It is now common practice to include immediate side-line evaluations<sup>1-4</sup> as well as limited test batteries<sup>5-10</sup> administered prior to the start of an athletic season (baseline measure) and at pre-determined times following injury to determine when an athlete has returned to normal by comparing post-injury measurements to baseline measures or pre-established norms.

The inclusion of sophisticated balance measures in the assessment of concussion is a relatively recent recommendation. Traditional balance testing of athletes following concussion has consisted of non-instrumented, often subjective, gross measures<sup>11-15</sup>. Technological advancements have resulted in the ability to precisely measure balance disturbances which often occurring with concussion<sup>12</sup>. Guskiewicz<sup>11;16</sup> has demonstrated

the sensitivity of a Sensory Organization Test in detecting differences between healthy, uninjured subjects and concussed athletes following injury. Significant differences in postural control have even been noted in the absence of significant cognitive differences<sup>11</sup>. While both neuropsychological assessments and sophisticated balance testing have been identified as being helpful to practitioners, clinical expertise of physicians remains the primary source for decision making regarding return to play following concussion<sup>17</sup>. Perhaps one explanation for this is that neuropsychological testing and sophisticated balance testing have been criticized as being time and labor intensive to administer and cost limiting to many sports medicine budgets.

Current assessment procedures may also be limiting in that neuropsychological testing and balance testing are conducted separate from each other, yet participation in sport frequently demands dynamic motor activities be combined with rapid cognitive decision making. In other words, athletes must think while performing motor tasks. While sports medicine personnel have advocated the inclusion of sport specific activities into the testing, rehabilitation, and decisions regarding return to participation following orthopedic related injuries, they have strayed from that model in the assessment of athletes with concussions. The athlete who is unable to concurrently perform both cognitively and physically is not only at risk of further injuring themselves, but will not likely be able to perform up to expectations. Based on this, a logical step in concussion assessment methodology might be to integrate cognitive assessment and motor assessment into a dual task testing protocol. This would provide insight into the ability of the athlete to multi-task, thus simulating the demands of their sport.

Dual task testing protocols have been described in the literature with a variety of populations. Marked decreases in the performance of both a mental task and a balance task while performing them concurrently have been reported in normal and “dizzy” patients<sup>18</sup>, in amputees<sup>19;20</sup>, in older adults<sup>21-24</sup>, in those with Parkinsons disease<sup>25-27</sup>, and those with head injuries<sup>28;29</sup>. Dual task method research studies are based on three assumptions: a) that there is a limit of attention in the central processing system, b) performance of the chosen tasks demand part of the limited processing capacity of the central nervous system, and c) two tasks sharing the same processing capacity will result in decreased performance of one or both of the tasks if the capacity is exceeded<sup>22;29-31</sup>.

The purpose of this study was to identify the viability of combining a cognitive task frequently used in the assessment of concussions (serial 7s subtraction test) with a simple balance task (balance beam tandem walk) into a dual task testing paradigm, with a projected goal of using this test for the assessment of athletes with concussions. This test has been named the Multi-Task Head-injury Assessment Test (MT-HAT). Further, because neurocognitive and balance testing have the potential to be time and labor intensive plus require expensive equipment, the investigators felt it was necessary to design a test which would address these issues.

## METHODS

### Subjects:

Certified Athletic Trainers (ATCs) from seven different colleges and universities in the United States assisted with data collection during the fall 2001 sport season. Approval for research with human subjects was obtained from each institution’s

appropriate research review boards. Subsequently, ATCs at each institution recruited athletes who participate in sports with a high risk for concussion (football, soccer, field hockey, and cheerleading) to serve as participants in the study. Logistics and cost restraints required two different methods of training the data collectors. One group of data collectors participated in a training session led by the principle investigator at the National Athletic Trainers' Association annual meeting in Los Angeles, CA, June 2001. This testing session included independently scoring 4 trials of each task, performed by a single participant. The participant intentionally performed to the best of their ability on some trials and committed errors on others. The remaining data collectors viewed a video tape describing the data collection procedures and independently scored a taped performance similar to the performance from the other training session.

Data collection procedures:

Upon reporting to the designating testing site, participants read and signed the consent form, completed a brief demographic information sheet and completed a symptom severity check list. Demographic information was used to eliminate participants who had suffered a significant lower extremity injury in the previous 6 months, were taking medications with a noted side effect of dizziness, had current sinus infection, or reported a history of vertigo. The symptom severity scale consisted of a 20 item check list. Participants were instructed to indicate if they had experienced any of the listed 20 symptoms during the previous 7 to 10 days by circling yes or no. For those symptoms on which they circled yes, they were to indicate the severity (intensity) to

which they had experienced them on a 1 (mild) to 6 (severe) likert scale. See figure 3.3.

From this, a total symptom score was derived by totaling the likert scale ratings.

Instruments:

*Cognitive task: Serial 7s subtraction test.*

Participants were instructed to count backwards by 7's as fast as possible for 30 seconds from random starting points between 95 and 105. If they reached "0" within the 30 seconds, they were to continue counting backwards resuming from 100. Data collectors wrote down the starting number and all answers provided by the participants, correct or incorrect. Incorrect responses were not corrected during testing. The total number of correct subtractions was then divided into 30 seconds and a rate of computation (seconds per correct subtraction) was calculated. Brown<sup>23</sup> and Rankin<sup>24</sup> used a similar task (counting backwards by 3s) but noted in their discussion the presence of a learning effect. We selected 7s based on results from our pilot testing which found no learning effect across trials with serial 7 subtractions ( $p = .747$ ) yet a significant learning effect with serial 3 subtractions ( $p = .014$ ).

*Balance task: Tandem walk on a balance beam.*

Using a standard 2"x4"x8' wooden beam, participants were instructed to perform a tandem walk as quickly as possible from one end to the other using a heel to toe gait and then back to the starting end (going backwards) while keeping their hands on their hips. Timing was conducted manually using a standard stop watch which was started when the back heel left a mark within 2 inches of the end of the board and stopped when any part of the foot crossed this same line 2 inches from the end of the beam. The

number of errors was counted for each error 1 second was added to the time at the completion of the trial. Errors included a touch down on the floor (lose balance), taking a step of larger than approximately 2" between the heel and toe, removing the hands from the hips, or reversing directions before traversing to within 2" of the end of the beam. Our pilot study demonstrated a learning effect between trials 1 and 2 which was not present by trials 3 and 4. Therefore, participants in this study were allowed 5 practice trials before timing/scoring the 6<sup>th</sup> trial.

*Dual task:*

Participants concurrently performed the cognitive task and the balance task as described above. They were instructed to continue to walk as fast as possible AND count as fast as possible while completing each trial.

*Procedures:*

Participants performed one trial of either the cognitive task or the balance task independently before performing the first trial of the dual task. The solo tasks were counterbalanced between schools so as to decrease a testing order bias. The above processes were repeated (solo task AND dual task) two more times with the solo task trials always preceding the dual task trial. However, participants were not given additional practice trials on the balance beam prior to the second and third test trials.

Statistical analysis:

This testing methodology resulted in five dependent variables being identified. A solo task rate of performance on the serial 7s (S7s), a dual task rate of performance on the

serial 7s (D7s), and time to complete the beam walk in both the solo condition (SBW) and dual task condition (DBW), and a symptomology score.

Data were analyzed using SPSS for windows Version 10.1 (SPSS Inc., Chicago). Intertester consistency was computed by comparing the standard deviation of 7 raters on 4 trials of each dependent variable relative to the mean. Additionally, all raters scores were correlated to the principle investigator and each other by way of a Pearson product correlations. Mean scores for the three trials on each of the four dependent variables were computed and analyzed with matched pair student t-tests to identify differences between the solo and the dual performance of the cognitive and balance tasks. Each of the four dependent variables were then analyzed using a repeated measures analysis of variance (ANOVA) to identify consistency of performance across the three trials. Pairwise comparisons, were used to identify differences between individual trials. Finally, each of the four dependent variables was again analyzed using a repeated measures analysis of variance (group X trial) with demographic variables of gender, previous history of concussion, attention deficit disorder and learning disability to identify group differences. Alpha level was set at  $p < .05$  for all analyses.

## RESULTS

Data were collected on 456 participants. Thirty-six participants (7.9%) were deleted from the original sample because they were unable to complete at least one correct subtraction on at least one trial in either the solo or dual task conditions leaving a sample size of 420 (293 males, 127 females). Twenty-seven percent of this sample reported having a previous concussion, 5.5% attention deficit disorder, and 4.3% a

learning disability. Ninety percent of subjects reported symptoms totaling less than 11 points. The sample's symptom mean was 3.68 with a standard deviation of 5.95.

Additional demographic information is presented in Tables 3.1 and 3.2.

Seven data collectors participated in the training session at the 2001 NATA meeting with an additional 23 data collectors viewing the video tape. Mean scores for seven data collectors and the standard deviation associated with these measures on the 4 trials for each of the dependent variables is presented in table 3.3. Our intertester variability and correlation measures indicate high consistency in test administration and scoring. A perusal of the standard deviations relative to their mean and Pearson product correlations of the raters to each other (table 3.4), suggests that 7 different raters scored 4 trials of the dependent variables similarly. Variances of less than .76 seconds per correct number were noted for the serial 7s subtraction test while variances ranging from .15 to .81 seconds were noted for the beam walking tasks. The Pearson product correlations resulted in consistency amongst testers with correlations ranging from .991 to .998.

Means and standard deviations for the three trials and the mean performance of the cognitive task and the motor task performed in both the solo and dual task conditions are presented in Table 3.5. The matched pair student t-tests analysis revealed that during the dual task performance of serial 7s, participants maintained their rate of performance ( $t_{(419)} = .060$ ,  $p = .952$ ) from the solo task performance. However, on the dual task performance of the beam walking task, participants significantly slowed down ( $t_{(419)} = -27.662$ ,  $p < .001$ ) from the solo performance of the task. The change in time from

12.03sec. (solo) to 21.16sec. (dual), represents an average of 43% increase in time to complete the task.

