Current Trends in Dual-Task Assessment for a Sports Related Concussion: A Systematic Review

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Table of Contents

List of Tables

PART I

Introduction

Evaluating and managing concussions is a required proficiency of every athletic trainer [1]. The current National Athletic Trainers' Association (NATA) position statement suggests using a battery of tests in order to assess multiple aspects of a concussion, including physical symptoms, neurocognitive function, and motor control [1, 2]. Most valid and reliable clinical concussion assessment tools have shown that athletes' post-concussion scores return to baseline within: seven days for symptom score, two days for Standardized Assessment of Concussion, three to five days for balance assessment, and seven to 14 days for a computerized neurocognitive tests [3-7]. The NATA position statement takes these differences into account and suggests the use of a test battery to assess a concussion and safely return an athlete to play [1]. While this protocol has provided athletic trainers with standardized and reliable criteria for concussion management, each assessment tool is limited to evaluating a single aspect at a time, either physical symptoms, neurocognitive function, or motor control.

Single-Task (ST) tests that are simple in nature for both cognitive and physical aspects can be administered together to create a multi-task examination, referred to as a Dual-Task (DT) assessment [8]. This type of concussion assessment may be more suitable for athletes since sports participation requires an attention split between cognitive and physical aspects [8-11]. Attention consists of alerting, orienting, and executive components [12], which can be influenced by a concussion. The execution of DT requires patients to split attention, which makes it more challenging than the ST test battery; subsequently it has potential to have higher sensitivity for detecting deficits caused by concussion [8]. Dual -Task tests have been completed on healthy athletes and shown differences in performance between ST and DT; however, not many studies have examined the effects of DT on concussed subjects compared to healthy control subjects [7, 13-15].

In 2013, a systematic review and a meta-analysis were published summarizing the effect of DT testing in concussed and healthy individuals, most of which were completed in controlled laboratory settings [14, 15]. Six days post-injury, ST tests indicated no difference between the concussed and healthy groups; however DT tests indicated deficits in the concussed group, suggesting the ability of DT to detect concussion signs more precisely [14]. Overall, DT using gait consistently indicated deficits in concussed group while DT using balance indicated inconsistent results [14]. Cognitive tasks used in these studies varied making the direct comparison difficult.

Gait assessment has been used in order to predict the likelihood of falls in the elderly [9, 16]. The timed get up and go test in combination with a cognitive task, such as counting backwards by threes, have been reported to be more sensitive in identifying the elderly individuals who are at risk for balance deficiencies compared to a ST assessment [9, 16]. A decrease in gait speed of up to 10% during DT assessment was reported [17]. Although there are a plethora of studies examining the effects of DT, most DT research was completed using expensive equipment in a controlled laboratory setting, and the clinical applicability of DT testing is ambiguous[8, 14, 18-20].

This systematic review provides the most current DT literature available; updating the previously published review articles, and explores that possibility of DT use for concussion assessment in the clinical setting. The purpose of this systematic review is to:

1. Provide the most current information regarding DT assessment for concussion
2. Identify the most common DT paradigms and trends in the current literature
3. Summarize the effects of DT testing when compared to ST
4. Explore the effect size for current DT testing methods
5. Define the most clinically viable DT assessment

Methods

Search Strategy

The PubMED/Medline *(n=25*), Psychology and Behavioral Science (n=*85*) and CINAHL (n=*238*) online databases were used to search terms applicable to DT testing. These databases were searched individually and the results were combined in order to eliminate duplicates. Search terms used were “concussion” and “mild traumatic brain injury (MTBI)” to specify the pathology, and “Dual-Task” and “Divided Attention” to specify the assessment strategies. All combination of pathology terms and assessment strategy terms were used. The search was limited to human studies, published in English between the dates of July 10th, 2013 and April 12th, 2016.

Study Selection

A total of 348 articles were identified using the searched terms. Initial screening involved title and abstract review to exclude: 1) duplicates 2) non-original research, 3) unpublished research, 4) articles published in non-peer-reviewed journal, and 5) if included in a previously published review article. Following the abstract and title screening, 33 studies remained for further review. These studies were thoroughly reviewed under the following selection criteria: 1) clear description of Dual-Task testing methods, 2) quantitative outcome measure of DT, 3) inclusion of subjects with concussion, and 4) inclusion of control group. Studies involved brain injuries that did not represent a concussion or mild traumatic brain injury (eg., Severe brain injury, multiple sclerosis, and spinal cord injury) were excluded. Following a thorough content review, a total of seven studies met the selection criteria and were subsequently included in the review.

Summary of Designs and Methodologies

Most studies (n=6) utilized a longitudinal design involving two or more testing sessions [21-26]. One study involved 2 testing sessions [23] and the other five studies involved 5 different sessions at 72 hours, 1 week, 2 weeks, 1 month and 2 months' post-concussion [21, 22, 24-26]. One study utilized a cross sectional design [27]. All studies compared concussed individuals to healthy control individuals as outlined in the inclusionary criteria [21-25, 27]. One study compared concussed adults to concussed adolescents [21]. The majority of the studies (n=5) defined a concussion as "an injury caused by a direct blow to the head, face, neck or elsewhere in the body with an impulsive force transmitted to the head, resulting in impaired neurologic function and acute clinical symptoms" as stated in the 3rd International Consensus Statement on Concussion in Sport [21, 22, 24-26, 28]. Two studies did not provide a concussion definition [23, 27].

Common Dual-Task Measures

The most common DT paradigm utilized were gait and walking task with a cognitive task or an obstacle avoiding task (n=6*)* [21, 22, 24-27]; only one study utilized a simple clinical balance task with a simple cognitive task [23]. The cognitive tasks consisted of either visual or auditory tasks with varying complexity; auditory Stroop, visual Stroop, verbal fluency (reciting the words starting with a particular letter), and question and answer (Q&A) (reciting month backward, counting backwards, and spelling of five letter words backwards) [21-27]. Three of the studies utilized accuracy and reaction time as outcome measures for the cognitive task [21, 24, 25]. The balance task was assessed using a force plate [23], while the gait tasks were evaluated using a motion analysis system [21, 22, 24-27]. Majority of studies assessed symptom scores in order to identify the severity of concussion symptoms [21-25].

Table 1. Summary of selected Dual-Task articles

Authors, Year (Journal)	Dual-Task/ paradigm description	Sample size, population	Study design/assessment time points	Comparison Between Concussed and Control	Key findings
Howell et. al., 2015 (American Journal of Sports Medicine) [21]	- Level walking (self-selected speed) while completing the auditory Stroop test	*n*= 76 38 concussed and 38 control, adolescents and young adults - Laboratory	- Longitudinal, repeated measures - Concussed and control were tested at 72 hrs., 1 wk., 2 wks., 1 mo. and 2 mo. post-injury	- **COM M/L displacement:** concussed adolescents had greater total and peak compared to controls and adult groups through 2 months (p= .001) - **Peak COM M/L velocity:** concussed adolescents had greater compared to controls (p<.001) only at 2-month point (p=.004) - **Peak COM anterior velocity:** concussed young adults had less compared to controls at 72 hours (p=.01) - **Cognitive accuracy**: concussed adolescents had less accuracy compared to control through 2 months (p=.005).	- Adolescents had decreased ability to control balance and sway during dual-task (DT) walking, when compared to control and young adults, initially and over 2 months. - Recommend conservative treatment for concussed adolescents.
Howell et al. 2014 (Experimental Brain Research) [24]	- Level walking as a single task and while completing 1 of 3 cognitive tasks: Single auditory Stroop (SAS), multiple auditory Stroop (MAS), question and answer tests (Q&A).	*n*= 46 23 concussed and 23 healthy, adolescents - Laboratory	- Longitudinal, repeated measures - Concussed and control were tested at 72 hrs., 1 wk., 2 wks., 1 mo. and 2 mo. post- injury	- **COM M/L displacement**: concussed had greater displacement compared to controls through 2 months in the MAS and Q&A (p=.001). - **Peak COM anterior velocity:** concussed had less anterior velocity compared to control over 2 months (p=.008). - **Gait Speed:** concussed walked slower compared controls immediately post injury (72 hours) for all tasks but improved though 2 months (p=.015). - **Cognitive accuracy:** concussed were less accurate compared to control on MAS and Q&A over 2 months (p=.015).	- Complexity of tasks have an effect on gait - as cognitive task complexity increases, dynamic balance control decreases. - Varying DT complexity represents a useful way to identify motor or cognitive recovery. - Q&A had the greatest effect on peak COM M/L velocity. - Both concussed and control walked slowest at initial testing session. - At 2 months – concussed was more accurate on SAS than MAS and control was more accurate on SAS and MAS than Q&A (p=.015).

