INVESTIGATION OF VALIDITY, RELIABILITY, AND PRACTICE EFFECTS OF THE IMMEDIATE POSTCONCUSSION ASSESSMENT AND COGNITIVE TEST (ImPACT) AND TRADITIONAL PAPER-PENCIL NEUROPSYCHOLOGICAL TESTS

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ABSTRACT

DANIEL L. KONTOS: Investigation of Validity, Reliability, and Practice Effects of the Immediate Postconcussion and Cognitive Test (ImPACT) and Traditional Paper-Pencil Neuropsychological Tests
(Under the direction of Kevin M. Guskiewicz, PhD, ATC)

The purpose of this study was to determine: 1) if an athlete's age significantly affects neuropsychological test performance, 2) if an athlete's performance remains consistent across serial neuropsychological tests, and 3) the concurrent validity of the Immediate Postconcussion and Cognitive Test (ImPACT) scores when compared to traditional paper-pencil test scores of similar cognitive domains. A healthy sample of 20 college and 20 high school athletes completed both ImPACT and traditional paper-pencil neuropsychological test batteries on three separate occasions. Means and standard deviations, 2x3 mixed model ANOVAs (age x session), reliability ($ICC_{2,1}$) and precision (SEM) values, and linear regressions were calculated on outcome measures for both test batteries. The ANOVAs revealed significant main effects of age for the Trail Making Test Form B (TMT-B) total time and ImPACT processing speed composite score with college athletes performing better than high school students on both measures. The ANOVAs also revealed significant main effects of session for the Brief Visuospatial Memory Test – Revised (BVMT-R) total recalled (immediate and delayed), the TMT-B total time, Stroop Test total score, and ImPACT processing speed composite score. Reliability measures ranged from 0.12 to 0.72 with the majority of the outcome measures achieving a moderate level of reliability across testing sessions. Linear regressions revealed that ImPACT test scores had low levels of shared variance with select paper-pencil neuropsychological tests. Coefficients of determination for these linear regressions left much of the variance unexplained (52-88%). Only the ImPACT Three Letters average counted correctly reached a moderate level (R^2=0.481). This study demonstrates the need of the clinician to understand the differences in neuropsychological test performance for athletes of different age groups and across serial neuropsychological tests. It is also recommended that caution be exhibited when evaluating ImPACT test results of athletes 15-17 and 19-21 as the concurrent validity has not been conclusively proven.

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CHAPTER 1

INTRODUCTION

Sports-related concussion is the most common type of athletic head injury (Guskiewicz, Weaver, Padua, & Garrett, 2000) with an estimated 1.6 to 3.8 million sports-related brain injuries occurring each year in the United States.(Rutland-Brown, Langlois, Thomas, & Xi, 2006) Assessment and management of these injuries has become a more prevalent topic of interest and debate of the past two decades, including an identifiable increase in the use of neuropsychological testing in the management of sports-related concussion.(McCrory, Makdissi, Davis, & Collie, 2005; Randolph, McCrea, & Barr, 2005)

The traditional focus of neuropsychology has been the assessment of cognitive processes to anatomically localize structural brain injuries, but the focus has shifted to functionally assess and track the progress of patients with neurological disorders.(McCrory, Makdissi, Davis, & Collie, 2005) This change of focus led to the creation of a standard clinical neuropsychological assessment involving administration of various tests measuring cognitive abilities, psychological functioning, and to a lesser degree, sensory and motor functioning.(Randolph, McCrea, & Barr, 2005) Increasing interest in the application of computer technology to the neurosciences and clinical psychiatry (Butcher, Perry, & Hahn, 2004; Gottschalk et al., 2000) has led to modifications in standard clinical neuropsychological assessment practices.

Advantages in computerized testing methods have the potential to enhance the field of psychological assessment.(Butcher, Perry, & Hahn, 2004) These advantages include infinite randomized forms, ability to test reaction time in milliseconds, control over presentation of test stimuli, standardized self administration, group testing, rapid testing, decreased setup, preparation and costs, internet based delivery, automated analysis, ease of data collection, centralized data storage, analysis, and reporting.(Grindel, Lovell, & Collins, 2001; McCrory, Makdissi, Davis, & Collie, 2005; Randolph, McCrea, & Barr, 2005; Schatz & Browndyke, 2002)

Computerized tests were initially designed to detect severe impairments in patients with neurological and psychiatric illness, in patients with brain lesions, and in people exposed to neurotoxic substances.(Collie, Darby, & Maruff, 2001) More recently, computerized batteries have been developed to create tests that are sensitive to subtle changes in cognition similar to those expected to occur in sports related traumatic brain injury.(Collie, Darby, & Maruff, 2001; Schatz, Pardini, Lovell, Collins, & Podell, 2006) Despite the rapidly growing use of computer-based neuropsychological batteries, these cognitive tests have not been validated for use in the follow-up of sports-related concussion.(McCrory, Makdissi, Davis, & Collie, 2005) Standardized neuropsychological paper-pencil tests have undergone extensive validation studies and concurrent and clinical validity have been typically well established.(Randolph, McCrea, & Barr, 2005) However, there is a noticeable lacking of validation studies for the Immediate Postconcussion Assessment and Cognitive Test (ImPACT) and only a few studies have been found supporting its validity.(Iverson, Franzen, Lovell, & Collins, 2004; Iverson, Lovell, & Collins, 2005)

As neuropsychological assessment of concussion moves toward computer-based testing, efforts should be made to establish the validity for these neuropsychological test batteries, particularly construct and concurrent validity. Construct validity will support the idea that the computer-based testing tool does indeed measure neuropsychological performance. Concurrent validity will be demonstrated through high correlations with previously validated measures of neuropsychological performance (i.e. paper-pencil tests) and will support the idea that the two measures may be evaluating similar constructs.

Psychometric data from computer-based measures should be established in comparison to long-standing and psychometrically sound test measures.(Schatz & Browndyke, 2002) Establishing this comparison is critical in order to have studies addressing the psychometric properties of the cognitive tests used in the management of sports concussion.(McCrory, Makdissi, Davis, & Collie, 2005) Because there are few studies that address or establish this comparison, more research is needed to fully establish the psychometric properties of newer computer-based measures, particularly by parties not involved in their commercial development.(Schatz & Browndyke, 2002)

As sports-related concussion has received more attention in recent years, the management and care of concussions has been given some reconsideration.(Guskiewicz et al., 2004) Whether administered by computer or on traditional paper-pencil forms, baseline neuropsychological testing followed by a postinjury comparison is now used by a number of high school and collegiate programs.(Buzzini & Guskiewicz, 2006; Randolph, 2001) The vast majority of people participating in contact and collision sports are under 19 years of age.(Buzzini & Guskiewicz, 2006) Also, the majority of concussions occur at the high school level (McClincy, Lovell, Pardini, Collins, & Spore, 2006) which makes it necessary to understand the effects of age on cognitive performance when conducting neuropsychological testing.

It is also important to determine the effects of age on cognitive performance as differences have been noted in acute neuropsychological recovery between high school and collegiate athletes; with high school athletes recovering at a slower rate than collegiate athletes following a concussion.(Field, Collins, Lovell, & Maroon, 2003; Lovell, Collins, Iverson, Johnston, & Bradley, 2004)

Repeated administrations of the same neuropsychological tests are now more common in neuropsychological evaluations (Benedict & Zgaljardic, 1998) as serial testing is used to track an athlete's neurocognitive recovery over time. The influence of practice effects on these neuropsychological test scores must be carefully considered when retesting or administering serial neuropsychological testing of individuals. Performance on many neuropsychological tests may be improved by prior exposure to testing stimuli and procedures.(Collie, Maruff, Darby, & McStephen, 2003) Improvement in test performance due to practice effects cause inflated neuropsychological test scores which can mimic neurocognitive recovery, and may lead to returning an athlete to competition prematurely.

Therefore, the purposes of this study are to determine: 1) if an athlete's age significantly affects neuropsychological test performance, 2) if an athlete's performance remains consistent across serial neuropsychological tests, and 3) the concurrent validity of ImPACT test scores when compared to traditional paper-pencil test scores of similar cognitive domains.

Research Questions

1. Is neuropsychological test performance significantly different between high school and college athletes?
    a. Are paper-pencil neuropsychological test scores of high school athletes significantly different than paper-pencil neuropsychological test scores of college athletes?
    b. Are ImPACT test scores of high school athletes significantly different than ImPACT test scores of college athletes?
2. Are athletes' neuropsychological test performances consistent across serial neuropsychological tests?
    a. Are athletes' paper-pencil neuropsychological test performances consistent across serial neuropsychological tests?
        i. Do practice effects exist for paper-pencil neuropsychological test scores when conducting serial neuropsychological testing?
            1. Are practice effects for paper-pencil neuropsychological test scores influenced by age?
    b. Are athletes' ImPACT test performances consistent across serial neuropsychological tests?
        i. Do practice effects exist for ImPACT test scores when conducting serial neuropsychological testing?
            1. Are practice effects for ImPACT test scores influenced by age?
3. Are ImPACT test scores valid measures of neuropsychological test performance based on comparisons to paper-pencil neuropsychological test scores of similar cognitive domains?

Research Hypotheses

1. Athletes' neuropsychological test performance will be significantly different between age groups during neuropsychological testing.
    a. Paper-pencil neuropsychological test scores of high school athletes will be significantly different than paper-pencil neuropsychological test scores of college athletes.
    b. ImPACT test scores of high school athletes will be significantly different than ImPACT test scores of college athletes.
2. Athletes' neuropsychological test performances will not be consistent across serial neuropsychological tests.
    a. Athletes' paper-pencil neuropsychological test performances will not be consistent across serial neuropsychological tests.
        i. Practice effects will exist for paper-pencil neuropsychological test scores when conducting serial neuropsychological testing.
            1. Practice effects for paper-pencil neuropsychological test scores will not be influenced by age.
    b. Athletes' ImPACT test performances will not be consistent across serial neuropsychological tests.
        i. Practice effects will exist for ImPACT test scores when conducting serial neuropsychological testing.
            1. Practice effects for ImPACT test scores will not be influenced by age.

3. ImPACT test scores will have high levels of shared variance with paper-pencil neuropsychological test scores of similar cognitive domains when testing neuropsychological performance.

Definition of Terms

1. Immediate Postconcussion Assessment and Cognitive Test (ImPACT): a computerized neuropsychological test battery used to assess cognitive function in the areas of attention, verbal recognition, visual recognition, working memory, visual processing speed, visual learning, visual memory, reaction time, motor response speed, impulse control, and response inhibition.
2. Traditional paper-pencil neuropsychological tests: cognitive tests administered verbally or on paper forms used to assess different areas of cognitive function.
3. Hopkins Verbal Learning Test-Revised (HVLT-R): a cognitive test used to assess verbal learning, immediate memory, and delayed memory.
4. Brief Visuospatial Memory Test-Revised (BVMT-R): a cognitive test used to assess visual memory.
5. Trail Making Test Form B (TMT-B): a cognitive test used to assess visual scanning, complex attention, mental flexibility, and visual-motor speed.
6. Symbol Digit Modalities Test (SDMT): a cognitive test used to assess psychomotor speed, visual short-term memory, attention, and concentration.
7. Stroop Test: a cognitive test used to assess cognitive flexibility, inhibition.

Operational Definitions

1. Healthy: an individual with no history of diagnosed concussion within the last five years and no known neurocognitive deficits or psychological conditions.
2. High school age athletes: athletes 15-17 years of age
3. College age athletes: athletes 19-21 years of age
4. Active: individuals engaged in athletics three or more days per week.

Delimitations

1. Individuals with history of diagnosed concussion in the last five years will be excluded.
2. Individuals with known neurocognitive deficits or disorders will be excluded.
3. Individuals with known psychological disorders or conditions will be excluded.
4. Individuals with color blindness will be excluded.
5. Individuals 18 years of age will be excluded to eliminate the possibility for age overlap between high school and college age athletes.
6. Individuals with participation in athletics for less than three days of the week will be excluded.

Limitations

1. Self-report of background and medical history given by each participant was not checked for accuracy. In the event false information was given, a participant may have been allowed to participate in this study when they would have otherwise been excluded.

2. The amount of effort given by each participant and their willingness to participate may cause variations in test scores that may otherwise not exist.
3. Shortcomings of individual tests such as design flaws, ambiguity, etc., may cause variations in test scores that may otherwise not exist.
4. The ability of the examiner to properly and consistently administer the test batteries may cause variations in test scores that may otherwise not exist.
5. Mental or physical fatigue may cause variations in test scores that may otherwise not exist.
6. The time of day at which testing occurs may cause variations in test scores that may otherwise not exist.
7. The day of the week which testing occurs may cause variations in test scores that may otherwise not exist.
8. Environmental influence (temperature, noise, etc) may cause variations in test scores that may otherwise not exist.
9. Proper interpretation of the data including the ability to correctly match psychometric properties of ImPACT's subtests with corresponding paper-pencil tests to ensure accurate findings.
10. Participants' daily activities and sleeping habits were not monitored or controlled between test sessions which may cause variations in test scores that may otherwise not exist.
11. A convenient sample of athletes chosen based on proximity and availability may not accurately represent the population.

12. The ability of each participant to follow instructions given by the computer may cause variations in test scores that may otherwise not exist.
13. Test forms were not randomized across test sessions which may lead to variations in test scores across test sessions that may otherwise not exist.

Assumptions

1. Individual will report accurate medical history.
2. Participants will give their best effort.
3. Shortcomings of individual tests will not significantly affect test scores.
4. The ability of the examiner will not significantly affect test scores.
5. The time of day at which testing occurs will not significantly affect test scores.
6. The day of the week which testing occurs will not significantly affect test scores.
7. Environmental influence (temperature, noise, etc) will not significantly affect test scores.
8. Effects of mental and physical fatigue on the overall data will be minimized or eliminated through counterbalancing.
9. Data will be properly interpreted and ImPACT and paper-pencil tests will be correctly matched for psychometric properties being tested.
10. Participants' daily activities between testing sessions will not significantly affect test scores.
11. A convenient sample of athletes chosen based on proximity and availability will accurately represent the population.
12. Each participant will follow instructions exactly as they are given by the computer.

13. Changes in test scores across test sessions will not result from test forms that were not randomized across test sessions.