Using the Huynh-Feldt correction factor for violations of sphericity, results of the repeated measure ANOVA reveals a significant learning effect across trials on solo 7s rate ( $F_{(1.96,819.54)}=11.74$ ,  $p<.000$ ,  $\eta^2=.026$ ), solo beam walking ( $F_{(1.94,811.14)}=43.44$ ,  $p<.000$ ,  $\eta^2=.094$ ), dual 7s rate ( $F_{(1.97,824.71)}=13.613$ ,  $p<.000$ ,  $\eta^2=.031$ ), and dual beam walking ( $F_{(1.74,731.82)}=36.32$ ,  $p<.000$ ,  $\eta^2=.08$ ). Within subject contrasts suggest that all of these significant differences were linear in nature. Pairwise comparisons, using a Bonferoni adjustment for multiple comparisons, indicates a significant difference ( $p<.05$ ) on each dependent variable between all trials except trial 2 and trial 3 of the S7s ( $p=.421$ ).

Figures 3.1 and 3.2.

Repeated measure analysis of variance (group X trial) to identify group differences on various demographic variables revealed male participants performed significantly better than female participants on S7s ( $F_{(1,418)}=10.475$ ,  $p=.001$ ) and D7s ( $F_{(1,418)}=13.56$ ,  $p<.001$ ). However, there was a significant gender by trial interaction on S7s ( $F_{(2, 836)}=3.722$ ,  $p=.025$ ,  $\eta^2=.009$ ) suggesting females learn this task faster than males. Athletes reporting a history of previous concussion performed significantly better than those not reporting a history of concussion on S7s ( $F_{(1,418)}=9.780$ ,  $p=.00$ ) and athletes reporting a learning disability performed significantly worse on D7s ( $F_{(1,418)}=16.376$ ,  $p<.001$ ) than those not reporting a learning disability. Those reporting a learning disability demonstrate greater learning effects across trials of the dual tasks as represented by significant group by trial interactions, D7s ( $F_{(2, 836)}=3.718$ ,  $p=.025$ ,

$\eta^2=.009$ ) and DBW ( $F_{(2, 836)}=4.325$ ,  $p=.017$ ,  $\eta^2=.010$ ) respectively. See Tables 3.6 through 3.9 for trial means, F statistics and p-values.

## DISCUSSION

The purpose of this study was to identify the viability of combining a cognitive task frequently used in the assessment of concussions (serial 7s subtraction test) with a simple balance task (balance beam tandem walk) into a dual task testing paradigm, with a projected goal of using this test for the assessment of athletes with concussions. In order to achieve this purpose, four questions needed to be answered. 1) Did the tasks selected exceed the attentional capacities of the information processing centers? 2) If this test is to be used for serial testing following concussion, will learning effects confound interpretation? 3) Can this test be consistently administered? and 4) How do various group demographics effect performance.

Theoretical models of attention appear to support the notion that attention is a human resource which is modulated by the executive control center of the information processing system. Attention is commonly measured by assessing the interference created by performing more than one task at a given time. Numerous authors have demonstrated that postural control and balance activities require attentional resources<sup>18-20;22-24;27;30;32-35</sup>. Preservation of balance, whether static or dynamic, requires the integration of visual, vestibular and somatosensory inputs with the selection and execution of appropriate musculoskeletal responses. A loss of balance might represent a failure within the system and be explained by a deficit in the brain's higher order processing centers.

Guerts<sup>28</sup> used a dual task paradigm to assess static and dynamic postural instability in a sample of traumatic brain injured subjects. The postural control measures consisted of quiet standing with eyes open and while wearing dark goggles, as well as a weight shifting task with visual feedback. The cognitive task consisted of a verbal presentation of eight single digit additions to which the participants identified correctness of the problem, presented spatially across each 30 second trial. Dual task interference was not found for the balance data or the arithmetic task. Potential explanations for the lack of interference found included the possibility that the arithmetic task was too easy to induce dual task effects and that static balance tasks are often relegated to automatic processing at the subcortical level, thus bypassing the central processing component often required for more challenging postural control tasks. This conclusion is supported by Vuillerme<sup>33</sup> who theorized that the addition of a second task to static postural control tasks, actually may facilitate the automatic processes at a sensory-motor level.

Peterson et al.<sup>36</sup> conducted a pilot study assessing the viability of combining a 30 second static balance task scored using the Balance Error Scoring System (BESS) with a 30 second trial of the Paced Auditory Serial Addition Task (PASAT). Results from 20 healthy college age subject found slightly, although not significantly, improved performance on both the BESS and the PASAT when the tasks were performed concurrently rather than independently. Again, the explanation for these results was that the static positions during the BESS test did not demand as much of the attentional resources as anticipated. Lajoie et al.<sup>32</sup> demonstrated that subjects reaction times to a verbal stimulus increased as balance and locomotor tasks increased in complexity from

sitting, standing with a broad base of support, standing with a narrow base of support, to walking. As hypothesized, our results of increased beam walk time from the solo task performance to the dual task performance reflect interference within the information processing system. Thus, to answer our first question of the selected tasks exceeding the attentional system capacities, it appears that the selected tasks are successful in competing for attentional resources.

Shumway-Cook and associates<sup>21</sup> reported research assessing the effect of two different cognitive tasks on the postural stability of older adults with and without a history of falls. They compared performance on two different balance tasks (firm and foam surfaces) while performing a visual-spatial cognitive task and while performing a verbal task. Participants demonstrated that simultaneous performance of cognitive and postural tasks did result in decrements in postural control performance for all three groups, but not in cognitive tasks. These results are consistent with our findings. Specifically, when participants were free to choose the task on which to expend their attentional resources, they maintained their average rate of cognitive function ( $\bar{x}_{(s7s)}=4.79$ ;  $\bar{x}_{(d7s)}=4.77$ ) while sacrificing motor performance ( $\bar{x}_{(sbw)}=12.03$ ;  $\bar{x}_{(dbw)}=20.50$ ) during the dual task test. These data suggest that the motor task is impaired more than the cognitive task and provide face validity evidence in that the tasks selected created the anticipated interference.

Our repeated measure ANOVA and subsequent post-hoc tests indicate that there is a small, but significant linear learning trend across trials for both the cognitive task and the motor task meaning that participants continued to perform better across all three trials

in both the solo and dual task conditions. Pilot testing did not reflect similar learning effects on S7s. In fact, pilot testing participants demonstrated a 4% increase (worse) on S7s rate. Our methodology did reflect anticipated learning effects on the beam walk task as we included five familiarization trials prior to testing. Perhaps more familiarization trials were necessary to decrease this effect. However, greater learning occurred with the S7s (18%) and the D7s (20%) than with the SBW (9%) and the DBW (11%). According to Fisk<sup>31</sup>, one limitation to dual task tests is that tasks with a consistent stimulus input can become automatized with practice. As tasks become automatized, fewer attentional resources are demanded for efficient performance. If the balance task in this project became automatized with practice that could explain the learning effects across trials with the beam walking task in both the solo and dual task conditions. Further, perhaps the automatization of the beam walk task freed attentional resources which were transferred to maintenance of the cognitive task during the dual task performance. This could explain the learning effect across trial of the D7s.

From a clinical perspective, if this test is to be used in concussion assessment (question 2), a decision as to whether to use the mean of the three trials, the mean of the last two trials, or simply the third trial exclusively for comparison of pre-injury performance to post-injury performance must be made. Attention is a multifaceted construct closely related to memory, visual and mental tracking, and concentration. Its components, as identified by Lezak<sup>37</sup>, include vigilance, working memory, mental tracking and complex attention. The serial 7s test is an assessment of mental tracking which refers to the number of pieces of information a person can attend to at a given

time. Normal adults are capable of remembering one thing while doing another. In this case, remembering that they are suppose to count backwards by 7s and the number from which they are to subtract from. Other tests which assess mental tracking include repeating the months in reverse and digit span in reverse. Standard administration of both of these tests does not provide familiarization trials. The Paced Auditory Serial Addition Test (PASAT) is another test which requires the manipulation of numbers. A significant practice effect from the first administration to the second administration is noted with the PASAT, but further practice does not result in further learning<sup>38</sup>. The MT-HAT demonstrates large standard deviations relative to the mean and significant within subject variability, especially on the serial 7s tasks. Therefore, it is recommended that the mean performance of the three trials be used for post-injury comparative purposes.

The effect of repeated trauma on the brain has been studied, with little consensus amongst the experts<sup>39;40</sup>. Boxing, football, and soccer have all been identified as sports where frequent sub-concussive blows may contribute to long-term and permanent cognitive deficits. Because our sample was comprised of a large percent of football and soccer athletes, below par performance on the cognitive variables for those athletes with a history of previous concussion, would not have been surprising. Interestingly, our athletes reporting a history of previous concussion performed better than those reporting no history of previous concussion. Tysvaer and Lochen<sup>41</sup> examined thirty-seven former Norwegian National Soccer players and found 81% demonstrated mild to severe deficits in measures of attention, concentration, memory and judgement. Matser et al.<sup>42</sup> compared 33 amateur soccer players to 27 amateur athletes on 16 different

neuropsychological tests to determine if participation in amateur soccer resulted in chronic traumatic brain injury. While the amateur soccer players demonstrated impaired planning and memory measures, the study was rife with methodological concerns. First, both the control group and the soccer players were heavy alcohol users limiting the generalization of the results to other populations. Second, 83% of the soccer players had experienced a prior concussion not due to soccer participation. The severity of these prior concussions was not discussed and the potential exists that these prior injuries could significantly be lowering the group means. Macciocchi et al.<sup>39</sup> reported performance on a brief neuropsychological test battery of 12 athletes who sustained multiple concussions within 1 or 2 years of baseline testing. Athletes sustaining a second injury did not perform significantly worse than athletes who sustained only a single injury, nor did they perform worse than after their first concussion or than preseason baseline measures. These authors concluded that two concussions do not result in significant deficits in cognitive function. From our data analysis, it appears that history of previous concussion does not significantly impair performance on S7s nor on any of the other measures obtained. It is unlikely that previous experience with this task during an injury evaluation impacted our results. The small effect size (.016) would indicate that this finding is more likely a reflection of individual differences than differences due to history.

It is not uncommon for athletic trainers and physician to use a serial 7s subtraction test during the assessment of concussion. Results from this study revealed that approximately 8% of college athletes were unable to sufficiently complete this task

when uninjured. Thus, inability to perform this task post concussion, might reflect native inabilities rather than abilities inhibited by the injury. In addition, our findings suggest that females have a tendency to perform worse than males on both S7s and D7s when the mean of the three trials is compared. This perhaps could be explained by differences in sample size between the two genders. It is also important to note, however, the significant gender by trial interaction. This suggests that males and females do not perform the same across trials. In fact, a perusal of the trial means would suggest that females demonstrate greater learning across trials.