Table 1. (Continued) Summary of selected Dual-Task articles

Cossette et al. 2014 (Archives of Physical Medicine and Rehabilitation)[27]	- Walking with obstacle avoidance (6m unobstructed, 15cm obstacle, 15cm step down) with 4 different cognitive conditions (none, verbal fluency, Stroop, arithmetic).	*n*= 14 7 healthy and 7 mild traumatic brain injury (MTBI) - Laboratory	- Cross sectional - Concussed tested average of 158 days' post injury	- **Gait Speed:** MTBI walked slower compared to control (p<.001). - **Dual Task Cost:** MTBI had higher DTC compared to control for all combinations (p=.014) (except stepping down combined with verbal fluency and Stroop).	- Stepping down obstacle was not as sensitive to detecting MTBI compared to obstacle avoidance - Level walking and obstacle avoidance were the most sensitive in discriminating between MTBI and healthy. - Verbal fluency had the greatest effect on gait speed.
Howell et al., 2013 (Archives of Physical Medicine and Rehabilitation)[25]	- Level walking (self-selected speed) while completing the auditory Stroop test.	*n= 40* adolescents 20 concussed and 20 control - Laboratory	- Longitudinal, repeated measures - Concussed and control were tested at 72hrs, 1 wk., 2 wks., 1 mo. and 2 mo. post-injury	- **Peak COM anterior velocity:** concussed had less anterior velocity compared to control over 2 months (p=0.037). - **COM M/L displacement:** concussed had greater displacement compared to control over 2 months (p=0.013). - **Peak COM M/L velocity:** concussed had higher velocity compared to control controls through 2 months (p=0.027). - **Gait Speed**: concussed walked slower compared to controls through 2 months (p=0.001). - **Dual Task Cost:** concussed was higher compared to control through 2 months (p=0.019) - **Step Length:** concussed had decreased step length compared to control at initial and 1 wk. (p=0.012). - **Cognitive accuracy:** concussed was less accurate compared to control through 2 months (p=0.004).	- Concussed had a larger DTC in M/L sway and velocity compared to control that lasts up to 2 months. - Concussed walk slower during DT than ST, and this difference was greater in concussed when compared to control. - Cognitive accuracy was decreased in concussed compared to control over the 2 month testing period. - Concussed step length returned to normal after 2 weeks.
Howell et al., 2015 (American College of Sports Medicine)[22]	- Observe concussed adolescents performing a walking test combined with a cognitive task (Stroop) before and after returning to activity (RTA)	*n*= 50, 25 concussed and 25 healthy - Laboratory	- Longitudinal study, repeated measures - 72hrs, 1 wk., 2 wks., 1 mo. and 2 mo. post-injury	- **COM M/L displacement:** concussed worsened by a mean difference of 23.6% after RTA (p=.005) - **Peak COM M/L velocity:** concussed worsened by a mean difference of 42.2% after RTA (p=0.001).	- Frontal plane motion during DT may be more sensitive than sagittal plane motions RTA post-concussion. - RTA did not change symptom score - RTA negatively affected DT score - Computerized tests remained stable post- RTA. - Concussed RTA 23.5 ± 14.4 days' post-concussion

Table 1. (Continued) Summary of selected Dual-Task articles

Dorman et al., 2015 (Journal of Science and Medicine in Sport) [23]	- Postural stability task in combination with a cognitive task (months backwards) in eyes open and eyes closed conditions	*n= 44* Clinic setting 18 concussed and 26 healthy	- Cohort, repeated measures - Concussed tested 4 times with the first visit within 10 days of injury - Control tested 2 times	- **Ellipse Area and Velocity:** Concussed were different from control at first and second visits (p<.0001 – .0161) (mean differences were not provided).	- Reciting months backwards may not be difficult enough to elicit a change between concussed and control - Suggested using a more challenging DT scenario - Ellipse area may be better to detect deficits compared to velocity. - Concussed ellipse area and velocity ware greater at initial test compared to later visits for most conditions.
Howell et. al., 2015 (Journal of Biomechanics)[26]	- Level walking (self- selected speed) while competing an auditory Stroop.	*n= 17* Laboratory setting 10 concussed and 7 control	- Longitudinal, repeated measures - Concussed and control were tested at 72hrs, 1 wk., 2 wks., 1 mo. and 2 mo. post-injury	- **Gait Speed:** concussed walked slower compared to controls at 72 hours (p=.003), 1 week (p=.013) and 2 weeks (p=.0031). - **Peak M/L acceleration:** concussed had less acceleration compared to controls at toe off(p=.04). Moderate sensitivity (.70) and specificity (.71) at 72hours and 1 week.	- Acceleration alterations in frontal plane during DT walking were present following a concussion. - Concussed walked slower during DT than ST, this difference was greater in concussed compared to control for up to 2 weeks. - Accelerometer may be a more cost effective method of having objective data during DT testing.

Abbreviations key: *COM* center of mass, *M/L* medial/lateral, *DTC* dual task cost, *DT* dual-task, *ST* single-task, *RTA* return to activity, *MTBI* mild traumatic brain injury, *SAS* single auditory Stroop, *MAS* multiple auditory Stroop, *Q&A* question and answer.

Results

Participants

All studies included concussed and healthy control participants [21-27]. Four studies included athletes from football, basketball, volleyball, soccer and wrestling [21, 22, 24, 25]. One of the four studies included athletes from rugby and snowboarding in addition [21]. The other three studies did not include specific description of the activity performed by participants [23, 26, 27]. All studies included both male and female participants [21-27]. The age range of the participants was 14-27 [21-23, 25, 27]; two studies included participants over the age of 23 [21, 26]. Sample sizes for concussed subjects ranged from 7 – 38. Four out of the seven studies included matched healthy controls based on sex, height, body mass, age and sport [21, 22, 24, 25], while three studies did not match the control group [23, 26, 27]. No studies reported any significant differences in age, height, and body mass between concussed and control groups [21-25, 27].

Gait Speed

Four studies reported that concussed participants walked slower immediately post injury (72 hours) compared to control; one of which reported deficits up to two weeks' post-concussion [24-27]. One study reported that participants with a MTBI walked slower than controls during DT obstacle avoidance testing when combined with a cognitive task; this difference was not indicated during the ST testing of walking and stepping down [27]. The authors concluded that the stepping down task did not have high postural demands and was not as sensitive as DT obstacle avoidance tasks in discriminating differences between concussed participants and controls [27]. Dual Task Cost (change in gait speed between ST and DT) was greater in concussed group compared to controls, and this difference lasted over a 2-month period [25, 27]. The same study also found that step length decreased in concussed individuals in both ST and DT compared to controls, which persisted for one-week post-concussion; step width was not affected [25]. Overall, concussed individuals walked at a slower speed with decreased step length, which was resolved sometimes around two weeks to one-month post-concussion. It was also noted that researchers did not see significant differences in gait acceleration between concussed and controls[26].