Variables

Dependent Variables

1. Paper-pencil neuropsychological test scores
    a. Hopkins Verbal Learning Test-Revised
        i. Total recalled (immediate)
        ii. Discrimination index (immediate)
        iii. Percent recognized (immediate)
        iv. Total recalled (delayed)
        v. Discrimination index (delayed)
        vi. Percent recognized (Delayed)
    b. Brief Visuospatial Memory Test-Revised
        i. Total recall (immediate)
        ii. Percent recalled (immediate)
        iii. Delayed recall (delayed)
        iv. Percent recalled (delayed)
    c. Trail Making Test
        i. Total time
    d. Symbol Digit Modalities Test
        i. Total score
    e. Stroop Test

i. Total score

2. ImPACT test scores
    a. Composite Scores
        i. Verbal memory
        ii. Visual memory
        iii. Processing speed
        iv. Reaction time
        v. Impulse control
    b. Word Memory
        i. Learning percent correct (immediate)
        ii. Delayed memory percent correct
    c. Visual Memory
        i. Learning percent correct (immediate)
        ii. Delayed memory percent correct
    d. Symbol Matching
        i. Average correct reaction time (visible)
    e. Color Match
        i. Average correct reaction time
    f. Three Letters
        i. Average counted correctly

Independent Variables

1. Age group
2. Test session

CHAPTER 2

LITERATURE REVIEW

Neurocognitive deficits associated with mild head injury are often subtle, and difficult to assess as there are tremendous differences in individual cognitive abilities.(Barth, Freeman, Broshek, & Varney, 2001) This is the challenge facing individuals responsible for evaluating athletes with sports-related concussion. Neuropsychological testing has been identified as a sensitive and useful measure in the detection of the cognitive effects of concussion. (Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Lovell & Collins, 1998) Traditional paper-pencil neuropsychological tests have been documented as valid measures of cognitive function.(Maroon et al., 2000; Randolph, McCrea, & Barr, 2005) However, despite a lack of evidence proving validity, computerized neuropsychological testing is rapidly gaining popularity. The purpose of this review is to define sports-related concussion, discuss neuropsychological assessment, and examine selected neuropsychological tests.

Concussion

Despite no universal agreement on the definition of concussion (Collins, Lovell, & McKeag, 1999) or the various levels of severity (Guskiewicz, Weaver, Padua, & Garrett, 2000), the definition cited most frequently is that of a "clinical syndrome characterized by immediate and transient posttraumatic impairment of neural functions, such as alteration of consciousness, disturbance of vision, equilibrium, etc. due to brain stem involvement."(Committee on Head Injury Nomenclature of the Congress of Neurological Surgeons, 1966) This definition was recognized as having a number of limitations in accounting for the common symptoms and predominant clinical features of a concussion, such as headache and nausea (Aubry et al., 2002; Guskiewicz et al., 2004; McCrory et al., 2005), and also lacked the ability to include minor impact injuries that resulted in persistent physical and/or cognitive symptoms.(Aubry et al., 2002) In order to overcome some of the limitations of the definition put forth by the Congress of Neurological Surgeons in 1966, the Concussion in Sport Group (CISG) developed an updated definition.(Aubry et al., 2002)

> "Concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces. Several common features that incorporate clinical, pathological and biomechanical injury construct that may be used in defining the nature of a concussive head injury include the following:
>
> 1. Concussion may be caused by a direct blow to the head, face, neck or elsewhere on the body with an 'impulsive' force transmitted to the head.
> 2. Concussion typically results in the rapid onset of short lived impairment of neurological function that resolves spontaneously.
> 3. Concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect a functional disturbance rather than structural injury.
> 4. Concussion results in a graded set of clinical syndromes that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course.

5. Concussion is typically associated with grossly normal structural neuroimaging studies."(Aubry et al., 2002; Guskiewicz et al., 2004; McCrory et al., 2005)

Incidence. Sports-related concussion is the most common type of athletic head injury.(Guskiewicz, Weaver, Padua, & Garrett, 2000) Based on the 1991 National Health Interview Survey (NHIS) data, it was estimated that approximately 300,000 sports-related brain injuries (resulting in loss of consciousness) occur per year in the United States.(Sosin, Sniezek, & Thurman, 1996; Thurman, Branche, & Sniezek, 1998) In 2004, the Center for Disease Control and Prevention (CDC) estimated that approximately 1.5 million traumatic brain injuries (TBI) occurred during the year of 2003, and of those TBI's, 270,000 occurred as a result of "struck by/against" events.(Rutland-Brown, Langlois, Thomas, & Xi, 2006) "Struck by/against" events were classified as events in which a person was struck unintentionally by another person or object, such as falling debris or a ball in sports, and many, but not all sports-related TBI's were included in this category.(Rutland-Brown, Langlois, Thomas, & Xi, 2006) Although the number of sport-related head injuries appear to have decreased from 1991 to 2003, both sources have their limitations. It is important to realize that the CDC report of 2004 did not contain a separate category in which sports-related head injuries could truly be measured, and it is also impossible to tell how many sports-related concussions may have been classified into other categories. The NHIS data only included sports-related brain injuries that resulted in a loss of consciousness. Studies suggest that injuries resulting in loss of consciousness may only account for only eight percent (Schulz et al., 2004) to 19.2 percent (Collins, Iverson et al., 2003) of all sports-related brain injuries.(Rutland-Brown, Langlois, Thomas, & Xi, 2006) Based on these percentages, it is possible that an estimated 1.6 to 3.8 million sports-related brain injuries occur each year in the United States.(Rutland-Brown, Langlois, Thomas, & Xi, 2006)

Although certain sports pose a higher risk to participants (i.e. football, boxing, rugby, and hockey); concussions can occur in any sport, at any level of competition. The potential for concussion is related to the number of opportunities in the sport for activities that produce collisions.(Powell, 2001) Among high school athletes (Football, baseball, wrestling, boy's and girl's basketball, boys' and girl's soccer, field hockey, softball, and volleyball), 5.5% of all injuries were concussions with football accounting for 63% of all concussions.(Powell & Barber-Foss, 1999)

Mechanism. Concussions can be a result of a contact or non-contact based mechanism. Sufficient force in the opposite velocity vector may cause the brain to strike against the inner skull in the direction it was initially traveling (coup injury) or the brain may "rebound" from the direction of the deceleration and strike the inner lining of the skull in the opposite direction (contrecoup injury).(Barth, Freeman, Broshek, & Varney, 2001) A true coup or contrecoup injury may not exist as these injuries are a result of a linear velocity, however, the magnitude of the damage of a coup or contrecoup injury can be increased in the presence of significant rotation forces.(Barth, Freeman, Broshek, & Varney, 2001)

Non-contact injury can result from three types of stresses that can injure the brain: compressive, tensile, and shearing.(Cantu, 1996; Guskiewicz et al., 2004) Brief, uniform compressive stresses are fairly well tolerated by neural tissue, but tension and shearing stresses are poorly tolerated.(Guskiewicz et al., 2004)

Signs and Symptoms. A vast array of sign and symptoms can follow concussive injuries. Common signs and symptoms of concussion include headache, dizziness/vertigo, generalized weakness/fatigue, nausea/vomiting, visual disturbances, tinnitus, fogginess, photophobia, phonophobia, depression, anxiety, insomnia, hypersomnia, appears dazed, confusion/disorientation, lack of coordination, personality change, and loss of consciousness.(Barth, Diamond, & Errico, 1996; Grindel, Lovell, & Collins, 2001)

Athletes suffering from concussion also display deficiencies in neurocognitive functioning such as attention, memory, concentration, and information processing.(Collins et al., 1999; Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Leininger, Gramling, Farrell, Kreutzer, & Peck, 1990; Macciocchi, Barth, Alves, Rimel, & Jane, 1996) These neurocognitive functions are most sensitive to change after concussion and are prone to the effects of numerous factors including anxiety, fatigue, and pain.(Barr & McCrea, 2001) Increased anxiety causes disruption in attention, concentration, and complex mental operations, and those suffering from depression may experience disruption in attention concentration, memory, and executive function.(Alexander, 1995; Binder, 1986; Ettlin et al., 1992; Krupnick & Horowitz, 1981; Weingartner, Cohen, Murphy, Martello, & Gerdt, 1981) Individuals suffering from pain such as headaches, even pain not due to head injury, often display poor concentration and memory.(Alexander, 1995; Hollnagel & Norrelund, 1980) There is usually a direct correlation between self-reported symptoms and performance on neuropsychological tests.(Collins, Iverson et al., 2003; Guskiewicz et al., 2004; Maroon et al., 2000; Schatz, Pardini, Lovell, Collins, & Podell, 2006)

Post-concussive deficits can occur with minimal detectable anatomic pathology and often resolve completely over time, suggesting they are based on temporary neuronal dysfunction that can occur because of ionic shifts, altered metabolism, impaired connectivity, or changes in neurotransmission.(Giza & Hovda, 2001) Signs and symptoms and the deficits they cause are likely manifestations of underlying neuronal dysfunction due to the processes of the pathophysiological cascade; a metabolic cascade that has been demonstrated in rats in laboratory settings, but is hypothesized to occur similarly in humans.(Giza & Hovda, 2001)

<u>Pathophysiological Cascade.</u> Following a concussive event there is a rapid release of neurotransmitters.(Giza, Griesbach, & Hovda, 2005; Giza & Hovda, 2001) Excitatory transmitters, such as glutamate, bind to the N-methyl-D-aspartate (NMDA) receptor causing further neuronal depolarization with an efflux of potassium and influx of calcium.(Giza, Griesbach, & Hovda, 2005; Giza & Hovda, 2001; Shaw, 2002) These ionic shifts cause changes in the cellular physiology and trigger a pathophysiological cascade.(Giza, Griesbach, & Hovda, 2005)

This cascade includes an initial period of increased glucose metabolism due to the increased cellular energy demands needed to restore neuronal membrane potentials.(Giza & Hovda, 2001; Shaw, 2002) Following this initial period of hypermetabolism, the concussed brain enters a period of depressed metabolism and decreased cerebral blood flow which lasts for several days.(Giza, Griesbach, & Hovda, 2005; Giza & Hovda, 2001) In addition, continued increases of intracellular calcium (lasting up to 4 days) can lead to increased cell death due to oxidative metabolism impairment and also impairment of neural connectivity through disruption of neurofilaments and microtubules.(Giza, Griesbach, & Hovda, 2005; Giza & Hovda, 2001; Shaw, 2002)

Dysfunctional excitatory neurotransmission may also occur following a concussive event, and may affect the glutamatergic, adrenergic, and cholinergic systems.(Giza & Hovda, 2001) These impairments in cholinergic neurotransmission can lead to learning and spatial memory deficits.(Giza & Hovda, 2001; Hepler, Olton, Wenk, & Coyle, 1985; Miyamoto, Kato, Narumi, & Nagaoka, 1987)

Neuropsychological Testing

Applications of neuropsychological testing include the assessment of cerebral diseases such as dementia, developmental diseases such as dyslexia, the effects of pharmacological and surgical interventions, acquired immunodeficiency syndrome, multiple sclerosis, effects of exposure to hazardous substances, and head injuries.(Levin, 1994) The use of neuropsychological testing in the management of sport-related concussion is gradually becoming more common among sports medicine clinicians.(Guskiewicz, Ross, & Marshall, 2001) Although the reported usage of neuropsychological testing has increased from 2001 to 2005, the use of clinical examinations or symptom checklists remain the two most common methods for the assessment of a concussion.(Ferrara, McCrea, Peterson, & Guskiewicz, 2001; Notebaert & Guskiewicz, 2005) Neuropsychological testing provides a scientific method for evaluating symptoms of cognitive dysfunction resulting from sport-related concussion (Barr, 2001; Echemendia, Putukian, Mackin, Julian, & Shoss, 2001), and many of those testing measures have been identified as being sensitive and useful measures in the detection of the cognitive effects of concussion.(Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Lovell & Collins, 1998)

No single test is effective in diagnosing the presence or absence of concussion (Barr, 2001; Echemendia, Putukian, Mackin, Julian, & Shoss, 2001) and it is recommended that a battery of tests be used. Sport concussion batteries should include measures of cognitive abilities most susceptible to change after concussion, including attention and concentration, cognitive processing (speed and efficiency), learning and memory, working memory, executive functioning, and verbal fluency.(Guskiewicz et al., 2004) It is also recommended that reliability, validity (construct validity in particular), sensitivity, and specificity be considered as criteria for selecting neuropsychological test batteries.(Levin, 1994) In addition to cognitive function, symptom severity and postural stability can also be affected following a concussion and should be taken into consideration during a clinical assessment.(Guskiewicz, 2001; Guskiewicz, Ross, & Marshall, 2001)

Several neuropsychological tests have been identified as useful in assessing individuals after concussion because of their sensitivity to deficits in attention, concentration, information processing, and short-term memory.(Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Guskiewicz, Ross, & Marshall, 2001; Kelly, 2000; Lovell et al., 2003; Macciocchi, Barth, Alves, Rimel, & Jane, 1996) However, these tests are not specific to the diagnosis of concussion, and the test results are adversely affected by other conditions such as depression, learning disability, sleep disturbance, visual disturbance, and pain; especially headaches.(Kelly, 2000)

Neuropsychological tests are not flawless and limitations do exist. Some of these limitations include the testability of debilitated patients, assessment of other exceptional patients, shortcomings of individual tests, malingering, qualifications of the examiner, interpretation of data,(Levin, 1994) and willingness of the patient to cooperate.(Lovell & Collins, 1998)

Effects of Age. Baseline neuropsychological testing followed by a postinjury comparison is now used by a number of high school and collegiate programs.(Buzzini & Guskiewicz, 2006; Randolph, 2001) The vast majority of people participating in contact and collision sports are under 19 years of age (Buzzini & Guskiewicz, 2006) and the majority of concussions occur at the high school level (McClincy, Lovell, Pardini, Collins, & Spore, 2006), making it necessary to understand the effects of age on cognitive performance when conducting neuropsychological testing.

Normative data for ImPACT (version 2.0) shows that adolescents (ages 13-18) showed age effects for processing speed and reaction time.(Iverson, Lovell, & Collins, 2003a) This is based off a sample size of 424 students, however, no effect sizes were noted for these results. This same group of students was broken down by gender (341 males, 83 females) and the data was analyzed again for effects of age. Males (ages 13-18) displayed age effects on processing speed (d=0.58), reaction time (d=0.37), and impulse control (d=0.32) where performance increased with age. No such age effect was seen for the adolescent female population, possibly a result of the smaller population size. No effect sizes were reported for the adolescent female results. In the same study, using a sample of 507 university students, no differences were attributable to year. Ages of the university students and effect sizes were reported. No direct comparisons were conducted between adolescent and university students.

It is also important to determine the effects of age on cognitive performance as differences have been noted in acute neuropsychological recovery between high school and collegiate athletes; with high school athletes recovering at a slower rate than collegiate athletes following a concussion.(Field, Collins, Lovell, & Maroon, 2003; Lovell, Collins, Iverson, Johnston, & Bradley, 2004) Field et al. (Field, Collins, Lovell, & Maroon, 2003) examined the difference in recovery between high school and collegiate athletes using the HVLT for both age groups and the BMVT-R for only high school. Although a larger test battery was administered, the HVLT and BVMT-R were chosen based on the authors' previous experience with acute and demonstrable impairments of memory processes following concussion. Baseline measures were taken and one, three, five, and seven days following concussion. This study within age group matched controls to monitor recovery. No significant differences were seen between concussed collegiate athletes and their collegiate controls from three days to seven days postconcussion. However, concussed high school athletes showed significant differences all the way through the seventh day postconcussion.