Those athletes who reported a learning disability performed worse on D7s than those who do not report a learning disability. Collins et al.<sup>8</sup> reported that a history of a learning disability and a history of previous concussion in college football players resulted in lower performance on baseline neuropsychological measures. Specifically, they reported slower performance for those reporting a learning disability on tests which measure speed of information processing (Symbol Digit Modality Test) and executive function (Trail Making Test B). Attention was described earlier as a human resource which is modulated by the executive control center of the information processing system and the argument was presented that the MT-HAT test appears to create interference within the attention system. Further, with the MT-HAT test being a timed test, the speed at which the cognitive manipulations occur affect the performance. It would therefore appear that our results parallel previous studies<sup>8</sup> and that those with a learning disability score lower than those without. Interestingly though, a significant group by trial interaction was noted on both dual tasks (D7s and DBW). A review of the means by trial

suggests that those reporting a learning disability are able to perform the motor task comparable to those not reporting a learning disability by the third trial, but still lag behind on the performance of the cognitive task. This would suggest that these individuals be given extra familiarization trials on the dual tasks prior to test administration.

Results from the symptom severity checklist, while not critical to the development of the MT-HAT, warrant further discussion. While many authors advocate the inclusion of a symptom checklist, it appears that many different forms exist<sup>6;8;10;43;44</sup>. Most checklists include between 16 and 21 items which are rated on a 0 to 6 point likert scale with anchor descriptors indicating intensity (none to severe) or frequency (never to always). While it is not uncommon for college aged athletes to experience symptoms such as headache, fatigue, and nervousness on a daily basis, different anchor systems can yield different results. To address this concern, our symptom scale required the athlete to indicate by circling yes or no if they had experienced the listed symptom (20 items) and for those items to which they responded yes, indicate the severity, 1(mild) to 6(severe) to which they have experienced the symptom over the past 7-10 days. Despite the relatively large number of items on this particular list, we report a lower symptom rating at baseline ( $3.68 \pm 5.95$ ) compared to others ( $10.3 \pm 12.6$ )<sup>8</sup>. We feel better represents the “normal” state of a college athlete. However, the extremely large standard deviations noted with both studies might be an indication that the symptom list is not specific to concussion and actually reflects other constructs.

In conclusion, combining the easily administered dynamic beam walking task with a moderately challenging cognitive task created competition for available attention resources within the information processing system. While many sport affiliated neuropsychologists have identified attention resources as being impaired post concussion, none have suggested using dual task methodologies as an objective assessment tool. It is unlikely and unadvised to select a single test as the gold standard in concussion assessment. However, results from this study indicate that the Multi-Task, Head injury Assessment Test (MT-HAT) warrants further investigation as a possible assessment tool for athletes who have suffered a concussion. Just as it is recommended with all concussion assessment methods,<sup>45;46</sup> it is recommended that a pre-injury baseline assessment be obtained for the MT-HAT. Despite the significant learning effects across trials, the test demonstrates acceptable face validity. Further, this test is cost effective, time efficient and can be administered with little intertester error.

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Table 3.1 Demographic information. Means and standard deviation.

Gender	N	Age (years)	Height (cm)	Weight (kg)
Male	293	19.88 ± 1.57	183.64 ± 6.79	94.90 ± 20.26
Female	127	19.50 ± 1.32	166.04 ± 6.87	60.36 ± 8.27
Total	420	19.77 ± 1.50	178.31 ± 10.57	84.52 ± 23.63

Table 3.2 Health history by sport. Indicates number (percent) reporting.

Sport	N	Previous Concussion	ADD	LD
Football	230	64 (27.8)	14 (6.1)	13 (5.7)
Women's Soccer	80	26 (32.5)	3 (3.8)	4 (5.0)
Men's Soccer	43	11 (25.6)	1 (2.3)	0
Cheerleading	15	4 (26.7)	1 (6.7)	0
Field Hockey	16	2 (12.5)	1 (6.3)	1 (6.3)
Recreational Sport	36	7 (19.4)	3 (8.3)	0
<b>Total</b>	<b>420</b>	<b>114 (27.1)</b>	<b>23 (5.5)</b>	<b>18 (4.3)</b>

LD = learning disability, ADD = attention deficit disorder

Table 3.3 Inter-rater (N=7) consistency. Mean  $\pm$  standard deviation.

	Trial 1	Trial 2	Trial 3	Trial 4
Solo 7s	11.14 $\pm$ .38	12.29 $\pm$ .49	4.00 $\pm$ .00	6.57 $\pm$ .53
Dual 7s	6.71 $\pm$ .76	7.00 $\pm$ .00	3.86 $\pm$ .38	8.00 $\pm$ .00
Solo BW	12.83 $\pm$ .45	12.92 $\pm$ .15	12.75 $\pm$ .43	10.35 $\pm$ .27
Dual BW	21.30 $\pm$ .42	21.39 $\pm$ .81	21.18 $\pm$ .64	20.46 $\pm$ .51

BW = beam walk

Table 3.4 Pearson correlations of six raters to the principle investigator and each other.

	Rater 1	Rater 2	Rater 3	Rater 4	Rater 5	Rater 6
P.I.	.992	.995	.994	.995	.996	.995
Rater 1		.992	.991	.993	.993	.992
Rater 2			.995	.997	.997	.995
Rater 3				.999	.995	.997
Rater 4					.998	.998
Rater 5						.998

P.I. = principle investigator

Table 3.5 Mean scores and (SD) across trials on solo and dual task performance (N=420).

	Trial 1	Trial 2	Trial 3	Mean
Solo 7s rate*	5.32 (4.99)	4.66 (4.01)	4.39 (3.86)	4.79 (3.60)
Dual 7s rate*	5.29 (4.52)	4.76 (3.76)	4.25 (3.61)	4.77 (3.23)
Solo BW time**	12.55 (4.35)	11.98 (3.87)	11.52 (3.69)	§12.03 (3.74)
Dual BW time**	22.32 (9.7)	21.13 (9.25)	20.04 (8.29)	21.16 (8.56)

\*serial 7s rate expressed as seconds per correct subtraction - smaller number indicate better performance

\*\*BW=beam walk, expressed in seconds

§significantly slower than DBW ( $t(419) = -27.662, p < .001$ )

Table 3.6 Solo 7s rate - Normative data across trials by demographic variables.

	N	Trial 1	Trial 2	Trial 3	F	p
Male	293	4.74±4.44	4.36±4.04	4.16±4.10	F <sub>(1,418)</sub> =10.475	.001*
Female	127	6.63±5.88	5.36±3.82	4.93±3.15		
No prev. con.	306	5.72±5.36	4.98±4.37	4.66±4.05	F <sub>(1,418)</sub> =9.780	.002*
Prev. con.	114	4.21±3.62	3.82±2.60	3.66±3.15		
No LD	402	5.25±5.04	4.60±4.00	4.36±3.91	F <sub>(1,418)</sub> =2.034	.155
LD	18	6.78±3.41	6.07±3.71	5.06±1.95		
No ADD	397	5.33±5.08	4.68±4.05	4.41±3.93	F <sub>(1,418)</sub> =.134	.714
ADD	23	5.09±3.14	4.34±2.93	4.13±2.10		

Prev. con. = history of previous concussion, LD = learning disability, ADD = attention deficit disorder  
 scores reflect mean number of seconds to complete a correct subtraction by 7

F and p reflect , between group repeated measures-ANOVA results

Table 3.7 Dual 7s - rate - Normative data across trials by demographic variables.

	N	Trial 1	Trial 2	Trial 3	F	p
Male	293	4.77±3.92	4.52±3.87	3.92±3.29	F <sub>(1,418)</sub> =13.56	.000*
Female	127	6.50±5.46	5.37±3.45	5.07±4.18		
No prev. con.	306	5.56±4.56	4.90±3.78	4.42±3.80	F <sub>(1,418)</sub> =3.533	.061
Prev. con.	114	4.58±4.30	4.46±3.72	3.84±3.04		
No LD	402	5.12±4.34	4.63±3.69	4.20±3.62	F <sub>(1,418)</sub> =16.376	.000*
LD	18	9.24±6.28	8.17±3.88	5.80±3.35		
No ADD	397	5.27±4.55	4.79±3.81	4.25±4.55	F <sub>(1,418)</sub> =.064	.801
ADD	23	5.71±3.82	4.58±3.00	4.55±3.19		

Prev. con. = history of previous concussion, LD = learning disability, ADD = attention deficit disorder  
 scores reflect mean number of seconds to complete a correct subtraction by 7

F and p reflect , between group repeated measure-ANOVA results

Table 3.8 Solo Beam Walk - Normative data across trials by demographic variables.

	N	Trial 1	Trial 2	Trial 3	F	p
Male	293	12.43±4.46	11.71±3.82	11.27±3.76	F <sub>(1,418)</sub> =3.49	.062
Female	127	12.96±4.05	12.57±3.91	12.09±3.45		
No prev. con.	306	12.65±4.19	12.17±3.89	11.71±3.67	F <sub>(1,418)</sub> =1.805	.180
Prev. con.	114	12.42±4.72	11.46±3.76	11.00±3.69		
No LD	402	12.63±4.35	12.02±3.89	11.54±3.71	F <sub>(1,418)</sub> =.876	.350
LD	18	11.67±4.09	10.89±3.21	11.10±3.12		
No ADD	397	12.57±4.41	11.99±3.89	11.52±3.72	F <sub>(1,418)</sub> =.001	.975
ADD	23	12.85±2.97	11.68±3.39	11.48±3.09		

Prev. con. = history of previous concussion, LD = learning disability, ADD = attention deficit disorder  
 scores reflect mean seconds to complete tandem beam walk task

F and p reflect , between group repeated-ANOVA results

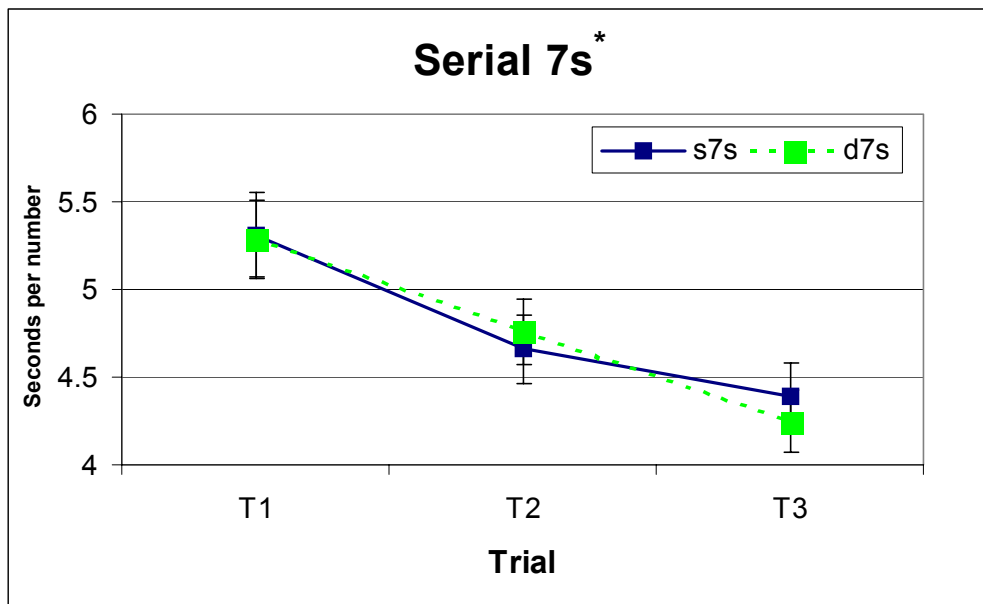
Table 3.9 Dual Beam Walk - Normative data across trials by demographic variables.