Peak Anterior Center of Mass Velocity

Concussed and control groups both demonstrated decreased peak anterior Center of Mass(COM) velocity during DT compared to ST, suggesting that the DT influenced the executive function, causing participants to walk slower [24, 25]. Furthermore, the peak anterior COM velocity during DT was influenced by the complexity of the cognitive task, which was more noticeable in concussed individuals [24]. Peak anterior COM velocity during DT test in the concussed group progressively improved over two month time period; however, these deficits remained in the concussed group up to 2 months post-concussion [24]. Of note, this difference reported in adults was not found in adolescents under the same DT methodology [21], suggesting that the peak anterior COM velocity may not be sensitive in identifying concussed adolescent individuals.

Peak Medial/Lateral COM Velocity and Displacement

Concussed individuals walked with higher Medial/Lateral (M/L) COM displacement (increased sway) and velocity compared to controls up to two months post-concussion [24, 25]; these deficits persisted even after returning to play [22]. Concussed adolescents had greater total M/L COM displacement when compared to adolescent controls while this difference was not indicated in adults [21]. The complexity of the cognitive task influenced the peak M/L COM velocity in both concussed and controls [24]. The postural sway, indicated by M/L COM displacement, improved post-concussion during the recovery period by 11.7%; however, it regressed back by 23.6% after returned to play, indicating the worsening of M/L sway compared to the immediate post-concussion measurement [22]. The same pattern was also seen in M/L COM velocity, indicated by the improvement of 16.5% during recovery, followed by a worsening of 42.2% after returning to activity [22].

Balance

Significant differences in balance ability, measured by ellipse area and center of pressure (COP) velocity, between concussed individuals and controls were reported during both ST and DT conditions at the first visit (within 10 days); only the DT conditions indicated the group difference for second visit (approximately 25 days) [23]. Postural control improved over a month time period for DT tasks indicated by decreased 95%-ellipse-area of COP and velocity [23].

Cognitive Task

The majority of the study utilized some variation of the Stroop test. Single auditory Stroop test induced greater peak anterior velocity reduction in concussed individuals compared to controls [25], while no effect was reported on M/L COM displacement during DT testing in both concussed and controls [24]. The control group also demonstrated greater accuracy in the auditory Stroop test compared to concussed individuals in both young adults and adolescents [21, 24, 25]. At two months post-concussion, concussed individuals demonstrated decreased accuracy on multiple auditory Stroop test compared to single auditory Stroop test while this difference was not indicated for controls [24]. Verbal fluency indicated a greater influence on gait during DT testing in both concussed individuals and controls when compared to that of the single visual Stroop test and Q& A [27]. Concussed young adults did not show any deficits in ST cognitive tests compared to controls [21].

Symptoms

Five of seven studies reported symptom scores on a Likert type scale [21-25]. Two studies did not report symptom scores [26, 27]. As expected, concussed individuals had a greater number of symptoms than controls at initial testing [21-25]. Two studies reported that there was no difference in symptom scores between concussed adolescents and controls after one-month post-concussion [21, 25]; another reported that symptom score was equivalent to that of controls as early as one-week post-concussion [21]. The improvements in postural stability generally coincided with reductions in reported symptoms [23].

Table 2. Effect size for selected variables

Study Details	Comparisons in relationship to concussed vs control used in effect size calculation	Type of effects size/ reported	Effect Size
Howell et al., 2013 [25]	1. Step length over time 2. Peak anterior COM velocity over time 3. Peak M/L velocity 4. M/L Displacement 5. M/L Displacement DTC over time	Partial eta squared η^2_p	1. Increased step length in concussed was greater than control over 2 months – 0.094 2. Concussed increased compared to control over 2 months – 0.080 3. Higher in concussed compared to control – 0.126 4. Concussed greater displacement compared to control during DT – 0.189 5. Concussed greater compared to control through 2 months – 0.154
Howell et al., 2014 [24]	1. Total M/L COM displacement during complex task 2. Peak M/L COM velocity during complex task 3. Peak anterior velocity at 72 hours 4. Walking speed over 2 months	Partial eta squared η^2_p	1. Concussed had greater displacement throughout 2months with complex tasks when compared to simple tasks – 0.110 2. Concussed and control less peak M/L velocity on simple DT and ST compared to complex DT – 0.206 3. Concussed had smaller within 72 hours compared to other testing times in concussed – 0.094 4. Concussed slowest at 72 hours compared to other time points – 0.085
Howell et al., 2015 [21]	1. M/L COM displacement at 72 hours post injury 2. Peak M/L COM velocity at 72 hours post injury 3. Peak anterior COM velocity 4. Cognitive task over 2 months	Eta squared η^2, Partial eta squared η^2_p	1. Adolescent concussed greater compared to control – 0.125 2. Adolescent concussed greater compared to control– 0.221 3. Young adult concussed less at 72 hours compared to other time points– 0.2 4. Concussed adolescents less accurate compared to control through 2 months -0.168
Howell et al, 2015 [22]	1. M/L COM displacement over time 2. M/L COM peak velocity over time 3. Peak anterior COM velocity over time	Partial eta squared η^2_p	1. Concussed greater compared to control pre- to post-RTA– 0.175 2. Concussed greater post- compared to pre- RTA compared to control– 0.104 3. Decrease in concussed in DT between pre and post RTA – 0.236
Howell et al., 2015 [26]	1. Average gait velocity over time 2. Peak frontal plane acceleration during 55-75% of gait cycle over time	Partial eta squared η^2_p	1. Concussed slower compared to control at 72hr and 1 week – .356 2. Concussed has less acceleration compared to control through 2-month period - .391
Cossette et al., 2014 [27]	1. Group by cognitive interaction 2. Group by cognitive by gait task interaction	Partial eta squared η^2_p	1. Mild traumatic brain injury (MTBI) walked slower compared to control - .30 2. MTBI slower compared to control - .089

Dorman et al. did not report effect size and is not included in the table.
Abbreviation Key: COM center of mass, *M/L* medial/lateral, *DTC* dual task cost, *DT* dual-task, *ST* single-task, *RTA* return to activity, *MTBI* mild traumatic brain injury.
Cohen's Benchmarks for η^2 from multiple regression: small (0.02), medium (0.13), large (0.26)[29]

Discussion

This systematic review of the most current research in DT illustrates the evidence supporting the efficacy of DT testing for concussion assessment. A significant deficit in DT outcomes even after a concussed athlete returns to play also suggest the possibility of a DT test to be more sensitive in detecting deficits associated with concussion compared to ST testing [22]. Postural sway during DT testing significantly increased after returning to activity; while ST testing outcomes (both walking task and computerized neurocognitive test) remained stable [22]. Sensitivity of DT using M/L COM acceleration at toe off during gait was reported to be .70 with specificity of .71 at 72 hours and one week post-concussion, which slowly declined over time: at 2 weeks, sensitivity of .60 and specificity of .57, at one-month, sensitivity of .30 and specificity of .71, and at 2 month sensitivity of .40 and specificity of .57 [26].

The loss of postural control and cognitive function are definitive signs of concussion; therefore, any DT paradigm aiming to assess concussions should take these into account. Earlier research investigating the use of balance tests for DT yielded conflicting results; some research indicated decreased balance ability [30, 31] while others indicated unchanged or increased balance ability with impaired cognitive performance [8, 32]. This might be attributed to the differences in attention allocated to each task based on an individual's perception of the task's difficulty [11, 33]. According to the "posture first" principle, postural control has higher priority in attention allocation, and its difficulty influences the proportion of attention allocated to the task, as more difficult postural tasks demand more attention [16]. Perceived difficulty of the balance task may be influenced by previous experience and training involving balance activity. A large learning effect is also associated with the Balance Error Scoring System (BESS), the most commonly utilized balance test for concussion, suggesting improvements in balance ability as individuals become more familiar with the balance task [9]. These factors could influence individuals' perceived difficulty of the balance task; resulting in high variability of attention allocation, leading to conflicting findings. These conflicting results of DT tests using balance tasks have led to a transition towards the use of gait tasks. Researchers have consistently found gait deficits during DT test in concussed individuals [7, 14, 19, 21, 24-27, 34, 35]. The complexity of the tests used in DT testing also influences the degree of deficit, with more challenging DT tests yielding a higher effect size [24].