One possible explanation for this delayed recovery are that more diffuse and prolonged cerebral edema occur in children relative to adults, however, the underlying mechanisms for are uncertain.(Bruce et al., 1981; Field, Collins, Lovell, & Maroon, 2003; Giza, Griesbach, & Hovda, 2005)

If returned to activity prematurely, this delayed recovery in high school athletes can place the still developing brain at an increased risk of both short-term and long-term complications.(Bruce et al., 1981; Snoek, Minderhoud, & Wilmink, 1984; Valovich McLeod, 2005) To track improvements it is important to use an age appropriate assessments such as neuropsychological testing.(Collins, Field et al., 2003; Field, Collins, Lovell, & Maroon, 2003; Lovell et al., 2003; Lovell, Collins, Iverson, Johnston, & Bradley, 2004; McCrea et al., 1998; Valovich McLeod, 2005)

Practice Effects. Repeated administrations of the same neuropsychological tests are now more common in neuropsychological evaluations.(Benedict & Zgaljardic, 1998) The influence of practice effects on these neuropsychological test scores must be carefully considered when retesting or administering serial neuropsychological testing of individuals. Performance on many neuropsychological tests may be improved by prior exposure to testing stimuli and procedures.(Collie, Maruff, Darby, & McStephen, 2003) Prior exposure to testing stimuli and procedures allows patients to develop better test taking strategies or possibly memorize the same information more than once.(Benedict & Zgaljardic, 1998) Because of these two reasons, memory tests seem to be at an increased risk of practice related measurement error. Further complicating practice effects of memory tests are the inclusion of a novel concept of procedure, visuospatial learning, and/or graphomotor responding.(Benedict & Zgaljardic, 1998) Improvement in test performance due to practice effects cause inflated neuropsychological test scores which can mimic neurocognitive recovery, and may lead to returning an athlete to competition prematurely.

Practice effects have been seen during serial neuropsychological testing with the improvement being most notable between the first and second administration of a cognitive test.(Benedict & Zgaljardic, 1998; Collie, Maruff, Darby, & McStephen, 2003) The use of alternate forms is one way clinicians and researchers have tried to minimize these practice effects. It has been shown that strong practice effects occur when using the same forms during serial neuropsychological testing and much smaller effects occur when using alternate forms.(Benedict & Zgaljardic, 1998; Schatz, Pardini, Lovell, Collins, & Podell, 2006) Because computerized neuropsychological testing draws from a seemingly infinite number of alternate forms, a decrease in practice effects during serial computerized testing should be expected. In fact, it has been shown during serial administration of ImPACT, that non-concussed high school athletes showed no significant practice effects on memory test performance.(Lovell et al., 2003; Schatz, Pardini, Lovell, Collins, & Podell, 2006) This claim is based on a study by Lovell et al. (Lovell et al., 2003) that found no increase in control group scores (N=24) for memory composite scores following four administrations of ImPACT (baseline, day 7, day 9, and day 11). Only the memory composite scores and postconcussion symptom totals were analyzed in this study which leaves several other outcome measures of ImPACT unexplored.

Neuropsychological Test Batteries

Currently, neuropsychological tests come in two varieties: paper-pencil and computerized. The reported advantages appear to favor computerized neuropsychological testing. Some of the advantages of computerized neuropsychological testing include infinite randomized forms, millisecond timing, control over presentation of test stimuli, standardized self administration, group testing, rapid testing, decreased setup, preparation and costs, internet based delivery, automated analysis, ease of data collection, centralized data storage, analysis, and reporting.(Grindel, Lovell, & Collins, 2001; McCrory, Makdissi, Davis, & Collie, 2005; Randolph, McCrea, & Barr, 2005; Schatz & Browndyke, 2002)

Standardized neuropsychological paper-pencil tests have undergone extensive validation studies and concurrent and clinical validity have been typically well established.(Randolph, McCrea, & Barr, 2005) Despite the seemingly endless list of advantages, it is important to note that computerized neuropsychological testing currently lacks validation for use in the follow up of sports-related concussion.(Makdissi et al., 2001)

Traditional Paper-Pencil Battery. Traditional paper-pencil neuropsychological tests have been thoroughly documented with respect to its reliability and concurrent and clinical validity (Maroon et al., 2000; Randolph, McCrea, & Barr, 2005), and several studies have employed paper-pencil neuropsychological tests to measure cognitive deficits and/or track improvements and recovery following concussion.(Collins et al., 1999; Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Guskiewicz, Ross, & Marshall, 2001; Lovell, Collins, Iverson, Johnston, & Bradley, 2004; Macciocchi, Barth, Littlefield, & Cantu, 2001; Matser, Kessels, Lezak, Jordan, & Troost, 1999; McCrea et al., 2005; McCrea et al., 2003)

Postconcussion Symptom Scale. The Postconcussion Symptom Scale (PCSS) was a paper version of ImPACT's PCSS and is a list of 22 symptoms which the participant is required to score their current symptoms based on a 6 point Likert scale. The scale ranges from zero to six; with a zero meaning the participant is not currently experiencing that symptom and a six meaning the symptom is being experienced at a severe level. A complete list of the symptoms found on the PCSS can be seen in Table 2.1.

Table 2.1. Symptoms on the Postconcussion Symptom Scale

Headache	Sleeping less than usual	Numbness or tingling
Nausea	Drowsiness	Feeling slowed down
Vomiting	Sensitivity to light	Feeling mentally foggy
Balance Problems	Sensitivity to noise	Difficulty concentrating
Dizziness	Irritability	Difficulty remembering
Fatigue	Sadness	Visual problems
Trouble falling asleep	Nervousness	
Sleeping more than usual	Feeling more emotional	

Hopkins Verbal Learning Test – Revised. The HVLT-R consists of a free recall and a recognition portion of the test. The free recall section consists of three trials. The subject is read a list of 12 words (four words from each of three different categories) and is instructed to repeat back as many words as they can, in any order. The next free recall trial begins once the subject has given all 12 words to the test administrator or once the subject states that they cannot recall any more words. After all three free recall trials are completed the recognition portion of the exam begins. A list of 24 words is read to the subject and after each word they are asked to identify whether that word is, or is not, part of the list they were just given.

This test is scored by counting the correct responses for each individual trial of the free recall, the number true positives recognized (words recognized that were part of the original list), the number of false positives errors made that were related (words recognized that were not part of the original list, but belonged to one of the categories of the original list), the number of false positives errors made that were unrelated (words recognized that were not part of the original list, and did not belong to one of the categories of the original list), and the discrimination index for words recognized (the number of true positives minus the total number of false positives).

A delayed version of this test can also be administered. For the free recall portion of the delayed trial the subject is not read the list of words. The subject is asked to list as many of the words from the list as they can, in any order. The delayed trial ends when the subject has given all 12 words or when the subject stats that they could not recall any more words. There is only one delayed free recall trial. For the delayed recognition portion, a list of 24 words is read to the subject and after each word they are asked to identify whether that word was, or was not, part of the list they were given earlier.

The delayed version of the test is scored by counting the correct responses for the delayed trial of the free recall, the number true positives recognized (words recognized that were part of the original list), the number of false positives errors made that were related (words recognized that were not part of the original list, but belonged to one of the categories of the original list), the number of false positives errors made that were unrelated (words recognized that were not part of the original list, and did not belong to one of the categories of the original list), and the discrimination index for words recognized (the number of true positives minus the total number of false positives).

Brief Visuospatial Memory Test – Revised. The BVMT-R consists of six figures arranged in two columns with three rows. The subject is instructed that they will be shown a sheet with 6 figures on it, which they will be given 10 seconds to study in order to remember as many of these figures as they can. They were also instructed that after the 10 seconds ends the sheet will be removed, and they will be given a blank sheet and asked to draw each figure exactly as it appeared and in its correct location on the page. Once the subject states that they were finished, the subject's sheet is removed and the next trial begins. Trials two and three are administered in the same way as trial one. A delayed trial is also administered. For the delayed trial the subject is not shown the sheet with the figures on it. They are provided a blank sheet and asked to draw as many of the figures from earlier as they can, exactly as they appeared and in their correct location on the page.

Two points are given for each figure; one for correct design and one for correct location. A design is scored correct as long as it generally matched the display without missing pieces or inversions. If a design is completely incorrect (i.e. does not resemble any figures on the display), then no location points are awarded either.

Outcome measures for this test are total recall (sum of the three trials), learning (the higher score of trials two and three minus trial one), delayed recall (raw score of the delayed trial), and percent retained [(delayed recall divided by the higher score of trials two and three) x 100].

Trail Making Test Form B. The TMT-B consists of 25 circles scattered about the page. Inside of each circle is either a number or a letter. The numbers range from 1-13 and the letters range from A to L. The subject is instructed to connect the circles in order, alternating between numbers and letters (1 to A, A to 2, 2 to B, etc). The subject is given a quick sample to ensure the directions are understood. The subject is also instructed to work as quickly as possible while trying not to make any mistakes, and trying not to lift the pencil from the paper. In the event a mistake is made, the subject is directed back to the last correct circle. Time is not stopped during a mistake. Time begins when the subject's pencil touches the paper at the first circle and time ends when their pencil hits the last circle. Time taken to complete the test and errors made are recorded. The total score is the time taken to complete the test.

Symbol Digit Modalities Test. The SDMT has a key at the top of the page consisting of a symbol matched with the numbers one through nine directly below it. The testing area has several rows, each row with 15 symbols and an empty box directly below each symbol. Athletes are instructed to fill the empty box with the number that matches the symbol using the key at the top of the page, and athletes are given a 10 symbol sample section at the beginning of the first row to ensure the directions are understood. Athletes are instructed to works as fast as possible while trying not to make any mistakes. All athletes are given 60 seconds to get as far as they can. The score for this test is the number of symbols and numbers correctly matched in the 60 second time period.

Stroop Test. The Stoop Test consists of a form with the words "RED," "BLUE," and "GREEN" arranged randomly in five columns of 20 for a total of 100 words. No word appears consecutively within a column. The words are printed in red, blue, and green ink, and color of the ink never matches the word that is written. The subject is instructed to name the color of the ink, ignoring the word that is spelled out. Athletes read down the columns starting with the column on the left. If the subject is able to complete all 100 words they are instructed to return top of the leftmost column and continue through the list again. Athletes are given 45 seconds to go through as many words as possible. The test administrator follows along using an answer key, and in the event a wrong answer is given the test administrator says, "No," and the subject attempts that word again. Time is not stopped in the event of a wrong answer. This test is scored by the number of words the subject was able to complete in the allotted time period.

A test battery similar to the one in Table 2.2 (with a substitution of the BVMT-R for the Controlled Oral Word Association Test) showed sensitivity measures two days post-concussion of 0.23.(McCrea et al., 2005) The sensitivity of this battery was similar to that of the Graded Symptom Checklist (0.27)(Lovell & Collins, 1998), the Balance Error Scoring

System (0.24)(Guskiewicz, Ross, & Marshall, 2001), and the Standard Assessment of Concussion (0.22)(McCrea et al., 1998).

Table 2.2. Paper-Pencil Neuropsychological Test Battery

Neuropsychological Test	Cognitive Process
HVLT-R	Verbal Learning Immediate Memory Delayed Memory
BVMT-R	Visual Memory
TMT-B	Visual Scanning Complex Attention Mental Flexibility Visual-Motor Speed
SDMT	Psychomotor Speed Visual Short-term Memory Attention Concentration
Stroop Test	Cognitive Flexibility Response Inhibition

Computerized Batteries. There are several computerized batteries now available. The Automated Neuropsychological Assessment Metrics (ANAM), CogSport, Concussion Resolution Index, and ImPACT are all currently available and have shown promise for concussion assessment.(Guskiewicz et al., 2004) Although there are choices, 75% of randomly surveyed certified athletic trainers that use computerized neuropsychological test batteries reported using ImPACT.(Notebaert & Guskiewicz, 2005)

ImPACT. ImPACT is a computerized neuropsychological test battery that is used to assess cognitive function in the areas of attention, verbal recognition, visual recognition, working memory, visual processing speed, visual learning, visual memory, reaction time, motor response speed, impulse control, and response inhibition. ImPACT is an automated program that guides the user through a series of neuropsychological tests. Before testing begins, the program prompts the user to input some demographical information and pertinent medical history. Next, the user is taken through a Postconcussion Symptom Scale (PCSS) and is instructed to score their symptoms based on how they feel at this moment. Upon completion of the PCSS, the user is prompted to begin the test battery. Instructions for each test module are displayed by the program prior to the start of each module. The user is prompted by the program between each subtest to ensure the user is prepared to begin the next test.

Table 2.3. ImPACT Test Modules

Test Module	**Cognitive Process**
Word Discrimination	Attention Verbal Recognition
Design Memory	Attentional Processes Visual Recognition Memory
X's & O's	Visual Working Memory Visual Processing
Symbol Matching	Visual Processing Speed Visual Learning Visual Memory
Color Match	Choice Reaction Time Impulse Control Response Inhibition
Three Letters	Working Memory Visual-Motor Response Speed

Word Memory. The user is shown a list of 12 words, one at a time, for a few seconds each. This list is then repeated in the same manner. After the user is taken through the list twice, they are prompted with a word and required to answer if the word shown was part of the original list by clicking "yes" or "no." Twenty-four words are shown in total, 12 words from the original list and 12 distractors.

A delayed trial for Word Memory is administered at the end of the test battery, but before the delayed trial for Design Memory. During the delayed trial, the user is prompted with a word and required to answer if the word shown was part of the original list by clicking "yes" or "no." Twenty-four words are shown in total, 12 words from the original list and 12 distractors.

Outcome measures for Word Memory include immediate hits (words correctly identified as being part of the original list of words), immediate correct distractors (words correctly identified as not being part of the original list of words), learning percent correct (total correct responses divided by 24 then multiplied by 100), delayed hits (words correctly identified as being part of the original list of words during the delayed trial), delayed correct distractors (words correctly identified as not being part of the original list of words during the delayed trial), delayed memory percent correct (total correct responses during the delayed trial divided by 24 then multiplied by 100), and total percent correct (total correct responses for both immediate and delayed trials divided by 48 then multiplied by 100).

Design Memory. The user is shown a series of 12 figures, one at a time, for a few seconds each. This group of figures is repeated in the same manner. After the user is taken through the figures twice, they are prompted with a figure and required to answer if the figure shown was part of the original group by clicking “yes” or “no.” Twenty-four figures are shown, 12 figures from the original list and 12 distractors.

A delayed trial for Design Memory is administered at the end of the test battery. During the delayed trial, the user is prompted with a figure and required to answer if the figure shown was part of the original group by clicking “yes” or “no.” Twenty-four figures are shown, 12 figures from the original list and 12 distractors.

Outcome measures for Design Memory include immediate hits (figures correctly identified as being part of the original group of figures), immediate correct distractors (figures correctly identified as not being part of the original group of figures), learning percent correct (total correct responses divided by 24 then multiplied by 100), delayed hits (figures correctly identified as being part of the original group of figures during the delayed trial), delayed correct distractors (figures correctly identified as not being part of the original group of figures during the delayed trial), delayed memory percent correct (total correct responses during the delayed trial divided by 24 then multiplied by 100), and total percent correct (total correct responses for both immediate and delayed trials divided by 48 then multiplied by 100).