	N	Trial 1	Trial 2	Trial 3	F	p
Male	293	22.07±10.35	20.93±9.49	19.87±8.60	$F_{(1,418)}=.476$	.491
Female	127	22.83±8.26	21.52±8.63	20.40±7.52		
No prev. con.	306	22.39±8.75	21.01±8.58	20.07±8.10	$F_{(1,418)}=.001$	.970
Prev. con.	114	22.07±12.10	21.37±10.84	19.92±8.79		
No LD	402	22.10±9.52	21.02±9.15	19.99±8.28	$F_{(1,418)}=1.567$	.211
LD	18	26.78±13.70	23.18±11.02	20.87±8.57		
No ADD	397	22.12±9.68	21.05±9.32	19.98±8.36	$F_{(1,418)}=.894$	.345
ADD	23	25.40±10.89	22.15±7.75	20.80±6.94		

Prev. con. = history of previous concussion, LD = learning disability, ADD = attention deficit disorder  
 scores reflect mean seconds to complete tandem beam walk task

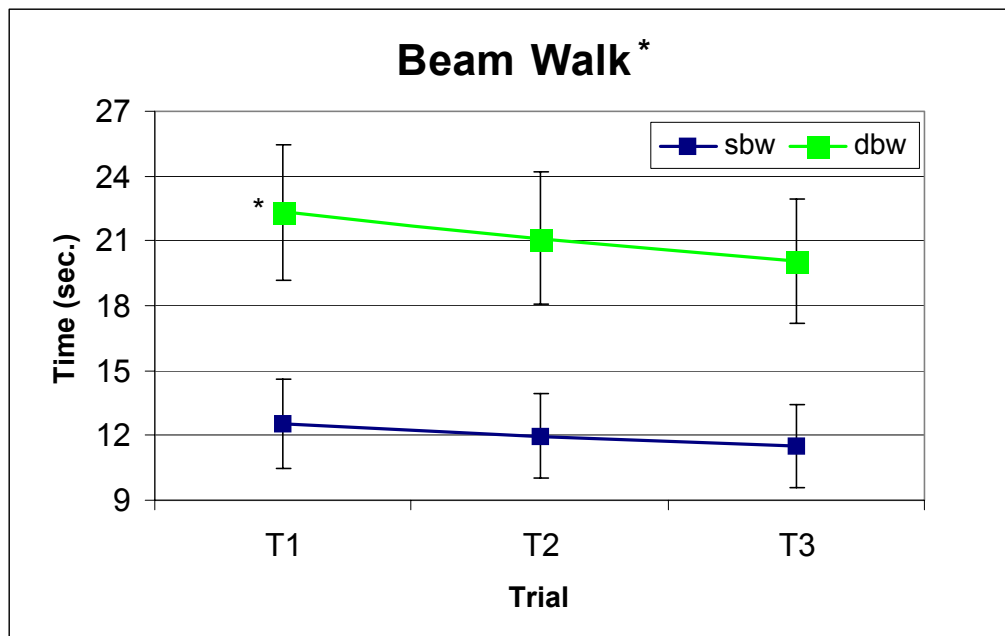
F and p reflect , between group RM-ANOVA results

Figure 3.1. Serial 7s subtraction rate, solo vs. dual task means and standard errors.



\*significant differences across trials, not between conditions.

Figure 3.2 Tandem beam walking, solo vs. dual task means and standard error variance.



\* significant differences within trials and between conditions

Figure 3.3. Symptom Severity Scale

Please indicate if you are experiencing any of the following symptoms by circling yes or no. For those that you circle yes, please indicate the intensity to which you are experiencing it.

Symptom	if yes.....		Mild		Moderate		Severe	
	no	yes	1	2	3	4	5	6
Headache	no	yes	1	2	3	4	5	6
Nausea	no	yes	1	2	3	4	5	6
Vomitting	no	yes	1	2	3	4	5	6
Balance Problems	no	yes	1	2	3	4	5	6
Dizziness	no	yes	1	2	3	4	5	6
Fatigue	no	yes	1	2	3	4	5	6
Trouble falling asleep	no	yes	1	2	3	4	5	6
Sleeping more than usual	no	yes	1	2	3	4	5	6
Drowsiness	no	yes	1	2	3	4	5	6
Sensitivity to light	no	yes	1	2	3	4	5	6
Sensitivity to noise	no	yes	1	2	3	4	5	6
Sadness	no	yes	1	2	3	4	5	6
Nervousness	no	yes	1	2	3	4	5	6
Numbness and tingling	no	yes	1	2	3	4	5	6
Feeling slowed down	no	yes	1	2	3	4	5	6
Feeling in a fog	no	yes	1	2	3	4	5	6
Difficulty concentrating	no	yes	1	2	3	4	5	6
Difficulty remembering	no	yes	1	2	3	4	5	6
Anxiousness	no	yes	1	2	3	4	5	6
Impatient	no	yes	1	2	3	4	5	6
Other	no	yes	1	2	3	4	5	6

## CHAPTER 4

# THE EFFECT OF CONCUSSION ON THE PERFORMANCE OF THE MULTI-TASK HEAD INJURY ASSESSMENT TEST<sup>1</sup>

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<sup>1</sup>Peterson, C.L., Ferrara, M.S., Casto, S.R., Piland, S.G. *To be submitted to Journal of Athletic Training*

### **Abstract**

**Objective:** To address the utility of a dual task testing method in the assessment of athletes with concussion.

**Design and Setting:** Participants completed a symptom severity checklist and performed a cognitive task and a motor task first independent of each other and then concurrently for a total of three trials prior to injury (baseline) and at days 1, 5, and 10 after a concussion.

**Subjects:** 456 college aged athletes completed baseline testing prior to the start of the 2001 fall sports season. Twenty-three suffered a concussion during the season and comprised an injured group while 17 uninjured athletes participated as matched controls at the conclusion of the season.

**Measurements:** Self-reported symptoms, rate of seconds per correct subtraction on serial 7s subtraction task and seconds to complete tandem beam walking during solo and dual task trials.

**Results:** Separate repeated measures ANOVA (2 groups X 4 days) revealed significant interaction for self-reported symptoms, and significant day main effects for solo 7s, dual 7s, solo beam walk, and dual beam walk. Planned comparisons indicate injured athletes performance is significantly worse day 1 post injury compared to baseline (SBW) and day 5 (SBW, D7s, DBW).

**Conclusions:** The MT-HAT test demonstrates significant changes in performance at 24-hours post injury with recovery curves for the balance tasks and D7s similar to previously

identified recovery curves for neuropsychological testing, postural control, and symptoms.

**Key Words:** Concussion in athletes, dual task testing, balance assessment, attention.

## **Introduction**

Despite recent advancements in neuroimaging techniques, the medical community is still unable to reliably image the brain and identify objective findings to account for the signs and symptoms associated with concussion<sup>1</sup>. Unlike most orthopedic injuries, concussion does not present with observable signs of inflammation, palpable areas of pain, weakness on manual muscle tests, nor laxity on stress tests. Therefore, one of the greatest challenges facing sports medicine clinicians is the accurate assessment of neurological function following cerebral concussion. Injury severity classification and return to play decisions are often based on subjective, non-quantifiable information. Experts now recommend the inclusion of neuropsychological test batteries,<sup>2-7</sup> brief sideline assessment tools,<sup>8-12</sup> and sophisticated postural control measures<sup>13-17</sup> in clinical settings to objectively assess injured athletes and assist in determining readiness to return to play. While the inclusion of neuropsychological testing and sophisticated balance testing has advanced the understanding of concussion in sport, the development of grading scales and return to play guidelines do not yet reflect the objective findings of such testing.

Further investigation of the tools which provide the most objective information and how to use this information continues to drive sport related concussion research. One concern with this testing is the time, equipment, and resources necessary to complete this testing limits the availability of it to those with extraordinary resources. Neuro-psychologists advocate the need for their personal expertise in administering and subsequent interpretation of cognitive testing<sup>18;19</sup>. Additional issues associated with the

implementation of neuropsychological testing could include validity of the test battery, problems associated with repeated testing, age, gender, and the level of play<sup>18</sup>. Further, because concussion can injure different anatomic areas of the brain, it is unlikely that one single test will be effective in identifying concussion<sup>18;19</sup>. While the availability of computer and web based neuropsychological tests decreases the personnel requirements, there may remain resource and financial limitations for many school based sport programs. Equipment for sophisticated balance testing can cost upwards of \$50,000 and be extremely time intensive to administer. Cost is certainly one problem associated with current concussion testing recommendations.

Another potential limitation to current testing recommendations is that neuropsychological testing and balance testing have been conducted separate from each other, yet sport performance requires athletes to think and move at the same time. Typically, assessment, rehabilitation and return to participation following an orthopedic injury integrates sport specific tests, yet the assessment of concussion and subsequent return to play decisions fail to capture the critical integration of cognitive function with physical activity. The athlete who is unable to perform normally both cognitively and physically is not only at risk of further injuring themselves, but will not likely be able to perform up to expectations. Therefore, concussion assessment methodologies need to progress to reflect the ability of the athlete to multi-task and thus simulate the demands of their sport.