While gait is an effective motor task to be used for DT, reliable assessment of reported gait variables could be challenging in a typical clinical setting. Most studies have found increased M/L COM displacement in concussed individuals [21, 22, 24, 25, 27]; however, assessment of M/L COM displacement, without the motion capture system, involves subjective assessment of postural sway similar to the BESS. Peak anterior COM velocity is also difficult to obtain in a typical clinical setting; however, this variable could be correlated with average gait speed. When gait task is performed within a standardized distance, time to completion reflects the gait speed. Slower gait speed under DT condition was identified in concussed individuals [18, 24], suggesting its potential as an DT outcome measure that is easily measureable in the clinical setting.

Dual-Task tests, using gait as a motor task, are commonly utilized in clinical setting in order to identify older adults at risk for falling [18]. While there is an abundance of tests for the elderly population, research has not yet reached a consensus to generate specific recommendations regarding the most appropriate outcomes for DT testing that is obtainable in a clinical setting [18]. Dual-Task for the elderly individuals often incorporates multiple different motor tasks to divide attention, such as carrying a cup of water while walking. This model is also incorporated for concussion assessment in the form of obstacle avoidance, and reported to have effects in discriminating concussed and control individuals when combined with a cognitive task [27]. Since the concussed individuals demonstrated more conservative gait strategies to avoid obstacles and walked at a slower speed when compared to control [27], it is possible that the difference in walking speeds between concussed and control individuals would be magnified resulting in larger effect size. The difficulty of the cognitive task will also affect the gait speed; however, the most appropriate motor task and cognitive task to be incorporated into gait task for concussion assessment is yet to be determined. The use of an accelerometer attached to the patient might be a feasible option in a clinical setting to obtain some of the gait variables, such as M/L acceleration; further investigation of its clinical applicability is warranted[26].

In summary, obstacle avoidance gait combined with cognitive task indicated the consistent effect in discriminating concussed individuals. Time to completion as a measure of gait speed has potential to be the clinically measureable outcome for the DT test. Cognitive tasks that do not require additional equipment including arithmetic task, verbal fluency, Q&A,

are clinically viable options. The complexity of the cognitive task directly influences the postural sway and gait speed of concussed individuals; the appropriate level of difficulty of the cognitive task should be determined based on the effect size for each age group. Previous research utilized a variety of different DT combinations, and it is difficult to make specific recommendations. Future research should focus on standardizing the DT protocol for the clinical use and establishing the reliable change index.

Part II

Review of Literature

Epidemiology

The population of young athletes in the United States is at risk for musculoskeletal injuries, head injuries, and even sudden death [36]. From 1980 to 2009, the US National Registry of Sudden Death in Young Athletes recorded 1,827 fatalities and 261 deaths due to blunt trauma [36]. Football had the highest risk with 57 percent of the deaths; 138 deaths due to a head and neck injury [36]. Emergency room data in South Carolina, from 1998 to 2011, recorded 16,642 traumatic brain injuries (TBI) [37]. Of these TBI reports, concussions were the most commonly diagnosed injury with 8,191 cases [37]. Not only has football recorded the highest incidents in death, but it also puts athletes at the highest risk for sustaining a concussion [36, 38-40]. Prior to the head and neck blunt trauma that caused their deaths, 17 football players were reported to have a concussion prior to their death [37]. Several different factors should be taken into account when looking at risk factors for concussions such as age, sport, and gender [36, 38-40].

In order to allow for a more direct comparison of concussions between the different age groups, researchers were able to use the High School Reporting Information Online and the National Collegiate Athletic Association Injury Surveillance System [39]. Each of these injury tracking systems have the same definition of injury and exposure, allowing them to be directly compared [39]. Nine high school sports were chosen in order to get a range of different athletes and exposure types [39]. The age range of 12-18 years had the highest incidence of head injuries at 6,187 (37%), followed by 0-11 years at 4004 (24%) [36]. From 2005-2006, 4431 high school injuries were reported, 396 were concussions [39]. At the collegiate level, 8,293 injuries were reported with 482 reported concussions [39]. Even though the college level had more concussions, researchers found percentage of concussions compared to total injuries was greater at the high school level (8.9%), than the collegiate level (5.8%) [39].

In 2007, researchers investigated the injury rates of 15 different sports in the NCAA over a 16 year period from the academic year of 1988-89 to 2003-04 [40]. During this time, 9,000 total concussions were reported, averaging about 563 concussions per year [40]. Concussions accounted for 9.8% of injuries during games and 12.8% during practice [40]. Football had the most reported concussions at 5,016, comprising 55% of the total concussions reported [40].

When looking at concussions per athletic exposure, women's ice hockey and soccer had significantly higher rate of reported concussions at 0.91 per 1000 and 0.41 per 1000, respectively ($p<0.05$) [40]. Over the 16 years, there was an increase in the amount of concussions per year, and researchers reported that this may be due to the increased awareness of concussions and the improvement of concussion detection and management [40].

An increase in awareness of concussion stresses the importance of valid and reliable concussion management strategies, which could benefit from more sensitive and accurate diagnostic tools. Currently the National Athletic Trainers' Association (NATA) has guidelines for assessment, diagnosis and management of concussions [1].

Management

When returning an athlete to participation, the NATA position statement on concussions points out that a series of tests should be used to help aid the health professionals' evaluation [1]. Self- reported symptoms, motor control, neurocognitive, and mental status testing can all be used when assessing and managing a concussion [1].

Neurocognitive Testing

Neurocognitive testing has been advised to be used as a sideline evaluation and during the return to play process [1]. Several different computerized tests along with paper and pencil tests have been researched for sensitivity and validity [41-43].

With the convenience of computerized neurocognitive testing, many athletic trainers have switched to computerized tests for concussion detection [43]. Using the High School Reporting Information Online (HS RIO) system and a questionnaire, researchers investigated the numbers of schools using computerized neurocognitive testing and reported concussions, as well as the management strategies of these athletes from 2009 – 2010 [43]. Of the 178 schools who returned the questionnaire, 39.9% used some form of computerized neurocognitive testing [43]. Of schools that used computerized tests, 93% used the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) and management of the concussion [43]. If athletes took the Immediate Post-Concussion Assessment Tool (ImPACT) after seven days they were more likely to be suspended from activity for longer than 10 days and report symptoms longer than those athletes that did not take any form of computerized testing ($p<0.001$), resulting in a more conservative concussion management protocol [43]. Neurocognitive testing allows health professionals to have a more comprehensive assessment and return to play protocol [1].

Immediate Post-Concussion Assessment Tool (ImPACT)

When assessing neurocognitive function, computer based assessments have become the most prevalent tool [44]. One study analyzed data in order to observe the common assessment tools and trends used by high school and college athletic trainers [44]. Three hundred and ninety-nine athletic trainers, with an average of 13 years of experience, completed a survey to assess practice trends [44]. Athletic trainers reported having used ImPACT for two to five years [44]. Baseline tests were administered by 94% of the athletic trainers, with the most commonly baseline tested sports were football, soccer and basketball [44]., Fifty-three percent of athletic trainers administered the first ImPACT test, one to two days' post-concussion, and 30% administered second test after the athlete was symptom free [44]. A section of the survey also asked when athletic trainers would return athletes to practice; 95% of athletic trainers reported they would not return athletes if they still had symptoms [44]. Authors also found that few athletic trainers had undergone ImPACT training for correct use and reading of the data [44]. In order to safely return athletes to play, athletic trainers should be participating in these kinds of training regimes [1, 44].