X’s and O’s. The user is shown a diagram consisting of multiple X’s and O’s scattered and randomly arranged. Three of the X’s and/or O’s are highlighted in yellow and the user is instructed to try to remember their location. Then, a distractor task involving reaction time begins. The program flashes either a red circle or a blue square. The user is instructed to left click on the mouse for a red circle and right click on the mouse for a blue square as quickly as possible. Following the distractor task, the diagram with X’s and O’s is shown again (without the highlighted letters) and the user is instructed to click on the X's and/or O's that were originally highlighted. This cycle completes one trial and the user is taken through a total of 4 trials.

Outcome measures for X's and O's include total correct (X and O locations correctly identified), total correct (number of mouse clicks correctly corresponding to red circle or blue square), average correct reaction time (time elapsed between presentation of red circle or blue square and a correctly corresponding mouse click), total incorrect (number of mouse clicks incorrectly corresponding to red circle or blue square), and average incorrect reaction time (time elapsed between presentation of red circle or blue square and an incorrectly corresponding mouse click).

Symbol Match. The user is given an answer key consisting of nine symbols corresponding to numbers 1-9. The program presents a symbol as the user inputs the matching number. During the test, the symbols in the key disappear and the user is required to work from memory as the program continues to present symbols.

Outcome measures for Symbol Match include total correct - visible (numbers correctly entered according to the symbol shown while the whole answer key was visible), average correct reaction time - visible (time elapsed between presentation of a symbol and a correctly entered number), total correct - hidden (numbers correctly entered according to the symbol shown while symbols in the answer key were hidden), average correct reaction time - hidden (time elapsed between presentation of a symbol and an incorrectly entered number).

Color Match. The user is shown the words "RED," "GREEN," and "BLUE" in alternating colors of red, green, and blue. The user is instructed to click as quickly as possible when the word and color match.

Outcome measures for Color Match include total correct (mouse clicks recorded while color and word matched), average correct reaction time (time elapsed between presentation of a word in the same color and a mouse click), total commissions (mouse clicks recorded while color and word did not match), and average commissions (reaction time time elapsed between presentation of a word in a different color and a mouse click).

Three Letters. The user is shown three letters of the alphabet and instructed to remember them. Then, a distractor task begins. The numbers one to 25 appear on individual squares randomly arranged in a five-by-five block. During the distractor task, the user is required to click on the squares counting backwards from 25 to one. The user eliminates as many squares as possible in the time allotted and then the program prompts for the three letters. The user inputs the three letters they were shown and this completes the trial. The user is taken through a total of five trials.

Outcome measures for Three Letters include total sequence correct (three letter sequences correctly entered), total letters correct (individual letters correctly entered), percentage of total letters correct (total letters correct divided by 15 and then multiplied by 100), average time to first click (average time elapsed across trials between presentation of five-by-five number grid and first number clicked), average counted (average numbers clicked across trials), and average counted correctly (average numbers clicked across trials clicked in correct order).

Composite Scores. Outcome measures that result from the six subtests are used to determine the five composite scores of ImPACT. These composite scores are verbal memory, visual memory, processing speed, impulse control, and reaction time. These composite scores offer a clinician a quick overview of the cognitive status of an individual being tested. A listing of the composite scores and their contributing outcome measures are shown in Table 2.4.

Table 2.4. ImPACT Composite Scores and Contributing Outcome Measures

Verbal Memory is an average of the following: *Word Memory Total Percent Correct* *Symbol Match Total Correct (hidden)* *Three Letters Percent of Total Letters Correct*
Visual Memory is an average of the following: *Design Memory Total Percent Correct* *X's and O's Total Correct (memory)*
Processing Speed is an average of the following: *X's and O's Total Correct (interference)/4* *Three Letters Average Numbers Correctly Counted*3*
Reaction Time is an average of the following: *X's and O's Average Correct RT* *Symbol Match Average Correct RT/3* *Color Match Average Correct RT*
Impulse Control is an average of the following: *X's and O's Total Incorrect (interference)* *Color Match Total Commissions*

ImPACT has been found as a useful tool in detecting subtle changes in neuropsychological performance of individuals following a concussion.(Collins et al., 1999; Collins, Iverson et al., 2003; Lovell, Collins, Iverson, Johnston, & Bradley, 2004) In addition, some research suggests that ImPACT is a sensitive and specific tool in the detection of concussions in athletes (Collins, Iverson et al., 2003; Iverson, Lovell, & Collins, 2005; Lovell et al., 2003; Lovell, Collins, Iverson, Johnston, & Bradley, 2004; Schatz, Pardini, Lovell, Collins, & Podell, 2006)

Previous studies supporting the validity of ImPACT have only utilized a small number of paper-pencil tests. One study found ImPACT to be a valid measure of processing speed and reaction time as compared to the SDMT with Pearson correlations of 0.70 and -0.60 respectively.(Iverson, Lovell, & Collins, 2005) This study used 72 athletes within 21 days of receiving a sports-related concussion and compared all the composite scores from ImPACT (version 2) with the exception of the impulse control composite score to the 90 second score of the SDMT. The exact testing protocol was not identified; therefore, many details of the procedure such as randomizing or counterbalancing testing order were not addressed.

Another study testing validity of ImPACT was done using the Trail Making Test Form A (TMT-A), TMT-B, SDMT, and Brief Visuospatial Memory Test (BVMT). This study found significant correlations between the BVMT (total recall) and the two ImPACT memory scores (r=0.50 for both), the BVMT (delayed recall) and the two ImPACT memory scores (r=0.85 for both), and also between processing speed and the SDMT (r=0.68) and TMT-B (r=-0.60).(Iverson, Franzen, Lovell, & Collins, 2004) This study used 25 athletes within 20 days of receiving a sports-related concussion. As only the abstract of this study was found, the specific methods were not available. What is known is that the athletes completed ImPACT (version 2) and the aforementioned traditional neuropsychological tests.

Rationale for the Study

Computerized neuropsychological testing is currently taking place despite a lack of proven or demonstrated validation of this tool. Decisions about treatment, rehabilitation and even return to play are being made based on the information from these computerized neuropsychological tests. In addition, neuropsychological testing is taking place in both high school and collegiate settings with little understanding of possible differences in test scores across age groups. If neuropsychological test scores do vary based on age, what effect will that have on treatment, rehabilitation, or return to play decisions? Furthermore, athletes suffering a concussion are often subject to repeated neuropsychological testing in order to track improvement in cognitive function. This serial testing can lead to practice effects and inflated test scores, which may be mistaken for cognitive recovery. Without proper validation and understanding of age effects and/or practice effects, incorrect decisions could be made, and athletes could be at an increase risk of further injury.

Future research, validation, and the development of computerized software in these areas will likely increase the availability of these assessment tools and give more support to the global application of neuropsychological testing in contact and collision sport.(Collins, Iverson et al., 2003; Grindel, Lovell, & Collins, 2001)

CHAPTER 3

METHODS

Power Analysis

Based on data from previous neuropsychological testing of concussed and non-concussed individuals (Benedict & Zgaljardic, 1998; Schatz, Pardini, Lovell, Collins, & Podell, 2006) and serial neuropsychological testing of only non-concussed individuals (Benedict & Zgaljardic, 1998), effect sizes were found to be equal to or greater than 1.0. Using an effect size of 1.0, sample sizes of only 13 participants per group were required to attain a power (1-β) of 0.80. In order to attain a power of 0.80 and to offset a potentially more conservative effect size in our proposed study, we recruited 20 participants in each group.

Subjects

Forty healthy, active, volunteer athletes participated in this study; 20 from the University of North Carolina (UNC) and a total of 20 from two high schools located in central North Carolina. Ages ranged from 15 to 17 years of age (mean=16.00 ± 0.86 years) for high school athletes and from 19 to 21 years of age (mean=20 ± 0.79 years) for college athletes. Height ranged from 154.94cm to 187.96cm (mean=171.77 ± 9.54cm) for high school athletes and from 151.48cm to 185.42cm (mean=173.31 ± 9.78cm) for college athletes. Mass ranged from 45.00kg to 85.50kg (mean=66.16 ± 11.83kg) for high school athletes and from 50.80kg to 97.52kg (mean=75.80 ± 12.16kg) for college athletes. An equal number of males and females were recruited into each age group. Participants from the following sports were recruited: men's soccer (N=7), women's soccer (N=5), softball (N=6), wrestling (N=5), men's lacrosse (N=5), track and field (N=3), gymnastics (N=2), cross country (N=2), dance (N=2), women's basketball (N=1), men's tennis (N=1), and volleyball (N=1).

Participants were neither included nor excluded from this study on the basis of ethnicity or race. Individuals that were excluded from this study include those with history of concussion in the last 5 years, known neurocognitive deficits or disorders, known psychological conditions or disorders, color blindness, individuals that were 18 years of age, and individuals that participated in athletics less than 3 days per week.

Procedures

Prior to participation, all participants were required to sign the appropriate IRB approved consent forms. High school participants were required to complete an IRB approved assent form and their legal guardian was required to complete an IRB approved consent form. College participants were required to complete an IRB approved consent form.

High school participants reported to a classroom at their high school and college participants reported to the UNC Sports Medicine Research Laboratory (SMRL). All participants reported to their respective testing site for a total of three visits with at least 24 hours, but no more than 72 hours, between each visit. Each testing session lasted for approximately one hour. All participants completed both ImPACT and paper-pencil tests batteries. The order in which the test batteries were administered was determined by the first participant in a random selection (i.e. coin flip). All following participants began with the test battery that counterbalanced the previous participant and used the same test battery order for all three test sessions.

For all participants, speed of testing was determined by the participant for both ImPACT and paper-pencil test batteries. Upon completion of one test module the participant gave confirmation that they are ready to proceed to the next test module and continued until all tests for that battery were completed. Upon completion of one test battery, the participant began the remaining test battery following a five minute rest period. The test session was concluded after the subject completed the second test battery.

Instrumentation

Participants were tested on both a computer-based test battery and a traditional paper-pencil based test battery to assess neuropsychological performance during three separate test sessions. The computer-based test battery used was the Immediate Postconcussion Assessment and Cognitive Test (ImPACT) Version 3 (ImPACT Applications, Inc., Pittsburgh, PA). The ImPACT was administered on a laptop computer with an optical mouse. The paper-pencil test battery consisted of a Postconcussion Symptom Scale (PCSS; ImPACT Applications, Inc., Pittsburgh, PA), Hopkins Verbal Learning Test-Revised (Johns Hopkins University, Baltimore, MD), Brief Visuospatial Memory Test-Revised (Psychological Assessment Resources, Inc., Lutz, FL), Trail Making Test Form B (Reitan Neuropsychological Laboratory, Tucson, AZ), Symbol Digit Modalities Test (Western Psychological Services, Los Angeles, CA), and the Stroop Test (Stoelting Company, Wood Dale, IL).

ImPACT. ImPACT is an automated program that guides the user through a series of neuropsychological tests. Before testing began, the program prompted the user to input some demographical information and pertinent medical history. Next, the user was taken through a Postconcussion Symptom Scale (PCSS) and was instructed to score their symptoms based on how they felt at that moment. Upon completion of the PCSS, the user was prompted to begin the test battery. Instructions for each test module were displayed by the program prior to the start of each module. The user was prompted by the program between each subtest to ensure the user was prepared to begin the next test.

Three test banks (1, 2, and 3) containing three different word and design groups were used to reduce learning effects across testing sessions. Athletes were instructed to pay close attention to and follow the instructions as they were given by the computer, to answer as quickly as they could, to answer as accurately as they could, and to give their best effort.

Postconcussion Symptom Scale. A paper version of ImPACT's PCSS was administered prior to the paper-pencil test battery to monitor for symptom changes in athletes from one test battery to the next. Athletes were instructed to complete the PCSS based on how they felt at that moment.

Hopkins Verbal Learning Test – Revised. Three alternate forms were used (A, B, and C) to reduce learning effects across testing sessions. Each form consisted of a free recall and a recognition portion of the test. The free recall section was administered first and consisted of three trials. The subject was read a list of 12 words (four words from each of three different categories) and instructed to repeat back as many words as they could and in any order. The next free recall trial was begun once the subject had given all 12 words to the test administrator or once the subject stated that they could not recall any more words. After all three free recall trials were completed the recognition portion of the exam began. A list of 24 words was read to the subject and after each word they are asked to identify whether that word was, or was not, part of the list they were just given.

A delayed version of this test was administered at the end of the test battery but before the BVMT-R delayed trial. For the free recall portion of the delayed trial the subject was not read the list of words. The subject was asked to list as many of the words from the list as they could, in any order. The delayed trial ended when the subject had given all 12 words or when the subject stated that they could not recall any more words. There was only one delayed free recall trial. For the delayed recognition portion, a list of 24 words was read to the subject and after each word they are asked to identify whether that word was, or was not, part of the list they were given earlier.

Brief Visuospatial Memory Test – Revised. Three alternate forms were used (1, 2, and 3) to reduce learning effects across testing sessions. Each form consisted of six figures arranged in two columns with three rows. The subject was instructed that they would be shown a sheet with 6 figures on it, which they will be given 10 seconds to study in order to remember as many of these figures as they can. They were also instructed that after the 10 seconds ends the sheet will be removed, and they would be given a blank sheet and asked to draw each figure exactly as it appeared and in its correct location on the page. Once the subject stated that they were finished, the subject's sheet was removed and the next trial was begun. Trials two and three were administered in the same way as trial one. A delayed trial was administered at the end of the test battery. For the delayed trial the subject was not shown the sheet with the figures on it. They were provided a blank sheet and asked to draw as many of the figures from earlier as they could, exactly as they appeared and in their correct location on the page.

Trail Making Test Form B. Only one form was used for this test. The subject was instructed to connect the circles in order, alternating between numbers and letters (1 to A, A to 2, 2 to B, etc). The subject was given a quick sample to ensure the directions were understood. The subject was also instructed to work as quickly as possible while trying not to make any mistakes, and trying not to lift the pencil from the paper. In the event a mistake was made, the subject was directed back to the last correct circle. Time was not stopped in the event of a mistake. Time began when the subject's pencil touched the paper at the first circle and time ended when their pencil hit the last circle. Time taken to complete the test and errors made were recorded.

Symbol Digit Modalities Test. Three alternate forms were used (A, B, and C) to reduce learning effects across test sessions. Athletes were instructed to fill the empty box with the number that matches the symbol using the key at the top of the page, and athletes were given a 10 symbol sample section to ensure the directions were understood. Athletes were instructed to works as fast as possible while trying not to make any mistakes. All athletes were given 60 seconds to get as far as they could.

Stroop Test. Only one form was used for this test. The subject was instructed name the color of the ink, ignoring the word that was spelled out. Athletes read down the columns starting with the column on the left. If the subject was able to complete all 100 words they were instructed to return top of the leftmost column and continue through the list again. Athletes were given 45 seconds to go through as many words as possible. The test administrator followed along using an answer key, and in the event a wrong answer was given the test administrator would say, "No," and the subject would try that word again. Time was not stopped in the event of a wrong answer.