The combination of a cognitive task with a balance task (dual task paradigm) has resulted in marked decreases in the performance of both the mental task and the balance

task when they are performed concurrently in normal and “dizzy” patients<sup>20</sup>, in amputees<sup>21;22</sup>, in older adults<sup>23-26</sup>, in those with Parkinson’s disease<sup>27-29</sup>, and those with severe head injuries<sup>30;31</sup>. Dual task theory is based on the assumptions that: a) that there is a limit of attention in the central processing system, b) performance of the chosen tasks demand part of the limited processing capacity of the central nervous system, and c) two tasks sharing the same processing capacity will result in decreased performance of one or both of the tasks if the capacity is exceeded<sup>32-35</sup>. If the performance of one activity requires attention, some or all attention resources must be allocated to perform that task. The introduction of a second attention demanding task may a) interfere with the first task, b) interfere with the second task, c) interfere with both tasks equally, or d) completely prevent either task from occurring.

The purpose of this study was to address the utility of a dual task testing method in the assessment of concussed athletes. Potentially, this test could serve as a financially feasible alternative to tests previously described which assist clinicians in the assessment of concussion and subsequent return to play decisions. It was hypothesized that athletes suffering a concussion would perform worse than uninjured control athletes on the selected tasks and that the injured athletes would demonstrate a deterioration in performance immediately after injury followed by a return to baseline measures within 5 to 10 days post-injury.

## **Methods**

### **Subjects:**

Certified Athletic Trainers (ATCs) from seven different colleges and universities in the United States assisted with data collection during the fall 2001 sport season. Approval for research with human subjects was obtained from each institution's appropriate research review boards. Subsequently, ATCs each institution recruited athletes who participate in sports with a high risk for concussion (football, soccer, field hockey, and cheerleading) to serve as participants in the study. Logistics and cost considerations resulted in two different methods of training the data collectors. One group of data collectors participated in a training session led by the principle investigator at the National Athletic Trainers' Association annual meeting in Los Angeles, CA, June 2001. The remaining data collectors viewed a video tape describing the data collection procedures. Both groups independently scored a live or taped performance during which the model intentionally made errors on some trials and performed to the best of their ability on other trials.

### **Data collection procedures:**

Upon reporting to the designating testing site, participants read and signed the consent form, completed a brief demographic information sheet and completed a symptom severity check list. Demographic information was used to eliminate participants who had suffered a significant lower extremity injury in the previous 6 months, were taking medications with a noted side effect of dizziness, had current sinus infection, or reported a history of vertigo. The symptom severity scale consisted of a 17

item check list. Participants were instructed to indicate if they had experienced any of the listed 20 symptoms during the previous 7 to 10 days by circling yes or no. For those symptoms on which they circled yes, they were to indicate the severity (intensity) to which they had experienced them on a 1 (mild) to 6 (severe) likert scale (Figure 4.6). From this a total symptom score was derived.

Baseline data was collected prior to the start of the 2001 fall sport season. All athletes who suffered a concussion during the course of practice or competition, were tested on days 1, 5 and 10 post-injury. At the conclusion of the sport season, an equated control group was generated by rank ordering all baseline performances and selecting athletes of the same gender who did not suffer a concussion and demonstrated  $\pm 10$  percentile of an injured athletes baseline performance on 3 of 4 dependent variables.

#### Instruments:

*Cognitive task: Serial 7s subtraction test.*

Participants were instructed to count backwards by 7's as fast as possible for 30 seconds from random starting points between 95 and 105. If they reached "0" within the 30 seconds, they were to continue counting backwards resuming from 100. Data collectors wrote down the starting number and all answers provided by the participants, correct or incorrect. Incorrect responses were not corrected during testing. The total number of correct subtractions was then divided into 30 seconds and a rate of computation (seconds per correct subtraction) was calculated. Brown<sup>25</sup> and Rankin<sup>26</sup> used a similar task (counting backwards by 3s) but noted in their discussion the presence of a learning effect. We selected 7s based on results from our pilot testing which found

no learning effect across trials with serial 7 subtractions ( $p = .747$ ) yet a significant learning effect with serial 3 subtractions ( $p = .014$ ).

*Balance task: Tandem walk on a balance beam.*

Using a standard 2"x4"x8' wooden beam, participants were instructed to perform a tandem walk as quickly as possible from one end to the other using a heel to toe gait and then back to the starting end (going backwards) while keeping their hands on their hips. Timing was completed manually using a standard stop watch which was started when the back heel left a mark within 2 inches of the end of the board and stopped when any part of the foot crossed the same line 2 inches from the end of the beam. The number of errors was counted and 1 second added per error to the time at the completion of the trial. Errors included a touch down on the floor (lose balance), taking a step of larger than approximately 2" between the heel and toe, removing the hands from the hips, or reversing directions before traversing the length of the beam. Our pilot study demonstrated a learning effect between trials 1 and 2 which was not present by trials 3 and 4. Therefore, participants in this study were allowed 5 practice trials before timing the 6<sup>th</sup> trial.

*Dual task:*

Participants concurrently performed the cognitive task and the balance task as described above. They were instructed to continue to walk as fast as possible AND count as fast as possible while completing each trial.

*Procedures:*

Participants performed one trial of either the cognitive task or the balance task independently before performing the first trial of the dual task. The solo tasks were counterbalanced between schools so as to decrease a testing order bias. The above processes were repeated (solo task AND dual task) two more times with the solo task trials always preceding the dual task trial. However, participants were not given additional practice trials on the balance beam prior to the second and third test trials.

Statistical analysis:

This testing methodology resulted in four dependent variables being identified. A solo task rate of performance on the serial 7s, (S7s), a dual task rate of performance on the serial 7s (D7s), time to complete the beam walk in the solo condition (SBW) and time to complete the beam walk on the dual task condition (DBW). In addition to these four variables, the total score reported on the symptom severity scale, was collected at each data point and analyzed.

Statistical analysis was conducted using SPSS version 10.1 (Chicago, IL) software with statistical significance set at  $p < .05$  for all analysis. For each subject, a three trial mean was computed on each variable for each day and used for subsequent analyses. Separate mixed model repeated measures ANOVAs (2 groups X 4 days) were conducted using the mean scores on each of the four dependent variables as well as the total score from the symptom checklist. Significant group differences by day were determined using a one-way ANOVA at each test day while significant differences across days within each group were identified using a one-way repeated measures ANOVA with

planned comparisons on both groups. All violations of sphericity were corrected using a Huynh-Feldt correction factor and the family wise error rate controlled with a Bonferroni correction factor for multiple comparisons.

### **Results**

Baseline data was collected on 456 participants. Thirty-six participants (7.9%) were deleted from the original sample because they were unable to complete at least one correct subtraction on at least one trial in either the solo or dual task conditions leaving a baseline sample size of 420 (293 males, 127 females) participants. Twenty-three athletes (5.5%, 19 males, 4 females) suffered a concussion during the course of the fall sport season. At the conclusion of the fall sport season, fifteen males and two females, who had not suffered a concussion were equated with athletes who had suffered a concussion using the previously described methods to form a control group. Of the injured athletes, 16 participated in football, 4 in women's soccer, 2 in men's soccer, and 1 in men's basketball. Nine (39%) of the injured participants reported a history of previous concussion while 5 (30%) of the control participants reported a history of a previous concussion. Of the 23 injuries, 4 were reported as grade 1 injuries and 19 as grade 2 injuries according to American Academy of Neurology guidelines. Two of the injured participants were missing single day data points and were not included in the repeated measures analyses, but were included in post-hoc, by day comparisons. Additional demographic information is presented in Table 4.1.

Means, standard deviations and between-group F-statistic ANOVA results for the four dependent variables and self-reported symptoms are presented by group and by test

day in Table 4.2. Based on the separate mixed model repeated measures ANOVAs (2 groups X 4 days) a significant interaction was found on the self-reported symptom checklist ( $F_{(3,108)} = 18.574$ ,  $p = .000$ ,  $\eta^2 = .340$ ), but not on any of the four dependent measures. Significant main effects were noted for test day on S7s ( $F_{(3,108)} = 6.791$ ,  $p = .001$ ,  $\eta^2 = .159$ ), D7s ( $F_{(3,108)} = 5.476$ ,  $p = .002$ ,  $\eta^2 = .132$ ), SBW ( $F_{(3,108)} = 8.367$ ,  $p = .000$ ,  $\eta^2 = .189$ ), and DBW ( $F_{(3,108)} = 15.511$ ,  $p = .000$ ,  $\eta^2 = .301$ ). No significant differences were found between the group's performance on S7s ( $F_{(1,36)} = .131$ ,  $p = .719$ ,  $\eta^2 = .004$ ), D7s ( $F_{(1,36)} = .192$ ,  $p = .664$ ,  $\eta^2 = .005$ ), SBW ( $F_{(1,36)} = 2.186$ ,  $p = .148$ ,  $\eta^2 = .057$ ), nor DBW ( $F_{(1,36)} = 1.683$ ,  $p = .209$ ,  $\eta^2 = .044$ ).

The one-way ANOVA to identify differences between the injured and control groups on symptoms at each day demonstrates the injured group reports significantly greater symptoms on Day 1 ( $F_{(1,37)} = 33.557$ ,  $p = .000$ ,  $\eta^2 = .476$ ) and Day 5 ( $F_{(1,38)} = 6.278$ ,  $p = .017$ ,  $\eta^2 = .142$ ) post injury. These groups reported similar symptoms at baseline ( $F_{(1,37)} = 3.813$ ,  $p = .058$ ,  $\eta^2 = .093$ ) and at Day 10 ( $F_{(1,38)} = .252$ ,  $p = .618$ ,  $\eta^2 = .007$ ). See figure 4.1.