When using ImPACT, clinicians should be aware of factors that may affect athletes' scores [45-47]. The current NATA Position Statement suggests baseline testing in order to provide health professionals with the data on an athletes' brain function in a non-concussed state [1]. Within the baseline testing, the NATA suggests that athletes with a concussion history, attention-deficit hyperactivity disorder or other comorbidity be accounted for on an individual basis [1]. Studies have been conducted to help create normative data for these specific individuals [45-47].

The number of young athletes with attention deficit hyperactivity disorder (ADHD) and learning disabilities (LD) has increased in the recent years [47]. In order to help find a normative ImPACT baseline score for these individuals, researchers complied the baseline data for young athletes with ADHD and LD [47]. Researchers gathered 6,612 valid ImPACT scores to be used; of those 262 had a history of ADHD, 90 had a history of LD, and 55 had a history of ADHD and LD [47]. Between the groups with and without the history of ADHD, there were significant differences in all 6 composite scores indicating the ADHD group scored worse in all areas [47]. Significantly different scores were found in visual motor speed, reaction time, and symptom scores between the groups with ADHD and LD when compared to the group with no history [47]. There were significant differences between groups with ADHD, LD, and both ADHD and LD in the visual motor speed score [47]. This data provides clinicians with baseline scores of athletes that have ADHD or LD, allowing for sensible adjustment regarding concussion assessments and return to play protocols for this population [47].

In the continental United States, studies have shown that athletes with different cultural backgrounds obtain lower scores on ImPACT when compared to current average baseline data [45, 46]. Two hundred and forty seven male athletes (13-18 years old) in the State of Hawaii, with English as a primary language, were included in this study [46]. Results were similar to a previous study completed in 2008, which indicated ImPACT scores in Hawaii to be slightly lower, but similar to those obtained norm on the mainland [46]. Clinicians in the State of Hawaii should be aware of the lower scores obtained in this population when comparing the ImPACT scores to the norm when the athlete does not have baseline scores [46].

Another variable that must be taken into consideration when using ImPACT is language [45]. A study investigated the difference in baseline scores to examine if Hispanic bilingual English/Spanish-speaking participants scored better when taking the ImPACT test in English or Spanish, when compared to native English-Speaking participants [45]. Researchers found that the Spanish speaking participants completing the test in Spanish or English did not perform as well as the participants with English as a first language when comparing the composite scores of verbal memory, visual memory, visual motor speed or reaction time [45]. Various factors influencing the normative data should be taken into consideration when using ImPACT to evaluate an athlete with a concussion [45-47].

Standardized Assessment of Concussion (SAC)

ImPACT testing is a form of neurocognitive testing that must be done with a computer in a quiet area [48]. Often times athletic trainers do not have the luxury of a quite area, so they use a variety of tools in order to assess concussions on the sideline [1]. In a study done by McCrea et al., researchers investigated the validity of SAC by comparing a concussed and a control group of subjects [42]. The subjects consisted of 63 concussed high school and college athletes and 55 control subjects. All athletes participated in football between 1998 and 1999 [42]. All subjects underwent baseline testing; once a concussion occurred, concussed athletes were tested on the sideline and 48 hours post injury [42]. Uninjured subjects took the baseline test, then were tested post-game and 48 hours post-game in attempt to keep conditions the same [42]. Results showed that the concussed athletes scored significantly lower on the sideline assessment when compared to baseline and control [42]. The SAC scores returned to baseline for the injured subjects 48 hours post-concussion [42]. This study indicated SAC as being 95% sensitive and 76% specific in identifying athletes with a concussion [42].

Motor Control

Motor control assessment can be used as an effective tool for a sideline evaluation, however, athletes often return to baseline within a few days [1] . The NATA suggests using combinations of different motor control tasks such as postural control, gait and hand motion when assessing a concussion [1]. Common tests used for assessing motor control are the Timed Up and Go Test (TUG), Balance Error Scoring System (BESS), and the Sensory Organization Test (SOT) [5, 16, 48, 49]. Each test is reported to be valid and reliable [4, 49].

Sensory Organization Test

The SOT is a tool that allows clinicians to objectively measure postural stability in a clinical or laboratory setting [11]. The six conditions of SOT are fixed surface and fixed vision (fixed-fixed), fixed surface and absent vision (fixed-absent), fixed surface and sway referenced vision (fixed-sway), sway referenced surface and fixed vision (sway-fixed), sway referenced surface and absent vision (sway-absent), sway referenced surface and sway referenced vision (sway-sway) [11]. The duration of each condition is 20 seconds [11].

Timed Up and Go Test

A Timed Up and Go test is a tool commonly used to identify elderly individuals who are at higher risk of falling [16, 49]. In order to determine the sensitivity and specificity for the Timed Up and Go (TUG) test and the Dynamic Gait Index, researchers examined an elderly population with vestibular disorders [49]. The average age of the participants was 60 years old with a range of 14-90 years old [49]. Data were analyzed using a one-way ANOVA and a

Pearson chi-square with odds ratio and a 95% confidence interval. Results indicated that during TUG test individuals who had a mean of 13.5 seconds reported one fall, 13.9 seconds reported recurrent falls, and 11.2 seconds did not report a fall. There was a significant difference between the fallers and the non-falling groups with the TUG test ($p<0.02$). Individuals with a score < 19 on the DGI were at risk of falling. Researchers found that both tests were sensitive to prediction of fall risk in people with a vestibular and balance disorder. For the TUG test, the longer it took for the subjects to return back to the chair, the greater risk they were for falling. The TUG test took less time to complete when compared to DGI and researchers suggested that it would be a more valuable tool in a clinic setting.

Balance Error Scoring System

In order to assess postural stability without the use of expensive laboratory equipment such as the SOT, the Balance Error Scoring System(BESS) may be used [4]. As described by Guskiewicz, the BESS tests consists of three conditions (double leg, single leg, and tandem), on two different surfaces (firm and foam) [4]. During the test, athletes are asked to place their hands on their hips, close their eyes and are instructed to remain as still as possible [4]. Each of the six different combinations are held by the athlete for 20 seconds each [4]. The single leg stance is performed with the non-dominant foot and, the non-dominant foot is also placed in the back position for the tandem trial [4]. Errors are counted by the administer and totaled at the end for an overall score, with the maximum errors per trial set at 10 [4].

In order to further investigate the BESS, one research has compared it to the SOT using the NeuroCom Smart Balance [5]. Sixteen concussed athletes were used in the study, 15 males and 1 female (19.2 ± 2.3 years), and a group of matched control subject [5]. Athletes were tested at days one, three, five, and 10 post-concussion, completing the BESS and SOT during each testing session in random order between subjects [5]. Data were analyzed using an ANOVA and a repeated measures ANOVA along with Bonferroni method to detect statistical significance with $p < 0.05$ [5]. Results showed nine subjects had symptoms lasting three days, and two subjects complained of symptoms up to five days post injury [5]. Also, researchers found significant differences between concussed and control groups on the BESS on day one on the foam pad that appeared to recover by day three [5]. This was also seen on the SOT scores [5]. No significant differences were found between the control and concussion group on the firm surface [5]. For concussion assessment, researchers suggest that BESS is a valuable sideline tool [5]. Researchers also suggest that clinicians should use more than one assessment tool when assessing a concussion to help make an accurate decision of such a complex injury [5].

Vestibular/Ocular Motor Screen (VOMS) Assessment

Many clinical tools for concussion assessment evaluate the balance and postural sway [4, 5]. Other researchers have investigated clinical tools that evaluate the vestibular and ocular motor impairments, and associated symptoms [50]. The Vestibular/Ocular Motor Screening (VOMS) Assessment measures five domains: smooth pursuit, horizontal and vertical saccades, convergence, horizontal vestibular ocular reflex (VOR) and visual motion sensitivity (VMS) [50]. After each assessment, participants were asked to rate symptoms on a scale of zero (none) to 10 (severe) [50]. Symptoms, measured on the PCSS scale, were only measured before the VOMS assessment [50]. Researchers used 78 healthy and 64 concussed athletes with the age of 18 years old or younger [50]. In order to be included in the study, the athletes had to be tested within 21 days of injury [50]. Athletes with a previous history of concussions were excluded from this study [50]. The VOMS assessment is used to provoke symptoms in both concussed and control subjects [50]. No control participant reported a score greater than two for any individual VOMS test and the concussed group scored significantly higher in the overall VOMS assessment [50]. Results showed that VOMS has a positive correlation with PCSS with sport related concussions [50]. The VOMS was able to successfully identify concussed athletes [50].