Data Analysis

SPSS Version 13.0 (SPSS Inc., Chicago, IL) was used to analyze the data. Mean scores and standard deviations were calculated for each outcome measure. Level of significance was set a priori at 0.05 for all analyses.

In order to address the first research question, one 2x3 mixed model ANOVA (age x session) was calculated for each clinically relevant outcome measure outlined in Table 3.1. These ANOVAs were then analyzed for the main effects between groups (age) to determine differences between high school and college age athletes for ImPACT and paper-pencil neuropsychological test scores.

The second research question was addressed using two statistics. First, an intraclass correlation coefficient ($ICC_{2,1}$) with standard error of measurement (SEM) was calculated to determine the consistency of athletes' performance across serial neuropsychological tests for each of the clinically relevant outcome measures outlined in Table 3.1. Second, a 2x3 mixed model ANOVA (age x session) was calculated for each clinically relevant outcome measure outlined in Table 3.1. These ANOVAs were then analyzed for the main effects within groups (session) to determine the presence of practice effects resulting from serial neuropsychological testing using both ImPACT and paper-pencil neuropsychological test batteries. Interaction effects from these ANOVAs were also analyzed in order to examine the influence of age on practice effects for both ImPACT and paper-pencil neuropsychological tests.

Linear regressions were used in order to address the third research question. Linear regression models were created using the Enter method and all non significant predictor variables were removed. This process was continued until all predictor variables in the regression model were statistically significant, or the entire model was found statistically non significant. The final regression models (Table 3.2) were analyzed to determine the level of shared variance between ImPACT scores and paper-pencil neuropsychological test scores of similar cognitive domains.

Table 3.1. Clinically Relevant Outcome Measures

Paper-Pencil	ImPACT
HVLT-R	Composite Scores
Total recalled (immediate)	Verbal memory
Discrimination index (immediate)	Visual memory
Total recalled (delayed)	Processing speed
Discrimination index (delayed)	Reaction Time
BVMT-R	Impulse control
Total recalled (immediate)	
Total recalled (delayed)	
TMT-B	
Total time	
SDMT	
Total score	
Stroop Test	
Total score	

Table 3.2. Linear Regression Variables

Paper-Pencil (Dependent Variable)	ImPACT (Predictor Variable)
HVLT-R	Word Memory
Percent Correct (immediate)	*Learning Percent Correct (immediate)*
Percent Correct (delayed)	*Memory Percent Correct (delayed)*
BVMT-R	Design Memory
Percent Correct (immediate)	*Learning Percent Correct (immediate)*
Percent Correct (delayed)	*Memory Percent Correct (delayed)*
SDMT	Symbol Matching
Total Score	*Average Correct Reaction Time (visible)*
Stroop Test	Color Match
Total Score	*Average Correct Reaction Time*
TMT-B	Three Letters
Total Time	*Average Counted Correctly*

Table 3.3. Analysis Plan Research Question 1

RQ	Description	Data Source	Comparison	Method
1	Is athletes' neuropsychological test performance significantly different between age groups during neuropsychological testing?	DV: Paper-pencil scores, ImPACT scores IV: Age	Paper-pencil scores for high school vs. college & ImPACT scores for high school vs. college	2x3 mixed model ANOVA (age x test session)
a	Are paper-pencil neuropsychological test scores for high school age athletes significantly different between paper-pencil neuropsychological test scores for college age athletes?	DV: Paper-pencil scores IV: Age	Paper-pencil scores for high school vs. college	Main effect between age groups
b	Are ImPACT test scores for high school age athletes significantly different between ImPACT test scores for college age athletes?	DV: ImPACT scores IV: Age	ImPACT scores for high school vs. college	Main effect between age groups

Table 3.4. Analysis Plan Research Question 2

RQ	Description	Data Source	Comparison	Method
2	Are athletes' test neuropsychological test performances consistent across serial neuropsychological tests?	DV: Paper-pencil scores, ImPACT scores IV: Test session	Paper-pencil scores for trial 1 vs. 2 vs. 3 & ImPACT scores for trial 1 vs. 2 vs. 3	2x3 mixed model ANOVA (age x test session) & $ICC_{2,1}$
a	Are athletes' paper-pencil neuropsychological test performances consistent across serial neuropsychological tests?	DV: Paper-pencil scores IV: Test session	Paper-pencil scores for trial 1 vs. 2 vs. 3	$ICC_{2,1}$
	Do practice effects exist for paper-pencil neuropsychological test scores when conducting serial neuropsychological testing?	DV: Paper-pencil scores IV: Test session, Age	Paper-pencil scores for trial 1 vs. 2 vs. 3	Main effect of test session
	Are practice effects for paper-pencil neuropsychological test scores influenced by age?	DV: ImPACT scores IV: Test session	Paper-pencil scores for trial 1 vs. 2 vs. 3	Interaction effects
b	Are athletes' ImPACT test performances consistent across serial neuropsychological tests?	DV: ImPACT scores IV: Test session	ImPACT scores for trial 1 vs. 2 vs. 3	$ICC_{2,1}$
	Do practice effects exist for ImPACT test scores when conducting serial neuropsychological testing?	DV: ImPACT scores IV: Test session	ImPACT scores for trial 1 vs. 2 vs. 3	Main effect of test session
	Are practice effects for ImPACT test scores influenced by age?	DV: ImPACT scores IV: Test session, Age	ImPACT scores for trial 1 vs. 2 vs. 3	Interaction effects

Table 3.5. Analysis Plan Research Question 3

3	Are ImPACT test scores valid measures of neuropsychological test performance based on shared variance with paper-pencil neuropsychological test scores of similar cognitive domains?	DV: Paper-pencil scores, ImPACT scores IV: Age	Paper-pencil scores vs. ImPACT scores matched by cognitive domain for all ages	Linear regression

CHAPTER 4

RESULTS

This study involved data collection from 40 healthy, active, volunteer athletes. Subjects included 20 high school aged athletes and 20 college aged athletes. Both genders were equally represented in each of the two age groups. Descriptive statistics are presented in Table 4.1 and Table 4.2. All athletes were assessed according to the protocol specified in Chapter 3.

We observed main effects for age on the TMT-B total time ($F_{1,38}$=6.161, p=0.018) and ImPACT processing speed composite score ($F_{1,38}$=5.029, p=0.031). Statistics for these analyses are presented in Table 4.3 and Table 4.4.

The reliability ($ICC_{2,1}$) and precision (SEM) values for the clinically relevant outcome measures on both paper-pencil and ImPACT neuropsychological test batteries are presented in Table 4.5 and Table 4.6. We observed main effects for session on the BVMT-R total recalled (immediate) ($F_{2,76}$=3.199, p=0.046), the BVMT-R total recalled (delayed) ($F_{2,64}$=3.356, p=0.049), the TMT-B total time ($F_{2,66}$=73.432, p<0.0005), the Stroop Test total score ($F_{2,76}$=96.851, p<0.0005), and ImPACT processing speed composite score ($F_{2,76}$=5.806, p=0.005). No significant interaction effects were observed for the influence of age on practice effects. Statistics for these analyses are presented in Table 4.3 and Table 4.4.

Linear regression modeling revealed that ImPACT Word Memory learning percent correct was the best predictor of the HVLT-R percent recognized (immediate) on the third session only (p=0.008, R^2=0.171), ImPACT Design Memory learning percent correct as the best predictor of the BVMT-R percent recalled (immediate) for all three sessions (p=0.001, R^2=0.248; p=0.028, R^2=0.121; p=0.024, R^2=0.127), ImPACT Design Memory delayed memory percent correct as the best predictor for the BVMT-R percent recalled (delayed) on the first session only (p=0.025, R^2=0.125), ImPACT Three Letters average counted correctly as the best predictor of the TMT-B total time on all three sessions (p<0.0005, R^2=0.481; p=0.008, R^2=.0172; p=0.009, R^2=0.168), ImPACT Symbol Match average correct reaction time (visible) as the best predictor of the SDMT total score on all three sessions (p=0.002, R^2=0.229; p<0.0005, R^2=0.345; p=0.006, R^2=0.182), and ImPACT Color Match average correct reaction time as the best predictor for the Stroop Test total score on the first and second sessions (p=0.001, R^2=0.256; p=0.021, R^2=0.132). Statistics for these analyses are presented in Table 4.7.

Table 4.1. Subject Descriptive Statistics (means ± SD)

	N	Age (yrs)	Height (cm)	Weight (kg)
High School	20	16.00 ± 0.86	171.77 ± 9.55	66.16 ± 11.83
College	20	20.00 ± 0.79	173.31 ± 9.78	75.80 ± 12.16
All Athletes	40	18.00 ± 2.18	172.54 ± 9.57	70.98 ± 12.80

Table 4.2. Primary Sports of All Athletes (N=40)

Sport	N
Men’s Soccer	7
Softball	6
Women’s Soccer	5
Wrestling	5
Men’s Lacrosse	5
Track and Field	3
Gymnastics	2
Cross Country	2
Dance	2
Women’s Basketball	1
Men’s Tennis	1
Volleyball	1

Table 4.3. Main Effects and Interaction Effects for Paper-Pencil Neuropsychological Test Scores (N=40)

	High School Mean (SD)	College Mean (SD)	Session Average Mean (SD)	Main Effect of Time	Main Effect of Age	Interaction Effect
HVLT-R (immediate)						
Total Recalled						
Session 1	26.30 (3.80)	27.20 (3.49)	26.75 (3.63)	$F_{2,76}$=2.676	$F_{1,38}$=0.039	$F_{2,76}$=1.812
Session 2	28.20 (3.25)	27.60 (2.78)	27.90 (3.00)	p=0.075	p=0.844	p=0.170
Session 3	27.75 (3.51)	26.90 (3.71)	27.33 (3.59)			
Group Average	27.42 (3.56)	27.23 (3.31)				
Discrimination Index						
Session 1	11.75 (0.44)	11.50 (0.76)	11.63 (0.63)	$F_{2,76}$=0.633	$F_{1,38}$=2.002	$F_{2,76}$=0.341
Session 2	11.80 (0.41)	11.65 (0.59)	11.73 (0.51)	p=0.534	p=0.165	p=0.712
Session 3	11.85 (0.37)	11.55 (0.94)	11.70 (0.72)			
Group Average	11.80 (0.40)	11.57 (0.77)				
HVLT-R (delayed)						
Total Recalled						
Session 1	9.80 (1.85)	10.40 (2.14)	10.10 (2.00)	$F_{2,76}$=0.031	$F_{1,38}$=0.726	$F_{2,76}$=0.139
Session 2	9.85 (2.11)	10.40 (1.73)	10.13 (1.92)	p=0.969	p=0.400	p=0.871
Session 3	9.90 (2.61)	10.20 (2.12)	10.05 (2.35)			
Group Average	9.85 (2.18)	10.33 (1.97)				
Discrimination Index						
Session 1	11.60 (0.60)	11.30 (1.30)	11.45 (1.01)	$F_{2,65}$=1.369	$F_{1,38}$=0.223	$F_{2,65}$=0.605
Session 2	11.15 (1.04)	11.25 (1.29)	11.20 (1.16)	p=0.260	p=0.640	p=0.525
Session 3	11.55 (0.60)	11.40 (1.10)	11.48 (0.88)			
Group Average	11.43 (0.79)	11.32 (1.21)				

*P-value significant at the 0.05 level

Table 4.3 (cont.). Main Effects and Interaction Effects for Paper-Pencil Neuropsychological Test Scores (N=40)

	High School Mean (SD)	College Mean (SD)	Session Average Mean (SD)	Main Effect of Time	Main Effect of Age	Interaction Effect
BVMT-R (immediate)						
Total Recalled						
Session 1	32.75 (2.79)	32.25 (3.99)	32.50 (3.40)	$F_{2,76}=3.199$	$F_{1,38}=0.351$	$F_{2,76}=0.298$
Session 2	33.45 (1.47)	33.35 (2.78)	33.40 (2.19)	p=0.046*	p=0.557	p=0.743
Session 3	32.65 (2.30)	31.80 (4.47)	32.23 (3.53)			
Group Average	32.95 (2.24)	32.47 (3.80)				
BVMT-R (delayed)						
Total Recalled						
Session 1	11.85 (0.49)	11.75 (0.79)	11.80 (0.65)	$F_{2,64}=3.356$	$F_{1,38}=0.708$	$F_{2,64}=0.169$
Session 2	11.90 (0.31)	11.85 (0.37)	11.88 (0.33)	p=0.049*	p=0.405	p=0.807
Session 3	11.65 (0.75)	11.45 (0.94)	11.55 (0.85)			
Group Average	11.80 (0.55)	11.68 (0.75)				
TMT-B						
Total Time						
Session 1	61.43 (13.79)	50.04 (14.53)	55.73 (15.12)	$F_{2,66}=73.432$	$F_{1,38}=6.161$	$F_{2,66}=1.562$
Session 2	47.36 (9.49)	40.61 (12.13)	43.98 (11.28)	p<0.0005*	p=0.018*	p=0.216
Session 3	40.20 (11.28)	33.74 (9.22)	36.97 (10.68)			
Group Average	49.66 (14.50)	41.46 (13.71)				

*P-value significant at the 0.05 level

Table 4.3 (cont.). Main Effects and Interaction Effects for Paper-Pencil Neuropsychological Test Scores (N=40)

	High School Mean (SD)	College Mean (SD)	Session Average Mean (SD)	Main Effect of Time	Main Effect of Age	Interaction Effect
SDMT						
Total Score						
Session 1	41.00 (5.85)	42.60 (6.55)	41.80 (6.18)	$F_{2,76}=0.909$	$F_{1,38}=0.549$	$F_{2,76}=0.236$
Session 2	40.45 (6.25)	42.15 (7.69)	41.30 (6.97)	$p=0.407$	$p=0.463$	$p=0.790$
Session 3	41.95 (5.94)	42.70 (5.89)	42.33 (5.85)			
Group Average	41.13 (5.95)	42.48 (6.64)				
Stroop Test						
Total Score						
Session 1	52.95 (10.86)	52.90 (7.90)	52.93 (9.37)	$F_{2,76}=96.851$	$F_{1,38}=0.033$	$F_{2,76}=0.306$
Session 2	59.95 (11.28)	61.20 (10.50)	60.58 (10.77)	$p<0.0005$*	$p=0.857$	$p=0.737$
Session 3	63.95 (12.23)	64.55 (11.82)	64.25 (11.87)			
Group Average	58.95 (12.17)	59.55 (11.18)				

*P-value significant at the 0.05 level

Table 4.4. Main Effects and Interaction Effects for ImPACT Composite Scores (N=40)