Injured athletes performance significantly differed across days on S7s ( $F_{(3,60)} = 5.157$ ,  $p = .006$ ,  $\eta^2 = .205$ ), D7s ( $F_{(3,60)} = 4.445$ ,  $p = .007$ ,  $\eta^2 = .182$ ), SBW ( $F_{(3,60)} = 9.640$ ,  $p = .000$ ,  $\eta^2 = .325$ ), and DBW ( $F_{(3,60)} = 11.652$ ,  $p = .000$ ,  $\eta^2 = .368$ ). Results of the pairwise comparisons, adjusted for multiple comparisons by using the Bonferroni method, indicate that on S7s, injured participants performed significantly slower at baseline ( $p=.039$ ) and at Day 1 post-injury ( $p=.004$ ) than at Day 10 post-injury. Within subject contrasts suggests this difference is linear in nature ( $F_{(1,20)} = 10.165$ ,  $p=.005$ )

indicating a learning effect across days (Figure 4.2). Analysis of performance on D7s, indicates injured participants performed significantly worse on Day 1 than on Day 5 ( $p=.026$ ) and Day 10 ( $p=.045$ ). Unlike S7s, however, D7s demonstrated a significant cubic trend ( $F_{(1,20)}=5.496$ ,  $p=.029$ ) suggesting impaired performance at Day 1 post injury most likely due to injury (Figure 4.3). Performance on the solo beam walk task revealed impairment on Day 1 post-injury compared to baseline ( $p=.010$ ), compared to Day 5 ( $p=.017$ ) and compared to D10 ( $p=.004$ ) (Figure 4.4) while the dual beam walk task revealed impairment at Day 1 compared to Day 5 ( $p=.006$ ) and Day 10 ( $p=.000$ ) (Figure 4.5). Again, these analyses reflect a trend suggestive of impaired performance on Day 1 due to injury. The control group demonstrated significant differences across days on D7s ( $F_{(3,48)} = 3.971$ ,  $p = .013$ ,  $\eta^2 = .199$ )(Figure 4.3) and on DBW ( $F_{(3,48)} = 6.003$ ,  $p = .002$ ,  $\eta^2 = .273$ ) (Figure 4.5). The planned comparisons suggest that the control participants improvements occurred from baseline to Day 10 on D7s ( $p=.037$ ), and from Day 1 to Day 10 on DBW ( $p=.01$ ). Contrasts suggest a linear trend reflective of a learning effect rather than impairment from injury.

### **Discussion**

Concussion is a unique injury that presents dilemmas for sports medicine physicians and athletic trainers in assessment and subsequent management. The Summary and Agreement statement from the 1<sup>st</sup> International Symposium on Concussion in Sport, Vienna 2001, includes in the definition of concussion that a concussion, in part, has short lived impairment of neurological function that resolve spontaneously and that neuropathological changes largely reflect functional disturbance rather than structural

injury<sup>36</sup>. From this definition, it appears one current challenge in concussion research is to identify assessment techniques which address neurological function.

The purpose of this paper was to assess the combination of a cognitive task and a motor task for the assessment of athletes who have suffered a concussion. Dual task testing methodologies, which result in decreased performance of one or both tasks when combined, is proposed as a measure neurological function<sup>23;25;31;32</sup>. A review of the information processing system supports this proposal. Information processing is the way in which individuals absorb stimuli from the environment and apply meaning to them. It consists of receptors receiving stimuli from the internal and external environment, processing of the stimuli through the sensory system, perceiving and assigning meaning to the stimuli, and effecting an appropriate response. To facilitate transmission through the system, the executive control center regulates available resources such as attention, memory and concentration. An analysis of our baseline data, reveals that performing the two selected tasks concurrently results in participants maintaining their rate of cognitive performance from the solo to dual task condition, but significantly slowing their motor task performance when combined with the cognitive task (Peterson, in review). These results support the methodology that the selected tasks create interference within the attentional system.

In attempt to identify tests which best assess impaired neurological function post concussion, numerous researchers have identified differences in performance between athletes who recently suffered a concussion and a healthy, non-concussed control group on various neuropsychological tests<sup>5;7;37-40</sup> as well as balance tasks<sup>13;15-17;40;41</sup>. However,

this body of literature is inconclusive about which tests demonstrate greatest sensitivity. For example, some researchers have found the Paced Auditory Serial Addition Test (PASAT) to be a sensitive indicator of concussion immediate post injury<sup>7</sup>, while others have found it less sensitive<sup>37</sup>. Maddocks and Saling<sup>37</sup> reported significant group differences on a Digit Symbol Substitution Test and on decision time from a Four Choice Reaction time test, but not on the PASAT or movement time from the Choice Reaction Time test. In another study, tests of verbal learning and memory appeared to be the most sensitive domains in discriminating athlete with concussions from controls at the 24-hour post-injury testing session in another study<sup>5</sup>. Guskiewicz<sup>13</sup> failed to identify group differences on four different neuropsychological test measures post injury, but did identify significant changes across testing days. Macciochi et al<sup>7</sup> reported injured athletes demonstrated less improvement on five neuropsychological tests (PASAT 3 & 4, Trails A & B, and Digit Symbol Test) than controls immediately following mild head injury. However, a review of the mean raw scores, indicates injured subjects actually perform better on these measures within 24 hours of the injury than at baseline. It appears that these tests demonstrate too great of a learning curve to identify impairment when compared to a pre-injury baseline measure and that simply performing equal to baseline may not be an appropriate criteria on which to base return to play decisions. Taken collectively, it appears that research reporting group differences on neuropsychological test measures, demonstrates inconsistent results. To further conflict the interpretation, some data suggest that injured athletes actually performed better immediately post-injury than they did at baseline. What should be learned from these

studies is that individual performances can and do differ drastically from others' performances. Further it has been identified that following a concussion, performance variability appears to be even greater<sup>39</sup>. Perhaps these large differences in performance can, in part, explain the lack of group differences identified using the statistical models selected. Group data have a tendency to obscure the variability associated with each test. Identification of differences between groups across multiple testing days using the same measures at each day lends itself nicely to a repeated measures analysis of variance. However, to compute between group differences, performance across days (baseline through day 10) is averaged together to compute a marginal mean. Large variances in an analysis of variance have a tendency to wash out between group differences. Further, if one group (injured) performs worse on a single day, but performs similar to the control group on all other days, and both groups have large variances associated with them, the between group measure would most likely not reflect significant differences. Therefore, one possible cause for lack of statistical significance on these measures is the large amount of variance both within individuals' trials and between individuals in both groups. One plausible explanation for such large variances in human participants is motivation. Like others<sup>39</sup>, it is possible that our injured group may have been more motivated to perform well on these tests as they may have been under the mistaken assumption that results from the testing might impact return to play decisions of the team medical staff. The control group, however, was informed that they were participating in a research study as control subjects and therefore the potential exists that they lacked motivation to perform to the best of their ability on every trial.

Our lack of significant group differences on the four dependent variables in this study perhaps could be explained by the subject variability described above. Another possible explanation is the relatively small number of subjects in both groups coupled with the small to moderate effect sizes found on the dependent measures. While group differences lend one type of support to a concussion test, comparing post-injury scores to baseline scores can be equally informative<sup>6;9;16;39</sup>. Echemendia<sup>39</sup> advocates “return to play decisions should be based on idiographic, not group comparisons(p.27). When only the injured group data were analyzed, Day 1 post-injury scores were significantly worse than baseline on SBW and significantly worse than Day 5 and 10 on the D7s, SBW, and DBW while the control group failed to demonstrate significant changes in performance immediately post injury. Additionally, it should be noted that the injured groups performance on Day 1 approached being statistically significant ( $p = .07$ ) from baseline on both of the dual task tests. Perhaps with a greater number of participants, these results would have been different.

We hypothesized that athletes with concussion would demonstrate greater interference on the dual tasks than uninjured athletes. This hypothesis was found to be true as injured athletes performance on D7s at Day 1 post-injury decreased 16 % from baseline while the control group demonstrated an 18% improvement. Further, the injured athlete’s DBW times at Day 1 post-injury slowed by 18% while the control group demonstrated only a 4% change. These results support and are explained by the dual task testing theory. Remember, this theory is based on the assumption that attention is limited

in capacity and others have demonstrated impaired performance on tests of attention following concussion<sup>7,30</sup>.

Thirty-nine percent of our injured sample reported having previously suffered a concussion. Given the likelihood that 4.5 to 5.5% of collegiate football players suffer a concussion on any given year<sup>42</sup> and the skewed nature of our injured sample (football athletes comprised 76%), this statistic does not appear to be unrealistic. Epidemiological studies suggest that the incidence of concussion at the high school level of competition is even higher<sup>42-44</sup>. By the time athletes reach the age and skill level required to compete at the collegiate level, they have amassed years of competitive experience. Multiplying the years of experience with the rate of incidence results in a logical explanation for this statistic. While the literature suggests that a history of previous concussion may result in greater and prolonged neurological impairment following subsequent injury<sup>45</sup>, it is unlikely this explained significant differences in performance at day 1 post-injury for our control group. Thirty percent of our control group also reported previously suffering a concussion yet failed to demonstrate impaired performance at day 1 post injury or when compared to the injured group at baseline assessment.

One criticism of current assessment and return to play guidelines is that they are based on subjective measures, such as symptoms, and signs, such as loss of consciousness, which are of short duration. Authors of the majority of sport related concussion studies speculate that neurologic function remains impaired for approximately 3 to 5 days post injury and that athletes who are symptom free and demonstrate normal function, can “safely” be returned to contact and collision sports

approximately 5 to 7 days post injury<sup>7;13;14;18;39</sup>. While symptomology is largely considered subjective in nature, when parametrically analyzed, as it was in this study, the results often support the return to play guidelines. Our self-reported symptoms was the only measure which demonstrated a significant interaction between the injured groups scores and the control group scores across testing days. Further, it demonstrated the greatest effect size ( $\eta^2 = .340$ ). Our injured athletes symptom score returning to normal sometime between Day 5 and Day 10 post-injury supports current guidelines which suggest that athletes should be symptom free before their return to contact and collision sports.

While counting backwards by 7s is often used by athletic trainers to identify impaired neurological function, it appears to not be a sensitive indicator. Traditional testing methods of serial 7s consists of scoring the ability to complete the task in non-parametric fashion (yes-no). For the purpose of this study, we chose to compute a rate of seconds per correct subtraction which allowed us to use inferential statistics for analysis. It is concluded that the cognitive task is best left as simply an attention consuming variable which creates interference while the assessment of performance on the balance tasks is a reflection of impairment due to injury when using the MT-HAT.

The strength of this methodology is the emergence of postural control and balance assessments as consistent measures of impaired neurological function following concussion. Our data parallels that reported by Guskiewicz<sup>40</sup> who found injured athletes performance on a Sensory Organization Test and a Balance Error Scoring System test differed significantly at Day 1 post injury when compared to baseline and Day 3 post

injury. Another strength of this methodology is that the assessment of motor function is less impacted by native intelligence than individual neuropsychological tests and brief neuropsychological test batteries. Performance of balance tasks challenge neurological function by demanding central integration of information received from the vestibular, visual and somatosensory systems. Under normal conditions, this presents few problems for a young healthy individual. However, these results suggest that the brain centers responsible for this information may be impaired for a short period of time following concussion.