Test Battery

In order to have a more comprehensive evaluation of each individuals concussion, athletic trainers are encouraged to use a battery of tests [1]. Test batteries often consist of two or more of the testing strategies [1]. Research has been completed on the Post-Concussion Symptom Scale (PCSS), BESS, and ImPACT tests in order to determine predictive validity of the test battery [38].

In the study done between 2008 and 2010, 106 patients, average age of 15.38 ±1.7 (range from 11-19 years), were concussed and met the inclusion criteria [38]. Each participant received at least two rounds of tests post-concussion up to 97 days post-concussion [38]. Statistical analysis showed correlations between BESS and ImPACT Impulse control ($r=-0.31$; $p=0.002$)

and between the change in scores of BESS and ImPACT verbal (r=0.37;p=0.000) [38]. Researchers found low concurrent validity between the change scores of the battery of tests despite their statistically significant results [38]. Conclusions suggested that a single clinical measurement tool does not appear to be sufficient enough to determine the resolution of symptoms and to clear concussed athlete for a full return to activity [38].

In another study, researchers investigated the sensitivity of concussion assessment batteries when administered within the first 24 hours of a diagnosed concussion [2]. Between the years of 1998 and 2005, 75 Division I male and female athletes were diagnosed by a team physician with a concussion [2]. The test battery consisted of symptoms scores, postural assessment, using Sensory Organization Test (SOT), and neurocognitive assessment. Three neurocognitive test were used in the study [2]. The first was a pencil and paper test battery that included the Hopkins Verbal Learning Test, the Trail Making Test, the Symbol Digit Modalities Test, the Digit Span, and the Controlled Oral Word Association Test [2]. The next two neurocognitive tests were the HeadMinder CRI and ImPACT, both were computerized tests [2]. Data were analyzed using a Pearson's Chi Squared test with significance level set at $p< 0.05$[2]. The nine item symptom checklist showed a statistically significant increase in duration or severity in 68% of subjects within the first 24 hours [2]. Twenty three athletes were evaluated using the pencil and paper neurocognitive test, 28 with HeadMinder CRI and 24 with ImPACT [2]. The pencil and paper test was successful in identifying 10 concussed athletes, but not the remaining 13 athletes [2]. The ImPACT was able to identify 15 athletes with at least one cognitive impairment at day one [2]. The ImPACT was able to identify significant changes in cognitive and symptom scores in 19 of the 24 athletes [2]. HeadMinder CRI identified 22 athletes with cognitive impairments [2]. As a complete battery of tests using the different neurocognitive tests, pencil and paper identified 95.7%, ImPACT 91.7% and HeadMinder 89.3% of concussions[2].

Dual - Task

As clinicians search to find more sensitive concussion tests, researchers have been attempting to develop a dual-task approach to diagnosing concussions that stresses different components of brain functioning [11, 51]. Different combinations have been tested on a variety of age groups [8, 11]. Dual - Task combinations often consist of a motor control test and a neurocognitive task [11]. Many of the DT studies have investigated an older population and attempting to find a test battery that can predict a person's fall risk [49]. Other studies have used laboratory equipment on healthy subjects to see the differences between single and dual-task assessments [11]. Minimal studies have been completed testing concussed athletes using lower cost equipment in order to detect changes in cognitive function or postural sway [7].

The attention system has been broken down into 3 components: alerting orienting, and executive [12, 51]. The research has shown that the attention system is different than other processing systems and deal with incoming stimuli, make decisions, and process outputs. These are the main components of DT testing procedures. Orienting and Executive are the components that go into the assessments. Orienting is the ability to focus and prioritize input and executive in a more general manner is target detection. However, the concussed participants may be seeing changes in the alerting component. The alerting component can be related to a warning signal, such as being able to detect what is around you and being able to orient where your body is in space. Research has pointed out that by doing one assessment you can bring out deficits in the attention system that are noticeable to an outside viewer.

Systematic Reviews

In 2013, one systematic review and one systematic review and meta-analysis were published looking at DT assessments on concussion management. The first review published by Register-Mihalik et. al., 19 articles were included that looked at articles published before July 9, 2013, included adult participants, used a DT assessment and a discussion that applied to a concussion or a mTBI assessment or management. The systematic review and meta-analysis published by Lee et. al., included 10 studies that included young university aged participants and reported having a concussion and compared injured group to a healthy control. Neither of the reviews were able to review articles that participants had baseline data on the concussed participants.

Postural Stability and Reaction Time Task

Prior to the season starting, most athletes are asked to complete baseline tests for concussion testing [1]. In a recent study, 105 healthy Division I football athletes participated in dual-task baseline testing using the Dynavision D2 Visuomotor Training Device (D2) and a

BOSU ball [13]. Participants were asked to complete trials of the D2 task while standing on solid ground and on the flat surface of a BOSU ball [13]. Overall performance and reaction time were measured for each condition [13]. Researchers found that reaction time increased from 0.33 ± 0.036 seconds to 0.38 ± 0.063 seconds when athletes were instructed to balance on the BOSU ball [13]. Researchers also found that general performance decreased when moving to the unstable surface from 93 ± 11 hits per minute to 83.7 ± 9.2 hits per minute [13]. This is a ten percent decrease in performance for both of the tasks [13].

Postural Stability and Cognitive Task

Researchers used SOT to measure postural sway and auditory tests to measure cognitive function in 20 college aged athletes [11]. Researchers used at modified SOT which extended the time from 20 seconds to 60 seconds [11]. The cognitive test was an auditory test that assessed the participants' reaction time to numbers and letters [11]. The test was given in three sections, differentiating between even and odd numbers, vowels and consonants, and a combination of both (switch trial) [11]. Participants would press the left key of a mouse if the letter was a vowel or the number was even and the right key if the letter was a consonant or an odd number [11]. Participants came in for two separate sessions, one session would be doing the balance assessment and the cognitive test separately and in the other, the participants would be doing them as a DT assessment [11]. Data for the balance assessments were analyzed using paired t-tests for differences between single and DT conditions [11]. Cognitive data was separated into response time and response accuracy and then analyzed separately between tests and conditions using an ANOVA [11]. Differences were seen in the balance assessment during the DT in the fixed-fixed ($p=.03$) and the fixed-sway ($p=.014$) conditions [11]. Researchers also found that response times were longer for switch trails than non-switch trials under both single and DT conditions ($p \leq 0.001$) [11]. Reaction time was longer and errors were greater for the DT condition when compared to the single task, but only in the switch trials [11]. When comparing to other studies, this study was able to confirm previous findings that the cognitive function would suffer in reaction time and errors, while balancing [11]. The errors increased and reaction time decreased when the balance task increased in difficulty. Researchers explain how cerebral processing during DT modifies how the central nervous system controls postural stability [11]. With these results, it can be shown that performing complex computer based tests and a postural test at the same time can be used as an alternate concussion assessment tool that is sensitive in detecting small changes in cognitive function in young adults [11].