	High School Mean	(SD)	College Mean	(SD)	Session Average Mean	(SD)	Main Effect of Time	Main Effect of Age	Interaction Effect
Verbal Memory									
Session 1	89.20	(7.73)	90.05	(6.48)	89.63	(7.05)	$F_{2,76}=0.373$	$F_{1,38}=0.331$	$F_{2,76}=1.278$
Session 2	86.65	(8.44)	90.30	(7.35)	88.48	(8.03)	$p=0.690$	$p=0.569$	$p=0.284$
Session 3	89.10	(7.67)	87.85	(10.79)	88.48	(9.26)			
Group Average	(88.32)	7.91	89.40	(8.34)					
Visual Memory									
Session 1	78.40	(9.34)	79.50	(10.45)	78.95	(11.20)	$F_{2,76}=1.629$	$F_{1,38}=0.795$	$F_{2,76}=0.188$
Session 2	79.95	(10.45)	82.95	(9.73)	81.45	(10.08)	$p=0.203$	$p=0.378$	$p=0.829$
Session 3	80.30	(7.46)	83.00	(9.67)	81.65	(8.63)			
Group Average	79.55	(9.05)	81.82	(10.86)					
Processing Speed									
Session 1	39.43	(7.88)	45.81	(6.03)	42.62	(7.64)	$F_{2,76}=5.806$	$F_{1,38}=5.029$	$F_{2,76}=2.233$
Session 2	43.03	(7.36)	46.86	(7.09)	44.95	(7.39)	$p=0.005$*	$p=0.031$*	$p=0.114$
Session 3	43.58	(6.45)	46.65	(6.55)	45.11	(6.60)			
Group Average	42.01	(7.34)	46.44	(6.48)					

*P-value significant at the 0.05 level

Table 4.4 (cont.). Main Effects and Interaction Effects for ImPACT Composite Scores (N=40)

	High School Mean	(SD)	College Mean	(SD)	Session Average Mean	(SD)	Main Effect of Time	Main Effect of Age	Interaction Effect
Reaction Time									
Session 1	0.55	(0.06)	0.52	(0.06)	0.53	(0.06)	$F_{2,76}$=2.012	$F_{1,38}$=1.206	$F_{2,76}$=0.118
Session 2	0.52	(0.06)	0.51	(0.08)	0.52	(0.07)	p=0.141	p=0.279	p=0.889
Session 3	0.53	(0.08)	0.51	(0.07)	0.52	(0.08)			
Group Average	0.53	(0.07)	0.51	(0.07)					
Impulse Control									
Session 1	9.20	(5.40)	6.20	(4.31)	7.70	(5.05)	$F_{2,76}$=0.039	$F_{1,38}$=2.531	$F_{2,76}$=0.390
Session 2	8.85	(7.51)	6.65	(4.13)	7.75	(6.09)	p=0.961	p=0.120	p=0.678
Session 3	8.75	(4.51)	7.05	(5.29)	7.90	(4.92)			
Group Average	8.93	(5.84)	6.63	(4.54)					

*P-value significant at the 0.05 level

Table 4.5. Reliability ($ICC_{2,1}$) and Precision (SEM) of Paper-Pencil Neuropsychological Test Scores (N=40)

Paper-Pencil	$ICC_{2,1}$	SEM
HVLT-R (immediate)		
Total recalled	0.56	2.412
Discrimination index	0.57	0.471
HVLT-R (delayed)		
Total recalled	0.59	1.498
Discrimination index	0.30	0.970
BVMT-R (immediate)		
Total recalled	0.50	2.485
BVMT-R (delayed)		
Total recalled	0.12	0.799
TMT-B		
Total time	0.39	11.800
SDMT		
Total score	0.72	3.691
Stroop		
Total score	0.69	6.659

Table 4.6. Reliability ($ICC_{2,1}$) and Precision (SEM) of ImPACT Composite Scores (N=40)

ImPACT	$ICC_{2,1}$	SEM
Composite Scores		
Verbal Memory	0.29	7.809
Visual Memory	0.45	8.270
Processing Speed	0.71	4.094
Reaction Time	0.60	0.051
Impulse Control	0.63	3.699

Table 4.7. Linear Regression Models (N=40)

Model	Dependent Variable	Predictor Variable	Session	Significance	Beta	Intercept	R^2
1	HVLT-R (immediate) Percent Recognized	ImPACT Word Memory Learning percent correct	1	$F_{1,38}$=1.199 p=0.280	0.140	84.708	0.031
			2	$F_{1,38}$=0.013 p=0.909	-0.006	99.431	0.000
			3	$F_{1,38}$=7.816 p=0.008*	0.185	81.317	0.171
2	HVLT-R (delayed) Percent Recognized	ImPACT Word Memory Memory percent correct	1	$F_{1,38}$=0.944 p=0.337	0.110	87.587	0.024
			2	$F_{1,38}$=2.381 p=0.131	0.101	88.095	0.059
			3	$F_{1,38}$=0.411 p=0.525	-0.030	100.390	0.011

Model 1: HVLT-R percent recognized (immediate) = ImPACT Word Memory learning percent correct(β) + Intercept
Model 2: HVLT-R percent recognized (delayed) = ImPACT Word Memory delayed memory percent correct(β) + Intercept
*P-value significant at the 0.05 level

Table 4.7 (cont.). Linear Regression Models (N=40)

Model	Dependent Variable	Predictor Variable	Session	Significance	Beta	Intercept	R^2
3	BVMT-R (immediate) Percent recalled	ImPACT Design Memory Learning percent correct	1	$F_{1,38}$=12.525 p=0.001*	0.486	49.322	0.248
			2	$F_{1,38}$=5.226 p=0.028*	0.234	72.818	0.121
			3	$F_{1,38}$=5.523 p=0.024*	0.393	54.415	0.127
4	BVMT-R (delayed) Percent recalled	ImPACT Design Memory Memory percent correct	1	$F_{1,38}$=5.410 p=0.025*	0.167	84.765	0.125
			2	$F_{1,38}$=0.007 p=0.935	-0.004	99.284	0.000
			3	$F_{1,38}$=2.122 p=0.153	0.154	83.159	0.053

Model 3: BVMT-R percent recalled (immediate) = ImPACT Design Memory learning percent correct(β) + Intercept
Model 4: BVMT-R percent recalled (delayed) = ImPACT Design Memory delayed memory percent correct(β) + Intercept
*P-value significant at the 0.05 level

Table 4.7 (cont.). Linear Regression Models (N=40)

Model	Dependent Variable	Predictor Variable	Session	Significance	Beta	Intercept	R^2
5	TMT-B Total time	ImPACT Three Letters Average counted correctly	1	$F_{1,38}=35.247$ $p<0.0005$*	-2.182	94.175	0.481
			2	$F_{1,38}=7.888$ $p=0.008$*	-1.004	63.165	0.172
			3	$F_{1,38}=7.672$ $p=0.009$*	-1.082	57.778	0.168
6	SDMT Total score	ImPACT Symbol Match Average correct RT (visible)	1	$F_{1,38}=11.288$ $p=0.002$*	-13.453	60.042	0.229
			2	$F_{1,38}=19.976$ $p<0.0005$*	-16.498	63.922	0.345
			3	$F_{1,38}=8.451$ $p=0.006$*	-6.705	51.974	0.182

Model 5: TMT-B total time = ImPACT Three Letters average counted correctly (visible)(β) + Intercept
Model 6: SDMT total score = ImPACT Symbol Match average correct RT (visible)(β) + Intercept
*P-value significant at the 0.05 level

Table 4.7 (cont.). Linear Regression Models (N=40)

Model	Dependent Variable	Predictor Variable	Session	Significance	Beta	Intercept	R^2
7	Stroop Test Total score	ImPACT Color Match Average correct RT	1	$F_{1,38}$=13.067 p=0.001*	-39.230	83.014	0.256
			2	$F_{1,38}$=5.780 p=0.021*	-28.635	81.078	0.132
			3	$F_{1,38}$=2.031 p=0.162	-24.240	81.266	0.051

Model 7: Stroop total score = ImPACT Color Match average correct RT(β) + Intercept
*P-value significant at the 0.05 level

CHAPTER 5

DISCUSSION

Effects of Age

As awareness of sports-related concussion and availability of neuropsychological testing increase, baseline neuropsychological testing is likely to increase. Testing is also likely to expand to include younger athletes, particularly those of high school age. Therefore, age-related differences in neuropsychological test performance should be explored. Our study found that age is not a factor in neuropsychological testing with the exception of a few tests. Significant age-related differences were found only on the TMT-B and ImPACT processing speed composite scores with college athletes performing better than high school athletes for both measures across all three test sessions. Both of these measures assess an individual's processing speed, and this result adds support to the findings of Iverson et al. where adolescents (ages 13-18) displayed age effects for processing speed.(Iverson, Lovell, & Collins, 2003a) The results from our study suggest a clinically significant difference as well and the clinician needs to be aware of this difference between age groups when evaluating an athlete's performance. It also suggests that a baseline score on these tests for a younger athlete should be reassessed once they become a collegiate athlete. Future research should continue to monitor the effects of age and should be expanded to include a larger spectrum of age groups to include athletes of high school, college, and even professional levels.

Reliability and Precision

One of the uses of neuropsychological testing is to track an athlete's improvement over a period of time resulting in serial administration of neuropsychological tests. The consistency of the athlete and the stability of the actual measure are difficult to differentiate. Regardless, performance consistency in the event of serial neuropsychological testing becomes critical for an accurate evaluation of the athlete. The reliability and precision values were calculated for clinically relevant outcome measures from both neuropsychological test batteries. The majority of the resulting reliability values were of a moderate level.

Tests that demonstrated low ICC values included the HVLT-R (delayed) discrimination index (0.30), the BVMT-R (delayed) total recalled (0.12), the TMT-B total time (0.39), ImPACT verbal memory composite score (0.29) and ImPACT visual memory composite score (0.45). The HVLT-R discrimination index (delayed) and the BVMT-R total recalled (delayed) showed high ceiling effects for absolute scores leaving little to no variability across test sessions. This lack of variability in scores being entered into the statistical analysis may have confounded the results of the ICC. However, no ceiling effect was seen with the TMT-B total time, ImPACT verbal memory composite score, or ImPACT visual memory composite score to account for the low reliability of these scores.

Two observations were made which may help to explain the range of reliability measures. First, tests with a set time limit for completion saw higher ICC values than tests with no time limit. The SDMT, Stroop Test, and ImPACT processing speed composite had a set time limit for completion and had the highest reliability values. This known end point of the test may cause an increase in motivation for the test taker. Second, tests with fewer degrees of freedom saw higher reliability measures. The SDMT presented very few options to complete each task during the test and showed high reliability between test sessions, whereas the TMT-B presented the test taker with seemingly limitless options and variables during the test and showed poor reliability between test sessions.

Scores for the TMT-B total time were noticeably different between sessions and the SEM for this measure was 11.80. Based on a 95 percent confidence interval, this suggests an expected range of nearly 48 seconds from one session to the next. In fact, SEM values calculated for all tests were considerably high. Even tests with high reliability values like the SDMT, the Stroop Test, and ImPACT processing speed composite displayed high SEM values suggesting poor test precision. All ImPACT composite scores had SEM values which created a range of expected test results that exceeded the 80 and 90 percent confidence intervals calculated by Iverson et al.(Iverson, Lovell, & Collins, 2003b)

Test reliability and precision should be carefully considered by the clinician when conducting serial neuropsychological testing. Based on ICC values, measures such as the HVLT-R total recalled (immediate and delayed), the Stroop Test and SDMT total score may be more appropriate for serial neuropsychological testing than the TMT-B total time, ImPACT verbal memory composite score, or ImPACT design memory composite score. Variability is likely to occur across any serial neuropsychological test, but these ICC and SEM values may give the clinician a better understanding of how much variability to expect from one test to the next.

Future research for the consistency of athletes' performance across serial neuropsychological tests should continue to be explored. Increased duration of serial neuropsychological testing may provide a more accurate measure of each athlete's performance over time. In addition, alternate analyses which may account for high ceiling effects may be ideal.

Practice Effects

Other factors affecting the consistency of an athlete's performance may lie within the test itself. It is known that using similar test forms during repeated neuropsychological testing has increased potential for learning effects compared to using alternate forms (Benedict & Zgaljardic, 1998; Schatz, Pardini, Lovell, Collins, & Podell, 2006). In an attempt to reduce practice effects for both test batteries across test sessions, alternate test forms were used for each session when available for the paper-pencil neuropsychological test battery (only one form was available for the TMT-B and the Stroop Test) and different test banks were used for each session for ImPACT.

We observed significant main effects for test session on the TMT-B total time, the Stroop Test total score, and ImPACT processing speed composite scores. These three measures exhibited what can be interpreted as a practice effect as scores increased following the first test session and remained elevated through the third session. ImPACT processing speed composite scores appeared to stabilize from the second to third sessions suggesting that the most significant effect of practice occurred between the first and second session. The TMT-B total score and Stroop Test also demonstrated the most significant increase from the first to second session, but unlike ImPACT processing speed composite scores the TMT-B and Stroop Test showed continued effects of practice through the third session. Previous research documents that the greatest increase in test scores due to practice effects occurs between the first and second administration (Benedict & Zgaljardic, 1998; Collie, Maruff, Darby, &

McStephen, 2003). The findings in this study seem to support this claim as a similar occurrence was observed for the TMT-B total score, the Stroop Test total score, and ImPACT processing speed composite score.

Clinicians should be aware of possible score increase due to practice effects for the TMT-B total time and Stroop Test total score when evaluating an athlete's recovery following a concussion. This is especially true for the first evaluation following a concussion as the clinician should expect an increase in these two test scores when compared to baseline measures if the individual is neurocognitively healthy. A decreased score or a lack of improvement on either of these two tests may suggest neurocognitive impairment and the clinician should be cautious when determining if an athlete fit to return to competition. Less clinical significance should be placed on the appearance of a learning effect for ImPACT processing speed composite score as these increases in test scores occur within the suggested reliable change estimates.(Iverson, Lovell, & Collins, 2003b)

The presence of practice effects in the TMT-B total score and Stroop Test total score may help to support the idea that alternate test forms decrease practice effects as these were the only two tests administered with only one test form and these tests had perhaps the greatest increase in scores over the three test sessions. The TMT-B had a pattern of connected circles that could be memorized and also introduced a new, learnable counting pattern with alternating numbers and letters. These two factors may have been responsible for the practice effect seen with the TMT-B. The Stroop Test's list of 100 color words in different color ink does not appear to be memorized from one test exposure to the next. However, the repeated exposure to this novel task may have led to practice effects resulting from test taking strategies, an increased awareness to the color of the ink, an increased inhibition to the word printed, or any combination of these factors. The ImPACT processing speed composite scores were created from two test modules, each of which utilized multiple test forms. Although ImPACT processing speed composite scores did display a practice effect, it appeared less drastic than the practice effects seen in the single form tests. Closer inspection reveals that one of the contributing components of the ImPACT processing speed composite score is the Three Letters average counted correctly score. This test requires a similar task to the TMT-B, but with only numbers and counting in reverse from 25 to one. So it is possible that the new counting pattern is responsible for the practice effect in both the TMT-B and ImPACT processing speed composite score.

Significant main effects for session occurred for both the immediate and delayed BVMT-R total recalled scores as well. However, this does not appear to be a learning effect. Although mean scores increased from the first to second session, the scores from the third session dropped lower below those of the first session. Although this change in scores is statistically significant, the fluctuation in scores occurs with a change of one point or less from one session to the next. This is a minimal change in score from one session to the next and appears clinically irrelevant. Despite observations of main effects for age and for session, no significant interactions were seen for the influence of age on practice effects.