It was concluded that the MT-HAT test demonstrates significant changes in performance at 24-hours post injury. The recovery curves of the balance tasks and D7s were similar to the recovery curve for signs and symptoms as well as those previously reported in the literature for neuropsychological tests<sup>5;7;37;46</sup>, tools for immediate sideline assessment<sup>8;47</sup>, and sophisticated balance assessment<sup>13;40</sup>. No two concussions are alike and recovery is certainly variable. Some injuries may impair the cognitive function of the brain while others may impair the motor control centers of the brain. Impaired function may resolve quickly while some symptoms may linger. While it is unlikely that any one single test will become the gold standard of assessment for concussion, the rationale behind, and preliminary results of research using the MT-HAT suggest this test warrants further consideration for use as an objective assessment tool.

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**Table 4.1 Demographics. Means  $\pm$  standard deviations.**

		N	Age (years)	Height (cm)	Weight (kg)
Injured	male	19	20.16 $\pm$ 1.54	184.43 $\pm$ 5.92	103.3 $\pm$ 20.44
	female	4	18.25 $\pm$ 1.26	165.10 $\pm$ 7.19	57.16 $\pm$ 5.68
Control	male	15	19.93 $\pm$ 1.03	189.31 $\pm$ 9.14	111.70 $\pm$ 26.76
	female	2	19.00 $\pm$ 1.41	167.64 $\pm$ 7.19	64.09 $\pm$ 12.21

**Table 4.2 Means  $\pm$  standard deviation for dependent variables across days.**

	Baseline	Day 1	Day 5	Day 10	F	p
Solo 7s						
injured †	5.17 $\pm$ 3.29	4.67 $\pm$ 2.75	4.10 $\pm$ 2.78	3.24 $\pm$ 1.90	.131	.719
control	5.32 $\pm$ 3.94	5.13 $\pm$ 5.82	4.32 $\pm$ 4.26	4.01 $\pm$ 3.99		
Dual 7s						
injured †	4.98 $\pm$ 2.92	5.93 $\pm$ 3.54 §	4.15 $\pm$ 2.28	3.69 $\pm$ 3.68	.192	.664
control	5.04 $\pm$ 3.96	4.14 $\pm$ 3.45	4.62 $\pm$ 4.44	3.28 $\pm$ 2.14		
Solo BW						
injured †	11.49 $\pm$ 3.15	14.39 $\pm$ 5.17 ‡	11.86 $\pm$ 3.46	11.27 $\pm$ 3.13	2.186	.148
control	10.57 $\pm$ 2.43	11.65 $\pm$ 3.76	11.04 $\pm$ 2.74	10.13 $\pm$ 2.81		
Dual BW						
injured †	18.73 $\pm$ 7.39	23.08 $\pm$ 9.63 §	17.77 $\pm$ 5.79	16.47 $\pm$ 6.07	1.638	.209
control †	17.61 $\pm$ 5.48	18.31 $\pm$ 6.74	16.08 $\pm$ 5.17	14.27 $\pm$ 4.06		
Symptoms						
injured †	8.67 $\pm$ 9.02	25.86 $\pm$ 17.39*	7.62 $\pm$ 11.32*	1.86 $\pm$ 5.14	19.463	.000*
control	4.00 $\pm$ 4.56	1.88 $\pm$ 3.20	1.15 $\pm$ 2.15	1.12 $\pm$ 1.50		

F and p statistics represent relationship between the groups, across days (repeated measures ANOVA)

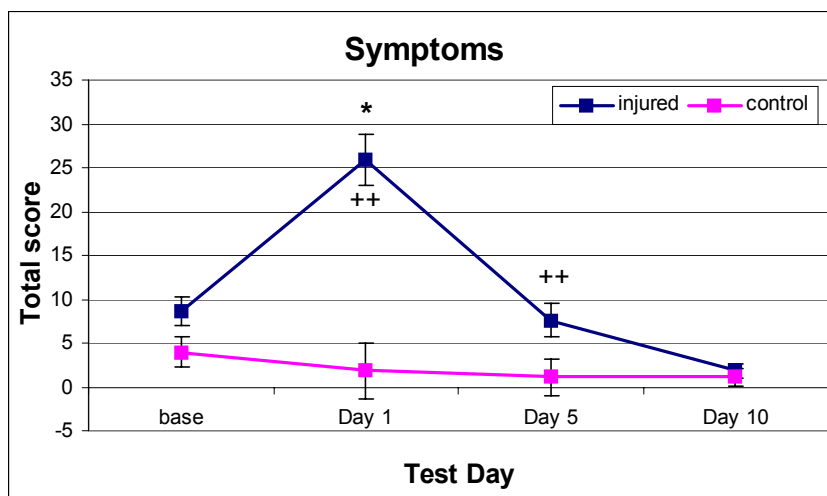
\*injured group significantly worse than control group

†within group significant difference across days

‡within group significantly different from baseline, D5 and D10

§within group significantly different from D5 and D10

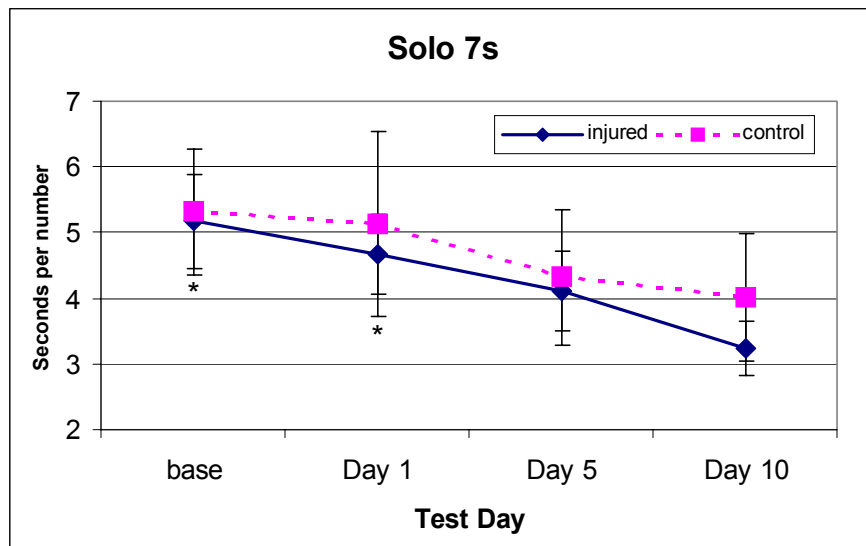
Figure 4.1 Injured and control group, mean symptoms across test days.



\* significantly different Day 1 relative to baseline and Day 5.

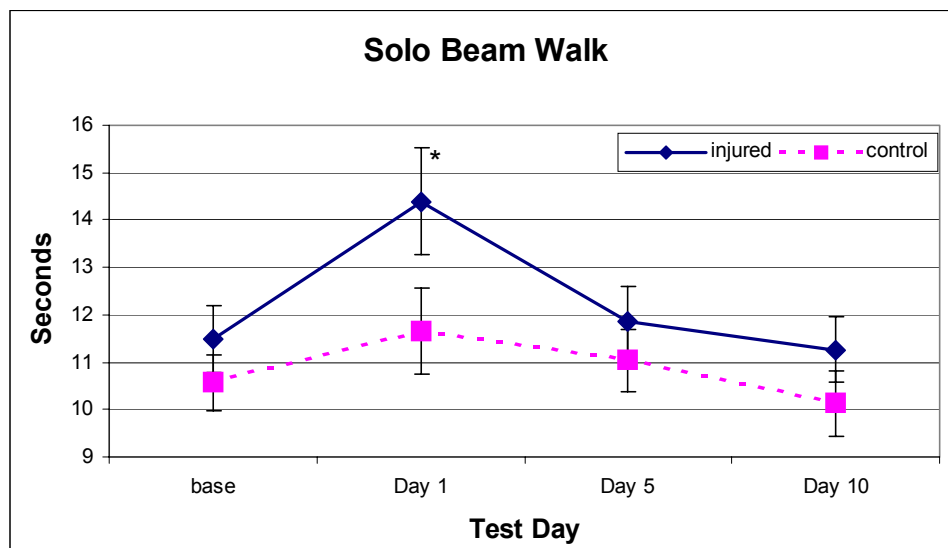
\*\* significant between group differences

Figure 4.2. Injured and control group, mean solo 7s across test days.



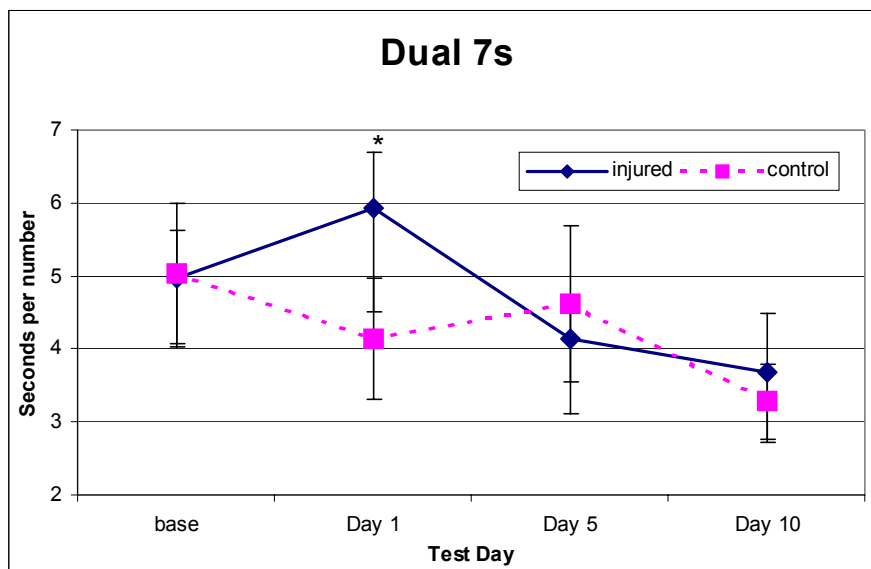
\*injured group significantly different at baseline and day 1 compared to day 10.

Figure 4.3. Injured and control group, mean solo beam walk across test days.