Studies have also compared DT conditions when using the SOT and the BESS as a postural assessment [8]. In a repeated measures design study, subjects again were tested during two sessions, 14 days apart, using DT methods [8]. The cognitive tasks used were the Procedural Reaction Time Task (PRT) and Procedural Auditory Task (PAT) [8]. The procedure was as follows: introduction to PAT and PRT, orientation to a balance task (either SOT or BESS), DT condition one, orientation to the second balance task, then finish with DT condition 2. In the cognitive tasks, subjects were given a number [visually (PRT) or auditory (PAT)] and were asked to identify the number was even or odd and click the appointed button on a mouse [8]. Reaction time and number of errors were recorded. For the eyes closed conditions during the DT testing, the PAT was given [8]. Each test lasted for 20 seconds for each trial [8]. Data were analyzed using a single two-way ANOVA for task and testing session for SOT, BESS, PRT, and PAT. Paired-samples t-tests were used to find the accuracy and differences between PAT. Results showed a significant improvement during the second session when compared to the first ($p<0.0005$) and in DT compared to single task ($p=0.004$) for balance performance on the SOT and BESS. Also there was a significant improvement in the second test session compared to the first ($p<0.001$) and the DT compared with the single task ($p=0.01$) for PRT and PAT performance. Authors explain that postural sway should improve when an external stimulus is added, such as a cognitive task, which proved to be true in the SOT test along with a learning effect between the two testing sessions[8]. However, authors concluded that scores may not improve with cognitive tasks if the balance test is more challenging [8]. Researchers also noted that healthy individual's most likely do not have the same issues with dividing attention as a concussed individual would.

Pellecchia investigated the influence of cognitive tasks on postural sway by using DT methods [52]. Subjects were 20 healthy adults, with no history of neurological or balance disorders, between the ages of 18 and 30 years old [52]. The neurocognitive tasks used were digit reversal, 2-bit classification, and counting backwards by threes [52]. The postural task sway was measured by having subjects stand on a force plate with a foam pad on top [52]. Subjects were asked to remain still with their arms by their sides on the foam pad while performing the cognitive tasks [52]. The center of pressure (COP) was measured for each cognitive task [52].

Data were analyzed by a separate repeated ANOVA to examine the effects of the cognitive tasks on the dependent measures. Pearson product moment correlations were used to analyze the relationship between smaller pieces of information and the dependent variables. Fisher's Least Significant Difference was used to make post-hoc comparisons. Results indicated that counting backwards by 3s resulted in the most changes in the distance of the center of pressure ($p<0.01$), anterior-posterior sway ($p<0.001$), and medial-lateral sway ($p<0.05$) when compared to all other cognitive tasks. Counting backwards by threes also had the higher error rate when compared to reversal and classification tasks ($p<0.05$). This shows that the more difficult the cognitive task results in increased postural sway [52].

In order to determine whether the incorporation of a cognitive task to a balance assessment could better discriminate between healthy young adults, healthy older adults and older adults with risk of falling [9]. Researchers used the Chattecx Balance System (CBS) in order to measure postural sway and center of pressure and counting backwards by threes for the cognitive task [9]. Results showed that the older adults with balance problems scored significantly worse in the stable and dynamic platform in the forward/backward with cognitive task conditions than the healthy older adults. The results demonstrate that the combination of these tests can help clinicians identify older adults that may be at risk of falling due to balance issues [9]. By adding the cognitive task to the dynamic postural assessment, researchers were able to magnify the differences between the healthy older adults and those at risk of falling [9].

Furthermore, authors have explored the "posture first" theory [53]. Researchers conducted a study that looked at the effect of balance perturbation on the performance of a cognitive task. Subjects stood on a platform with and without calf stimulation and with and without a cognitive task. In experiment 1 subjects were given no instruction and in experiment 2 subjects were given instructions to monitor balance performance. For the cognitive task, subjects were asked to count silently backwards by 7s starting from a random number (end numbers were taken from the subjects at the end to record correctness). Researchers concluded that body sway and cognitive function are not independent systems. Dual-task lead to a decrease in postural sway and a cognitive task was impaired when balance is perturbed.

Gait Assessment and Cognitive Task

Gait was originally chosen for older adults because as people age it requires more attention to walk when compared to the younger population [17]. Researchers attempted to highlight these deficits by assessing healthy older adults between the ages of 60-71 years [17]. The purpose of the research was to assess if stride time variability was due to walking slowly or walking while doing a cognitive task. Participants were instructed to walk a 20-m walkway either as a single task or a dual-task, which consisted of walking while completing a verbal fluency task. Results showed that performing a verbal fluency task while walking decreased mean stride velocity and stride time and increased stride time variability. This is showing that because when the brain is impaired, gait is no longer an automatic process. It requires more attention to walk when the brain is not functioning at its full potential, therefore by adding a cognitive task, it can overload in attentional capacity in older adults.

Shumway-Cook et al. conducted a study in order to determine the sensitivity and specificity of the Timed Up and Go Test (TUG) in single and dual conditions in 15 elderly adults between the ages of 65 and 85 [16]. Participants were tested under three condidtions: TUG as a single task, TUG while performing a cognitive task (counting backwards by threes), and TUG while performing a manual task (carrying a cup of water) [16]. A multivariate analysis of variance(MANOVA) was ran in order to find any significant differences between the groups ($p < 0.05$), along with a post hoc analysis[16]. In all conditions, participants with a history of falls took significantly longer to compete the task ($p < 0.001$) [16]. Times were as followed: single task 22.2 seconds, TUG with a manual task 27.2 seconds, and TUG with a cognitive task 27.7 seconds [16]. TUG was concluded to have have 87% sensitvity and 87% specificity in identifying fallers, and when adding a cognitive or manual task the sensitivity decreased to 80% and increased to 93% specificity [16]. Researchers concluded that TUG used as a single task or a DT is a clinically relevant low cost screening tool that is sensitive and specific for identifying wheather an older adult is at risk for falling based on their time to complete a task [16].

Many tests have been completed on healthy athletes when evaluating DT assessments, however, less have had the opportunity to look at the effect DT on concussed athletes [7]. In order to evauluate DT gait control and the sensitivity of current return to play protocols, one case study reported an 18 year old junior hockey player that had sustained a concussion [7]. The athlete had already taken part in a DT study as a non-concussed athlete [7]. The DT protocol consisted of the subject walking toward a designated area while doing the visual Stroop test, which was projected onto two screens in front of the subject. Initially, four trials were done unobstructed in order to determine the subject's preferred walking speed. After the speed was determined, the subject completed five trials with an obstacle in the walking path. No instruction was given as to how to avoid the obstacle. Walking speed, reaction time, and errors were recorded. Neuropsychological tests, that was constant with the baseline test completed previously were also completed by the participant at seven and 14 days post injury [7]. For the DT post-concussion trials, measures were taken at seven and 30 days and compared the pre-concussion trials [7]. Results showed that the athlete did not have any medical symptoms on day seven or 30 days post-concussion, with his neuropsychological testing returning to baseline at day 14 [7]. Data were analyzed using non-parametic staticial tests in order to find main effects across days and post-hoc analysis was done with Wilconxon test; significance was set at $p=0.05$. In the dual task tests, scores were significantly higher ($p<0.001$) seven days following a concussion and returned to just under baseline at 30 days ($p=0.038$) [7]. Obstical approach speed significantly decreased after sustaining a concussion ($p=0.006$). Post-hoc analysis revealed there was a decrease approach speed for both days when compared to baseline: at seven days ($p=0.002$) and 30 days($p=0.003$) [7]. The sports medicine staff deemed the concussion as "simple" and was able to return to play 7 days later [7]. This research demonstrated how an athlete with a "simple" concussion showed decreased ability with multi-task tests up to 30 days post-concussion [7]. Considering that sports are a multi-task environment, clinicians should consider using DT test in order to determine if an athlete is ready to return to play [7].

The same authors published another study looked at conucssed and healthy athletes at approximately 37 days post injury [34]. Subjects walked along a pathway that was either unobstructed or obstructed and with and without a visual cognitive task. The visual Stroop tests was used as the cognitive task. Data were collected using a motion analysis system. While the walking speed did not differ from concussed to heathly, concussed participants had higher Dual Task Costs, more errors in the cognitive task and larger clearance distances around the obstacle. Researchers concluded that DT assessments continue to show deficits post- concussion, even when traditional assessments recommend return to play.