Further research should target the individual outcome measures of ImPACT to target practice effects on a more specific level. If practice effects are observed within individual outcome measures it is possible that changes can be made to these test modules which may create a more consistent tool across neuropsychological tests.

Shared Variance and Concurrent Validity

One of the major issues facing computerized neuropsychological testing, particularly computerized testing platforms such as ImPACT, is insufficient support for its validity. Although studies have addressed validity of ImPACT(Iverson, Franzen, Lovell, & Collins, 2004; Iverson, Lovell, & Collins, 2005), these studies are few in number, validate only a portion of the test battery, and are criticized as being biased because they are linked to the creators of the computerized testing program.

The shared variance observed in our study between ImPACT outcome measures and paper-pencil neuropsychological test scores of similar cognitive domains was somewhat disappointing. We observed that the ImPACT Design Memory learning percent correct, ImPACT Three Letters average counted correctly and ImPACT Symbol Match average correct reaction time (visible) were the only ImPACT outcome measures that had significant linear regression models with their paper-pencil neuropsychological test cognitive match across all three sessions. ImPACT Word Memory learning percent correct, ImPACT Design Memory, and ImPACT Color Match average correct reaction time showed significant linear regression models, but only for one or two of the test sessions. These linear regression models were used to determine level of shared variance between ImPACT outcome measures and traditional paper-pencil neuropsychological test scores of similar cognitive domains. Unlike previous analyses in this study which used more clinically relevant measures, these regressions were calculated using outcome measures from both test batteries in an attempt to match cognitive domains more specifically and accurately.

Coefficients of determination for all of the significant prediction models were relatively low, with only the ImPACT Three Letters average counted correctly reaching a moderate level (R^2=0.481). In the majority of cases, more variance was explained in the earlier sessions compared to later sessions. This may suggest that these test scores become more dissimilar over time not necessarily due to the test itself, but as a result of changes in test performance. These changes in performance can occur from any number of different reasons including taking strategies which are specific to each individual test and/or task.

Because of the low coefficients of determination, 52 to 88 percent of the variance was unexplained for the relationships between the paper-pencil neuropsychological test score and the cognitively matched ImPACT score. Based on these results, the concurrent validity of ImPACT test scores based on comparisons with previously validated paper-pencil neuropsychological test scores of similar cognitive domains cannot be confirmed for healthy, active athletes 15 to 17 and 19 to 21 years of age. The inability of this study to prove the concurrent validity of ImPACT may suggest that the ImPACT test scores and paper-pencil neuropsychological test scores compared were simply identifying different constructs. These results do not suggest that ImPACT is not a useful tool in the detection and measurement of sports-related concussion.

Future research should be conducted to determine if earlier test sessions provide a more accurate representation of each test's intended measure. Also, more research is warranted to determine the validity of ImPACT as a neuropsychological testing tool, with larger sample sizes, increased age ranges, and possibly alternate means of comparison and analysis.

Limitations

As with any study, there were limitations in how the study was conducted. With respect to the subjects studied in our investigation, the most limiting factor was probably the amount of effort and motivation given by each subject. Without full effort on the part of the athlete on these or any neuropsychological test, performance can be expected to decrease. Another limitation was time. Whether it was time of day, day of the week, etc., an uncontrollable amount of factors based around time may have played a role in the performance of these athletes. Although attempts were made to test athletes at a consistent time of day, other variables of time were less controllable.

Environmental influences on the athletes may have also played a role in test performance. Attempts were made to reduce the effects of the environment by testing an individual in the same place for all test sessions and choosing a quiet area to minimize noise and distractions. However, because three separate testing sites were used it is possible that individuals may have performed differently at these different sites. Additional limitations may have included the selection of an appropriate sample of athletes and proper and consistent administration of the neuropsychological test batteries, and the ability to correctly match the psychometric properties of the ImPACT and paper-pencil neuropsychological test outcome measures.

Conclusions

Several outcomes of this study warrant attention from clinicians who deal with athletes at risk of sports-related concussion. First, this study showed that differences in neuropsychological test performance do occur between age groups. These differences seem to occur on measures of processing speed with college athletes performing better than high school athletes. As neuropsychological testing expands to include high school athletes, clinicians need to be aware of these differences when evaluating an athlete following a sports-related concussion.

In addition, this study showed that athletes' performance varies across serial neuropsychological tests. It is important for the clinician to know the reliability and precision of these tests in order to properly interpret the variations in test scores. In some cases, the variability across serial neuropsychological tests occurs due to practice effects. In the presence of a practice effect, the clinician can expect the greatest improvement in test scores to occur between the first and second administration of a neuropsychological test. A clinician must be able to differentiate between a learning effect and neurocognitive recovery in order to make an accurate decision on whether or not to return an athlete to competition.

Finally, this study was unable to prove the concurrent validity of ImPACT through comparisons with previously validated paper-pencil neuropsychological tests of similar cognitive domains. It is possible that ImPACT test scores and paper-pencil neuropsychological test scores that were compared in this study were simply identifying different constructs. Nevertheless, clinicians should use caution when interpreting ImPACT test scores during a neuropsychological evaluation until the validity of ImPACT can be conclusively proven.

APPENDIX 1:
MANUSCRIPT

Abstract

The purpose of this study was to determine: 1) if an athlete's age significantly affects neuropsychological test performance and 2) if an athlete's performance remains consistent across serial neuropsychological tests. A healthy sample of 20 college and 20 high school athletes completed both the Immediate Postconcussion and Cognitive Test (ImPACT) and traditional paper-pencil neuropsychological test batteries on three separate occasions. Means and standard deviations, 2x3 mixed model ANOVAs (age x session), and reliability ($ICC_{2,1}$) and precision (SEM) values were calculated on outcome measures for both test batteries. The ANOVAs revealed significant main effects of age for the Trail Making Test Form B (TMT-B) total time and ImPACT processing speed composite score with college athletes performing better than high school students on both measures. The ANOVAs also revealed significant main effects of session for the Brief Visuospatial Memory Test – Revised (BVMT-R) total recalled (immediate and delayed), the TMT-B total time, Stroop Test total score, and ImPACT processing speed composite score. Reliability measures ranged from 0.12 to 0.72 with the majority of the outcome measures achieving a moderate level of reliability across testing sessions. This study demonstrates the need of the clinician to understand the differences in neuropsychological test performance for athletes of different age groups and across serial neuropsychological tests.

Introduction

Over the past two decades there has been an identifiable increase in the use of neuropsychological testing in the management of sports-related concussion.(McCrory, Makdissi, Davis, & Collie, 2005; Randolph, McCrea, & Barr, 2005) Increasing interest in the application of computer technology to the neurosciences and clinical psychiatry (Butcher, Perry, & Hahn, 2004; Gottschalk et al., 2000) has led to modifications in standard clinical neuropsychological assessment practices.

Computerized testing methods have the potential to enhance the field of psychological assessment (Butcher, Perry, & Hahn, 2004) with some of this enhancement coming from advantages computerized testing has over the traditional paper-pencil tests. Advantages of computerized neuropsychological testing include infinite randomized forms, millisecond timing, control over presentation of test stimuli, standardized self administration, group testing, rapid testing, decreased setup, preparation and costs, internet based delivery, automated analysis, ease of data collection, centralized data storage, analysis, and reporting.(Grindel, Lovell, & Collins, 2001; McCrory, Makdissi, Davis, & Collie, 2005; Randolph, McCrea, & Barr, 2005; Schatz & Browndyke, 2002)

Repeated administrations of the same neuropsychological tests are now more common in neuropsychological evaluations (Benedict & Zgaljardic, 1998) as serial testing is used to track an athlete's neurocognitive recovery over time. The influence of practice effects on these neuropsychological test scores must be carefully considered when retesting or administering serial neuropsychological testing of individuals. Performance on many neuropsychological tests may be improved by prior exposure to testing stimuli and procedures.(Collie, Maruff, Darby, & McStephen, 2003) Improvement in test performance due to practice effects cause inflated neuropsychological test scores which can mimic neurocognitive recovery, and may lead to returning an athlete to competition prematurely.

Therefore, the purpose of this study was to determine: 1) if an athlete's age significantly affects neuropsychological test performance and 2) if an athlete's performance remains consistent across serial neuropsychological tests.

Methods

Subjects

Forty healthy, active, volunteer athletes participated in this study; 20 from the University of North Carolina (UNC) and a total of 20 from two high schools located in central North Carolina. Ages ranged from 15 to 17 years of age for high school athletes and from 19 to 21 years of age for college athletes. An equal number of males and females were used from both age groups.

Participants were neither included nor excluded from this study on the basis of ethnicity or race. Individuals that were excluded from this study include those with history of concussion in the last 5 years, known neurocognitive deficits or disorders, known psychological conditions or disorders, color blindness, individuals that were 18 years of age, and individuals that participated in athletics less than 3 days per week.

Procedures

Prior to participation, all participants were required to sign the appropriate IRB approved consent forms. High school participants were required to complete an IRB approved assent form and their legal guardian was required to complete an IRB approved consent form. College participants were required to complete an IRB approved consent form.

High school participants reported to a classroom at their high school and college participants reported to the UNC Sports Medicine Research Laboratory (SMRL). All participants reported to their respective testing site for a total of three visits with at least 24 hours, but no more than 72 hours, between each visit. Each testing session lasted for approximately one hour. All participants completed both ImPACT and paper-pencil tests batteries in a counterbalanced order for each trial. The first participant determined which test battery to begin testing by random selection (i.e. coin flip). All following participants began with the test battery that counterbalanced the previous participant and used the same test battery order for all three test sessions.

Speed of testing was determined by the participant for both ImPACT and paper-pencil test batteries. Upon completion of one test module the participant gave confirmation that they are ready to proceed to the next test module and continued until all tests for that battery were completed. Upon completion of one test battery, the participant began the remaining test battery following a five minute rest period. The test session was concluded after the subject completed the second test battery.

Instrumentation

Participants were tested on both a computer-based test battery and a traditional paper-pencil based test battery to assess neuropsychological performance during three separate test sessions. The computer-based test battery used was ImPACT Version 3 (ImPACT Applications, Inc., Pittsburgh, PA). ImPACT was administered on a laptop computer with an optical mouse. The paper-pencil test battery consisted of a Graded Symptom Checklist (ImPACT Applications, Inc., Pittsburgh, PA), Hopkins Verbal Learning Test-Revised (Johns

Hopkins University, Baltimore, MD), Brief Visuospatial Memory Test-Revised (Psychological Assessment Resources, Inc., Lutz, FL), Trail Making Test Form B (Reitan Neuropsychological Laboratory, Tucson, AZ), Symbol Digit Modalities Test (Western Psychological Services, Los Angeles, CA), and the Stroop Test (Stoelting Company, Wood Dale, IL).

ImPACT. ImPACT is an automated program that guides the user through a series of neuropsychological tests. Before testing began, the program prompted the user to input some demographical information and pertinent medical history. Next, the user was taken through a Graded Symptom Checklist (GSC) and was instructed to score their symptoms based on how they felt at that moment. Upon completion of the GSC, the user was prompted to begin the test battery. Instructions for each test module were displayed by the program prior to the start of each module. The user was prompted by the program between each subtest to ensure the user was prepared to begin the next test.

Three test banks (1, 2, and 3) containing alternate test forms were used to reduce learning effects across testing sessions. Athletes were instructed to pay close attention to and follow the instructions as they were given by the computer, to answer as quickly as they could, to answer as accurately as they could, and to give their best effort.

Graded Symptom Checklist. A paper version of ImPACT's GSC was administered prior to the paper-pencil test battery to monitor for symptom changes in athletes from one test battery to the next. Athletes were instructed to complete the GSC based on how they felt at that moment.

Hopkins Verbal Learning Test – Revised. Three alternate forms were used (A, B, and C) to reduce learning effects across testing sessions. Each form consisted of a free recall and a recognition portion of the test. The free recall section was administered first and consisted of three trials. The subject was read a list of 12 words (four words from each of three different categories) and instructed to repeat back as many words as they could and in any order. The next free recall trial was begun once the subject had given all 12 words to the test administrator or once the subject stated that they could not recall any more words. After all three free recall trials were completed the recognition portion of the exam began. A list of 24 words was read to the subject and after each word they are asked to identify whether that word was, or was not, part of the list they were just given. The delayed test was administered in the same manner as the immediate test, except the subject was not read the list of words and there was only one free recall trial.

Brief Visuospatial Memory Test – Revised. Three alternate forms were used (1, 2, and 3) to reduce learning effects across testing sessions. Each form consisted of six figures arranged in two columns with three rows. The subject was instructed that they would be shown a sheet with 6 figures on it, which they will be given 10 seconds to study in order to remember as many of these figures as they can. They were also instructed that after the 10 seconds ends the sheet will be removed, and they would be given a blank sheet and asked to draw each figure exactly as it appeared and in its correct location on the page. Once the subject stated that they were finished, the subject's sheet was removed and the next trial was begun. Trials two and three were administered in the same way as trial one. A delayed trial was administered at the end of the test battery. The delayed trial was administered in the same manner as the immediate trial, except the subject was not shown the sheet with the 6 figures.

Trail Making Test Form B. Only one form was used for this test. The subject was instructed to connect the circles in order, alternating between numbers and letters (1 to A, A to 2, 2 to B, etc). The subject was given a quick sample to ensure the directions were understood. The subject was also instructed to work as quickly as possible while trying not to make any mistakes, and trying not to lift the pencil from the paper. In the event a mistake was made, the subject was directed back to the last correct circle. Time was not stopped in the event of a mistake. Time began when the subject's pencil touched the paper at the first circle and time ended when their pencil hit the last circle.

Symbol Digit Modalities Test. Three alternate forms were used (A, B, and C) to reduce learning effects across test sessions. Athletes were instructed to fill the empty box with the number that matches the symbol using the key at the top of the page, and athletes were given a 10 symbol sample section to ensure the directions were understood. Athletes were instructed to works as fast as possible while trying not to make any mistakes. All athletes were given 60 seconds to get as far as they could.

Stroop Test. Only one form was used for this test. The subject was instructed name the color of the ink, ignoring the word that was spelled out. Athletes read down the columns starting with the column on the left. Athletes were given 45 seconds to go through as many words as possible. The test administrator followed along using an answer key, and in the event a wrong answer was given the test administrator would say, “No,” and the subject would try that word again. Time was not stopped in the event of a wrong answer.

Data Analysis

SPSS Version 13.0 (SPSS Inc., Chicago, IL) was used to analyze the data. Mean scores and standard deviations were calculated for each outcome measure. Level of significance was set a priori at 0.05 for all analyses.

In order to address the effect of age on neuropsychological performance, one 2x3 mixed model ANOVA (age x session) was calculated for each clinically relevant outcome measure outlined in Table 1. These ANOVAs were then analyzed for the main effects between groups (age) to determine differences between high school and college age athletes for ImPACT and paper-pencil neuropsychological test scores.