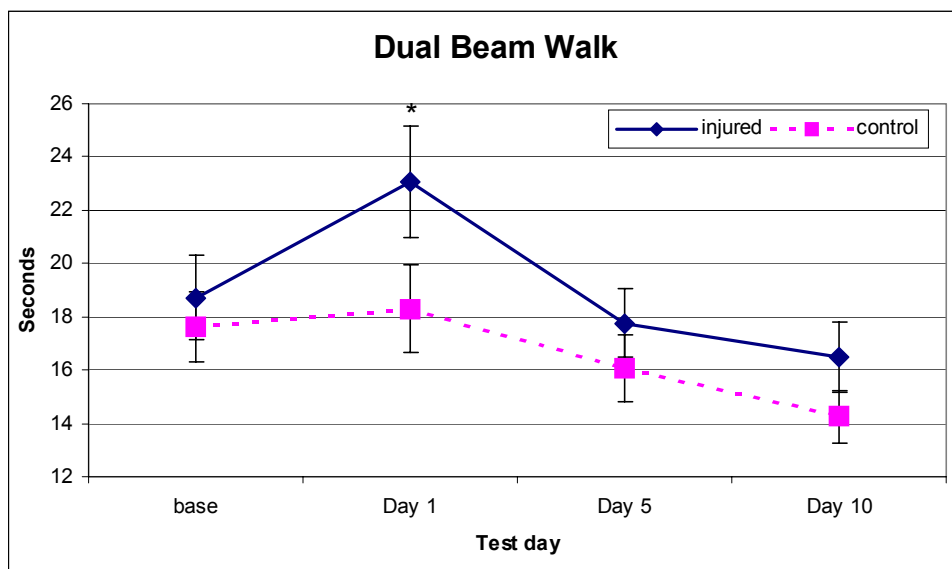
\* injured group scores significantly different at day 1 than baseline, day 5 and day 10.

**Figure 4.4. Injured and control group, mean dual 7s across test days.**



\* injured group scores significantly different than day 5 and day 10.

Figure 4.5. Injured and control group, mean dual beam walk across test days.



\* injured group significantly different at day 1 than day 5 and day 10.

## CHAPTER 5

### SUMMARY AND CONCLUSIONS

Concussions do not present with easily measured, objective assessment criteria, such as a positive finding on an x-ray or pain with palpation, and often two similar presenting cases can result in two completely different outcomes. Evaluation and subsequent return to play decisions are some of the most difficult challenges faced by sports medicine staffs. Concussions are commonly graded according to the presence or absence of symptoms and abnormal behavioral responses while return to play decisions are then based on the severity of the injury and persistence of subjectively assessed symptoms and behaviors. Recently, experts in sport related head injury have advocated the inclusion of neuropsychological and sophisticated balance testing to determine injury severity and to assist in making critical return to play decisions. While the inclusion of neuropsychological testing and sophisticated balance testing has advanced our understanding of concussion in sport, it has left us with many challenges. One concern is the time and equipment necessary to complete this testing, limiting the availability of it to those with extraordinary resources. Another potential limitation to current testing procedures is that neuropsychological testing and balance testing have been conducted separate from each other, yet sport participation often demands the combination of cognitive function with physical activities. The problem addressed by this study was the

development and use of a cost effective concussion assessment tool which integrates cognitive and balance function.

Pre-season, baseline data was collected on 456 healthy college athletes (320 males, 136 females). The cognitive task required participants to count backwards by 7s for 30 seconds from randomized starting points between 95 and 105. A rate of seconds to complete a correct subtraction was computed for the 30 second trial. The balance task required participants to complete a timed tandem walk (heel to toe) forward and backward on a standard 2"H X 4"W X 8'L wooden board. After performing the cognitive and balance tasks independent of each other, participants performed the tasks concurrently. The independent task conditions preceded the dual task conditions in a counterbalanced fashion for a total of three trials of all tasks. Thirty-nine subjects (8.6%) were eliminated from the original sample for inability to complete at least one of the serial 7 trials. Paired sample t-tests were used to compare mean scores on each task when performed independently to when the task was performed in conjunction with the other task. Paired sample t-tests indicate that subject's serial 7s rate did not significantly differ ( $p = .892$ ) from the independent performance of the task ( $\bar{x} = 4.78$ ) to the concurrent performance of the task, ( $\bar{x} = 4.75$ ) however, beam walk time significantly increased ( $p < .001$ ) from the independent performance of the task ( $\bar{x} = 11.51$ ) to the concurrent performance of the task ( $\bar{x} = 20.52$ ). Results indicate that when faced with a cognitive task and a balance task, athletes will preserve their rate of cognitive performance and sacrifice their balance task performance. In addition, significant learning effect across trials on solo 7s rate ( $F_{(1,96,819,54)}=11.74, p<.000, \eta^2=.026$ ), solo

beam walking ( $F_{(1.94,811.14)}=43.44$ ,  $p<.000$ ,  $\eta^2=.094$ ), dual 7s rate ( $F_{(1.97,824.71)}=13.613$ ,  $p<.000$ ,  $\eta^2=.031$ ), and dual beam walking ( $F_{(1.74,731.82)}=36.32$ ,  $p<.000$ ,  $\eta^2=.08$ ) were noted. Despite the noted learning effects, it is recommended that an average performance of the three trials be used for comparative purposes due to large standard deviations and significant within subject variability.

During the course of the fall 2001 athletic season, 23 athletes from the baseline sample suffered a concussion and performed the above testing within 24 hours of injury, as well as 5 and 10 days after injury. Seventeen uninjured athletes participated as matched (gender and baseline performance) controls at the conclusion of the season. Separate repeated measures ANOVA (2 groups X 4 days) revealed significant interaction for self-reported symptoms, and significant day main effects for solo 7s, dual 7s, solo beam walk, and dual beam walk. Planned comparisons indicate injured athletes performance is significantly worse day 1 post injury compared to baseline and day 5 on dual 7s, as well as solo and dual beam walking. The majority of sport related concussion studies speculate that neurologic function remains impaired for approximately 3-5 days post injury and that athletes who are symptom free and demonstrate normal function, can “safely” be returned to contact and collision sports approximately 5-7 days post injury. Our results tend to support this. On 3 of the 4 dependent measures, the injured group demonstrated marked decrease in performance from baseline at Day 1 post injury. By Day 5 post-injury, these measures had returned comparatively equal to baseline measures.

The strength of this methodology is the emergence of postural control and balance assessments as consistent measures of impaired neurological function following concussion. Our data parallels that reported by Guskiewicz<sup>40</sup> who found injured athletes performance on a Sensory Organization Test and a Balance Error Scoring System test differed significantly at Day 1 post injury when compared to baseline and Day 3 post injury. Another strength of this methodology is that the assessment of motor function is less impacted by native intelligence than individual neuropsychological tests and brief neuropsychological test batteries.

It is concluded that the MT-HAT test demonstrates sufficient interference to be considered a measure of function of the information processing system, specifically the allocation of attention. The recovery curves of the balance tasks and D7s are similar to the recovery curve for signs and symptoms. All recovery curves were consistent with previously reported results of selected neuropsychological tests, tools for immediate sideline assessment, and sophisticated balance assessment. Because no two concussions are alike and recovery varies, it is unlikely that any one single test will become the gold standard of assessment for concussion. The rationale behind, and preliminary results of research using the MT-HAT suggest this test warrants further consideration for use as an objective assessment tool.

## CHAPTER 6

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APPENDIX A

Common Concussion Grading Scales

Reference	Year	Mild Grade 1	Moderate Grade 2	Severe Grade 3	Grade 4,5,6
Ommaya & Gennarelli <sup>73</sup>	1974	No LOC, confusion	No LOC Confusion and PTA	No LOC, confusion, PTA, retrograde amnesia	4=LOC, confusion, PTA, RA 5=Coma, vegetative state 6=Death
Torg <sup>92</sup>	1982	No LOC confusion	No LOC delayed PTA	No LOC immediate PTA	4=Paralytic coma, knocked out 5=Coma 6=Death
Hughenoltz & Richard <sup>92</sup>	1982	No LOC PTA<1min.	LOC<5min. PTA<24hrs.	LOC>5min. PTA >24hrs	
Cantu <sup>13</sup>	1986	No LOC PTA<30 min.	LOC<5min. PTA 30 min.-24 hrs.	<30 min. >24 hrs.	
Wilberger & Maroon <sup>92</sup>	1989	Minimal or No LOC, PTA 15-20 min.	LOC<5min. PTA>20min.	LOC>5min. PTA>12hrs.	
Colorado <sup>48</sup>	1991	No LOC, No amnesia confusion	No LOC, confusion with immediate or delayed amnesia	Any LOC	
Jordan <sup>59</sup>	1994	No LOC, No amnesia confusion	No LOC Confusion, Amnesia < 24 hrs.	LOC & altered level lasting < 2-3 min., PTA > 24 hrs.	LOC & altered level lasting > 2-3 min.
Kelly & Rosenberg (AAN) <sup>49</sup>	1997	Transient confusion No LOC Symptoms<15min.	Transient confusion, No LOC Symptoms>15min.	Any LOC	

		<b>Mild Grade 0</b>	<b>Mild Grade 1</b>	<b>Moderate Grade 2</b>	<b>Severe Grade 3</b>
Guskiewicz <sup>34</sup>	2001	No LOC, mild confusion asymptomatic within 10 min., headache develops later	No LOC, AB CNA or COG < 1 hr. , AB coordination < 3 days, Headache probable 10 min. - 2 days	Brief LOC (10-60 sec.) <b>OR</b> altered < 2 min. AB CN or COG < 1 hr. AB coordination < 3 days Headache probable 24hrs - 4d	LOC > 1 min. OR altered > 2 min. AB CN, COG and or Coordination > 24 hrs. Headache most likely > 4days

LOC = Loss of Consciousness, PTA = Post traumatic Amnesia, AB = abnormal, CNA = cranial nerve assessment, COG = cognitive assessment

## APPENDIX B

## Glasgow Coma Scale

		Points
<b>Best motor response</b>		
To verbal command	Obeys	6
To painful stimuli*	Localizes pain	5
	Flexion - withdraws	4
	Flexion - abnormal (decerebrate)	3
	Extension (decerebrate)	2
	No response	1
<b>Best verbal response</b>		
With a painful stimulus if necessary	Oriented and converses	5
	Disoriented and converses	4
	Inappropriate	3
	Incomprehensible sounds	2
	No response	1
<b>Eye Opening</b>		
	Spontaneously	4
	To verbal command	3
	To painful stimuli	2
	No response	1
<b>TOTAL</b>		<b>3-15**</b>

\* Apply knuckles to chest

\*\*Score of 7 or less indicates coma