Another study also saw the value in DT assessment and examined the relationship of dynamic motor performance and neuropsychological test results [54]. Researchers compared concussed and healthy college athletes in DT testing, which consisted of walking while completing more complex cognitive tasks, and neurocognitive testing, using ImPACT. The findings of this study suggest that motor and cognitive effects of a concussionn may resove differently from each other, to empasize this point, researchers showed that there was a weak correlation beteen ImPACT and gait stability. Researchers suggest that complex motor performance tasks may be a better way to assess concussions that cognitive tests alone [54].

Pen and Paper motor task with cognitive assessmnet

While recent studies have foucsed on whole body movement in combination with a cognitive assessment, preliminary DT studies attemped to test the central executive component of the working memory in Alzheimers patitents [10]. In orer to investigate the executive component, researchers used a pen and paper method of DT testing. Subjects were instructed to follow a line that intersescted boxes on a paper while simultaneously completing a backards digit recall task. Researchers found that Alzheiers patients performed worse on the span and tracking task than the healthy controls. One specific area focused on during the dicussion was the theory behind DT testing. Researchers associated executive function with the frontal lobe, however, most lesions found on patients are located in the parietal/temporal lobes. This suggests that the synapeses may be what is impared in these patients. In conculsion, researchers recommend that the paper and pencil version of DT testing has potential to be used as a clinical tool in order to reccognize Alzheimers disease.

Recovery Time

The current NATA position statement, suggests that athletes should gradually return to play once they report symptom free and their clinical evaluations have returned to baseline [1]. For each athlete, concussion severity will often differ between individuals [1], though there are trends based on history of concussion, age, and gender [55].

History of Concussion

Using ImPACT, researchers investigated the differences in scores between athletes with and without a history of concussion and between male and female soccer athletes [55]. Two hundred and thirty four athletes (141 female and 93 male) were included in this study [55]. Of these athletes 101 had a history of concussion and 133 had no history [55]. Authors found that athletes with a history of concussions scored lower in reaction time, memory and visual processing scores than athletes with no history of concussions [55]. Athletes with a history of concussions were also tested seven days post-concussion while athletes with no prior concussion were tested 11 days post-concussion [55]. Results also showed that female athletes score worse on the neurocognitive tests and have a higher number of symptoms than the male soccer players [55].

In another study done by Covassin et al, researchers investigated the neurocognitive deficits in athletes with a history of two or more concussions when compared to athletes with no history of concussion after sustaining a head injury [56]. This study excluded football from the results [56]. The study was completed over the 2002-2003 and 2003-2004 academic school year [56]. Within those two years, 57 concussions were reported with 21 of those athletes having sustained two or more concussions [56]. Researchers used ImPACT to assess neurocognitive function [56]. Researchers found that athletes with two or more concussions scored lower on verbal memory and reaction time five days' post-concussion than those only having one concussion [56]. There were no significant findings between the two groups in regards to the symptom scores [56]. This may have occurred due to the familiarity of the test and the return to play protocol in the athletes with two or more concussions [56].

Age

In the 2012 study done by Zuckerman et al, authors investigated the return to play time between two different age groups of adolescent athletes [48]. The two age groups were ages 13-16 and 18-22, age 17 was excluded to have a clear margin between the groups [48]. Using ImPACT, researchers only used athletes that had completed two ImPACT post-tests within 30 days of sustaining the injury [48]. Of the 502 athletes that were reported to be concussed, authors used a random selection of 200 athletes, 100 in the younger age group and 100 in the older group [48]. Results showed that the ImPACT scores returned to normal within approximately seven days for the 13-16 year olds and five days for the 18-22 year olds in verbal memory, visual memory, reaction time, and processing speed [48]. The post-concussion symptom scale revealed that the 13-16 age group took eight days to return to normal, while the 18-22 group took six days

[48]. Authors concluded that the 13-16 age group took longer to recover from a concussion than the 18-22 year old age group [48].

Exercise

The ImPACT has been recommended to use in determining when to send athletes back to activity [1]. In a study done my Majerske et al., 2008, researchers used ImPACT and Post-Concussion Symptom Scale (PCSS) to examine how different activity levels affect symptoms and neurocognitive function [57]. This study involved 80 males (15.81 ± 1.35) and 15 females (16.32 ± 1.32), excluding athletes with a learning disability or taking any form of medication at the time of injury [57]. Athletes were tested on two occasions [57]. Researchers were unable to find a statistically significant relationship between symptom scores and activity level [57]. Clinically, researchers discussed how athletes that participate in intermediate levels of activity (school activity and light activity at home, such as moving the lawn or light jogging) after concussion had the best scores on the neurocognitive tests and the lowest symptom scores [57].

Comparison Between Individual Tests

Often times, certain tests will pick up on deficits longer than others [3]. Some are more sensitive to the immediate signs of a concussion, whereas others are able to pick up on the smaller details later in the recovery time. In order to properly design a return to play protocol, clinicians must be aware of the average time it takes for concussed athletes to return to baseline [6].

In the study conducted by Bleiberg et al., researchers investigated the recovery duration after concussions sustained during sports using a computerized neuropsychological test battery, the Automated Neuropsychological Assessment Metrics (ANAM) [6]. The assessment consists of matching to sample, math processing, spatial processing, the Sternberg Procedure, simple reaction time, and continuous performance test [6]. Participants consisted of 82 male college freshman from the United States Military Academy [6]. Of these 82 cadets, 64 sustained concussions from the required boxing program and 18 were used as controls [6]. All cadets took a baseline test prior to the beginning of the first class; once a cadet was diagnosed with a concussion, they were tested at zero to 23 hours, one to two days, three to seven days and eight to 14 days post-concussion [6]. Using Statistical Analysis System (SAS) version 8 software, data were analyzed using a mixed model analysis of repeated measures. Omnibus F tests were used to look for significance between group and time interval and the interaction effect of group by time for each. Post hoc t-tests were used to look at the main effect of time by using difference between baseline and follow-up at each interval [6]. Post-hock t-tests revealed significant differences from baseline at one to two days post injury($p<0.0001$), three to seven days ($p<0.0001$), eight to 14 days and showed recovery at three to seven days post-injury [6]. Limitations expressed by the researchers was the potential for practice effects when doing the testing sessions close together [6].

In another study to evaluate the acute effects of concussions and the amount of time it takes to recover, researchers used 150 college aged football players [3]. Ninety four players sustained concussions and 56 matched controls were used in this study [3]. In order to measure their recovery, the Graded Symptom Checklist, Standardized Assessment of Concussion, and Balance Error Scoring System were used [3]. Test were administered on the sideline, at two to three hours, and one, two, three, five, seven, and 90 days post injury [3]. Researchers tracked neurocognitive function at day two, seven and 90 by using a test battery that every athlete was required to take prior to participation in football separate from this study [3]. Data were analyzed using SPSS software, version 11.0. A 95% confidence interval was used in results. Results showed a difference in symptom scores through day five, cognitive impairments were seen through days two through five, and both showed to be resolved at day seven [3]. Balance was the most impaired during the first 24 hours and returned to normal days three to five [3]. The neurocognitive battery showed impairments in processing speed and verbal fluency through day seven [3]. Some limitations of this study were that they only had athletes with mild to moderate concussions, found that the head injuries were most likely under reported, and that they only used male football athletes [3].

Since different tests have the ability of detecting postural and neurocognitive deficits at different points of recover and it is important that athletic trainers use a variety of tests when managing a concussion [1, 3]. However, commonly used clinical tests scores will return to baseline by day seven when used individually and as a battery of tests [3]. Currently symptom scores have been commonly used in deciding when to return an athlete to play, however, many other clinicians are looking for a more objective tool in order to decide when to return athletes to play [1, 50]. As more information becomes available about the dual-task results in a laboratory setting, clinicians will begin to investigate more cost effective ways of implementing the dual-task assessments.

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