Consistency of athletes’ performance across serial neuropsychological tests was evaluated using two statistics. First, an intraclass correlation coefficient ($ICC_{2,1}$) with standard error of measurement (SEM) was calculated to determine the consistency of athletes’ performance across serial neuropsychological tests for each of the clinically relevant outcome measures outlined in Table 1. Second, a 2x3 mixed model ANOVA (age x session) was calculated for each clinically relevant outcome measure outlined in Table 1. These ANOVAs were then analyzed for the main effects within groups (session) to determine the presence of practice effects resulting from serial neuropsychological testing using both ImPACT and paper-pencil neuropsychological test batteries. Interaction effects from these ANOVAs were also analyzed in order to examine the influence of age on practice effects for both ImPACT and paper-pencil neuropsychological tests.

Results

This study involved data collection from 40 healthy, active, volunteer athletes. Subjects included 20 high school aged athletes and 20 college aged athletes. Both genders were equally represented in each of the two age groups. Descriptive statistics are presented in Table 2 and Table 3. All athletes were assessed according to the protocol specified in Chapter 3.

$ICC_{2,1}$ and SEM values for the clinically relevant outcome measures on both paper-pencil and ImPACT neuropsychological test batteries are presented in Table 4 and Table 5. We observed main effects for session on the BVMT-R total recalled (immediate) ($F_{2,76}$=3.199, p=0.046), the BVMT-R total recalled (delayed) ($F_{2,64}$=3.356, p=0.049), the TMT-B total time ($F_{2,66}$=73.432, p<0.0005), the Stroop Test total score ($F_{2,76}$=96.851, p<0.0005), and ImPACT processing speed composite score ($F_{2,76}$=5.806, p=0.005). Statistics for these analyses are presented in Table 6 and Table 7.

Discussion

Effects of Age

As awareness of sports-related concussion and availability of neuropsychological testing increase, baseline neuropsychological testing is also likely to increase. Testing is also likely to expand to include younger athletes, particularly those of high school age. Therefore, age-related differences in neuropsychological test performance should be explored. Our study found that age is not a factor in neuropsychological testing with the exception of a few tests. Significant age-related differences were found only on the TMT-B and ImPACT processing speed composite scores with college athletes performing better than high school athletes for both measures across all three test sessions. Both of these measures assess an individual's processing speed, and this result adds support to the findings of Iverson et al. where adolescents (ages 13-18) displayed age effects for processing speed.(Iverson, Lovell, & Collins, 2003a) The results from our study suggest a clinically significant difference as well and the clinician needs to be aware of this difference between age groups when evaluating an athlete's performance. It also suggests that a baseline score on these tests for a younger athlete should be reassessed once they become a collegiate athlete. Future research should continue to monitor the effects of age and should be expanded to include a larger spectrum of age groups to include athletes of high school, college, and even professional levels.

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We observed significant main effects for test session on the TMT-B total time, the Stroop Test total score, and ImPACT processing speed composite scores. These three measures exhibited what can be interpreted as a practice effect as scores increased following the first test session and remained elevated through the third session. ImPACT processing speed composite scores appeared to stabilize from the second to third sessions suggesting that the most significant effect of practice occurred between the first and second session. The TMT-B total score and Stroop Test also demonstrated the most significant increase from the first to second session, but unlike ImPACT processing speed composite scores the TMT-B and Stroop Test showed continued effects of practice through the third session. Previous research documents that the greatest increase in test scores due to practice effects occurs between the first and second administration (Benedict & Zgaljardic, 1998; Collie, Maruff, Darby, & McStephen, 2003). The findings in this study seem to support this claim as a similar occurrence was observed for the TMT-B total score, the Stroop Test total score, and ImPACT processing speed composite score.

Clinicians should be aware of possible score increase due to practice effects for the TMT-B total time and Stroop Test total score when evaluating an athlete's recovery following a concussion. This is especially true for the first evaluation following a concussion as the clinician should expect an increase in these two test scores when compared to baseline measures if the individual is neurocognitively healthy. A decreased score or a lack of improvement on either of these two tests may suggest neurocognitive impairment and the clinician should be cautious when determining if an athlete fit to return to competition. Less clinical significance should be placed on the appearance of a learning effect for ImPACT processing speed composite score as these increases in test scores occur within the suggested reliable change estimates.(Iverson, Lovell, & Collins, 2003b)

The presence of practice effects in the TMT-B total score and Stroop Test total score may help to support the idea that alternate test forms decrease practice effects as these were the only two tests administered with only one test form and these tests had perhaps the greatest increase in scores over the three test sessions. The TMT-B had a pattern of connected circles that could be memorized and also introduced a new, learnable counting pattern with alternating numbers and letters. These two factors may have been responsible for the practice effect seen with the TMT-B. The Stroop Test's list of 100 color words in different color ink does not appear to be memorized from one test exposure to the next. However, the repeated exposure to this novel task may have led to practice effects resulting from test taking strategies, an increased awareness to the color of the ink, an increased inhibition to the word printed, or any combination of these factors. The ImPACT processing speed composite scores were created from two test modules, each of which utilized multiple test forms. Although ImPACT processing speed composite scores did display a practice effect, it appeared less drastic than the practice effects seen in the single form tests. Closer inspection reveals that one of the contributing components of the ImPACT processing speed composite score is the Three Letters average counted correctly score. This test requires a similar task to the TMT-B, but with only numbers and counting in reverse from 25 to one. So it is possible that the new counting pattern is responsible for the practice effect in both the TMT-B and ImPACT processing speed composite score.

Significant main effects for session occurred for both the immediate and delayed BVMT-R total recalled scores as well. However, this does not appear to be a learning effect. Although mean scores increased from the first to second session, the scores from the third session dropped lower below those of the first session. Although this change in scores is statistically significant, the fluctuation in scores occurs with a change of one point or less from one session to the next. This is a minimal change in score from one session to the next and appears clinically irrelevant. Despite observations of main effects for age and for session, no significant interactions were seen for the influence of age on practice effects.

Further research should target the individual outcome measures of ImPACT to target practice effects on a more specific level. If practice effects are observed within individual outcome measures it is possible that changes can be made to these test modules which may create a more consistent tool across neuropsychological tests.

Limitations

As with any study, there were limitations in how the study was conducted. With respect to the subjects studied in our investigation, the most limiting factor was probably the amount of effort and motivation given by each subject. Without full effort on the part of the athlete on these or any neuropsychological test, performance can be expected to decrease. Another limitation was time. Whether it was time of day, day of the week, etc., an uncontrollable amount of factors based around time may have played a role in the performance of these athletes. Although attempts were made to test athletes at a consistent time of day, other variables of time were less controllable.

Environmental influences on the athletes may have also played a role in test performance. Attempts were made to reduce the effects of the environment by testing an individual in the same place for all test sessions and choosing a quiet area to minimize noise and distractions.

However, because three separate testing sites were used it is possible that individuals may have performed differently at these different sites. Additional limitations may have included the selection of an appropriate sample of athletes and proper and consistent administration of the neuropsychological test batteries, and the ability to correctly match the psychometric properties of the ImPACT and paper-pencil neuropsychological test outcome measures.

Conclusions

Outcomes of this study warrant attention from clinicians who deal with athletes at risk of sports-related concussion. This study showed that athletes' performance varies across serial neuropsychological tests. It is important for the clinician to know the reliability and precision of these tests in order to properly interpret the variations in test scores. In some cases, the variability across serial neuropsychological tests occurs due to practice effects. In the presence of a practice effect, the clinician can expect the greatest improvement in test scores to occur between the first and second administration of a neuropsychological test. A clinician must be able to differentiate between a learning effect and neurocognitive recovery in order to make an accurate decision on whether or not to return an athlete to competition.

Also, this study was unable to prove the concurrent validity of ImPACT through comparisons with previously validated paper-pencil neuropsychological tests of similar cognitive domains. It is possible that ImPACT test scores and paper-pencil neuropsychological test scores that were compared in this study were simply identifying different constructs. Nevertheless, clinicians should use caution when interpreting ImPACT test scores during a neuropsychological evaluation until the validity of ImPACT can be conclusively proven.

Table 1. Clinically Relevant Outcome Measures

Paper-Pencil	ImPACT
HVLT-R	Composite Scores
Total recalled (immediate)	Verbal memory
Discrimination index (immediate)	Visual memory
Total recalled (delayed)	Processing speed
Discrimination index (delayed)	Reaction Time
BVMT-R	Impulse control
Total recalled (immediate)	
Total recalled (delayed)	
TMT-B	
Total time	
SDMT	
Total score	
Stroop Test	
Total score	

Table 2. Subject Descriptive Statistics (means ± SD)

	N	Age (yrs)	Height (cm)	Weight (kg)
High School	20	16.00 ± 0.86	171.77 ± 9.55	66.16 ± 11.83
College	20	20.00 ± 0.79	173.31 ± 9.78	75.80 ± 12.16
All Athletes	40	18.00 ± 2.18	172.54 ± 9.57	70.98 ± 12.80

Table 3. Primary Sports of All Athletes (N=40)

Sport	N
Men’s Soccer	7
Softball	6
Women’s Soccer	5
Wrestling	5
Men’s Lacrosse	5
Track and Field	3
Gymnastics	2
Cross Country	2
Dance	2
Women’s Basketball	1
Men’s Tennis	1
Volleyball	1

Table 4. Reliability ($ICC_{2,1}$) and Precision (SEM) of Paper-Pencil Neuropsychological Test Scores (N=40)

Paper-Pencil	$ICC_{2,1}$	SEM
HVLT-R (immediate)		
Total recalled	0.56	2.412
Discrimination index	0.57	0.471
HVLT-R (delayed)		
Total recalled	0.59	1.498
Discrimination index	0.30	0.970
BVMT-R (immediate)		
Total recalled	0.50	2.485
BVMT-R (delayed)		
Total recalled	0.12	0.799
TMT-B		
Total time	0.39	11.800
SDMT		
Total score	0.72	3.691
Stroop		
Total score	0.69	6.659

Table 5. Reliability ($ICC_{2,1}$) and Precision (SEM) of ImPACT Composite Scores (N=40)

ImPACT	$ICC_{2,1}$	SEM
Composite Scores		
Verbal Memory	0.29	7.809
Visual Memory	0.45	8.270
Processing Speed	0.71	4.094
Reaction Time	0.60	0.051
Impulse Control	0.63	3.699

Table 6. Main Effects and Interaction Effects for Paper-Pencil Neuropsychological Test Scores (N=40)

	High School Mean (SD)	College Mean (SD)	Session Average Mean (SD)	Main Effect of Time	Main Effect of Age	Interaction Effect
HVLT-R (immediate)						
Total Recalled						
Session 1	26.30 (3.80)	27.20 (3.49)	26.75 (3.63)	$F_{2,76}$=2.676	$F_{1,38}$=0.039	$F_{2,76}$=1.812
Session 2	28.20 (3.25)	27.60 (2.78)	27.90 (3.00)	p=0.075	p=0.844	p=0.170
Session 3	27.75 (3.51)	26.90 (3.71)	27.33 (3.59)			
Group Average	27.42 (3.56)	27.23 (3.31)				
Discrimination Index						
Session 1	11.75 (0.44)	11.50 (0.76)	11.63 (0.63)	$F_{2,76}$=0.633	$F_{1,38}$=2.002	$F_{2,76}$=0.341
Session 2	11.80 (0.41)	11.65 (0.59)	11.73 (0.51)	p=0.534	p=0.165	p=0.712
Session 3	11.85 (0.37)	11.55 (0.94)	11.70 (0.72)			
Group Average	11.80 (0.40)	11.57 (0.77)				
HVLT-R (delayed)						
Total Recalled						
Session 1	9.80 (1.85)	10.40 (2.14)	10.10 (2.00)	$F_{2,76}$=0.031	$F_{1,38}$=0.726	$F_{2,76}$=0.139
Session 2	9.85 (2.11)	10.40 (1.73)	10.13 (1.92)	p=0.969	p=0.400	p=0.871
Session 3	9.90 (2.61)	10.20 (2.12)	10.05 (2.35)			
Group Average	9.85 (2.18)	10.33 (1.97)				
Discrimination Index						
Session 1	11.60 (0.60)	11.30 (1.30)	11.45 (1.01)	$F_{2,65}$=1.369	$F_{1,38}$=0.223	$F_{2,65}$=0.605
Session 2	11.15 (1.04)	11.25 (1.29)	11.20 (1.16)	p=0.260	p=0.640	p=0.525
Session 3	11.55 (0.60)	11.40 (1.10)	11.48 (0.88)			
Group Average	11.43 (0.79)	11.32 (1.21)				

*P-value significant at the 0.05 level

Table 6 (cont.). Main Effects and Interaction Effects for Paper-Pencil Neuropsychological Test Scores (N=40)

	High School Mean (SD)	College Mean (SD)	Session Average Mean (SD)	Main Effect of Time	Main Effect of Age	Interaction Effect
BVMT-R (immediate)						
Total Recalled						
Session 1	32.75 (2.79)	32.25 (3.99)	32.50 (3.40)	$F_{2,76}$=3.199	$F_{1,38}$=0.351	$F_{2,76}$=0.298
Session 2	33.45 (1.47)	33.35 (2.78)	33.40 (2.19)	p=0.046*	p=0.557	p=0.743
Session 3	32.65 (2.30)	31.80 (4.47)	32.23 (3.53)			
Group Average	32.95 (2.24)	32.47 (3.80)				
BVMT-R (delayed)						
Total Recalled						
Session 1	11.85 (0.49)	11.75 (0.79)	11.80 (0.65)	$F_{2,64}$=3.356	$F_{1,38}$=0.708	$F_{2,64}$=0.169
Session 2	11.90 (0.31)	11.85 (0.37)	11.88 (0.33)	p=0.049*	p=0.405	p=0.807
Session 3	11.65 (0.75)	11.45 (0.94)	11.55 (0.85)			
Group Average	11.80 (0.55)	11.68 (0.75)				
TMT-B						
Total Time						
Session 1	61.43 (13.79)	50.04 (14.53)	55.73 (15.12)	$F_{2,66}$=73.432	$F_{1,38}$=6.161	$F_{2,66}$=1.562
Session 2	47.36 (9.49)	40.61 (12.13)	43.98 (11.28)	p<0.0005*	p=0.018*	p=0.216
Session 3	40.20 (11.28)	33.74 (9.22)	36.97 (10.68)			
Group Average	49.66 (14.50)	41.46 (13.71)				

*P-value significant at the 0.05 level

Table 6 (cont.). Main Effects and Interaction Effects for Paper-Pencil Neuropsychological Test Scores (N=40)

	High School Mean (SD)	College Mean (SD)	Session Average Mean (SD)	Main Effect of Time	Main Effect of Age	Interaction Effect
SDMT						
Total Score						
Session 1	41.00 (5.85)	42.60 (6.55)	41.80 (6.18)	$F_{2,76}$=0.909	$F_{1,38}$=0.549	$F_{2,76}$=0.236
Session 2	40.45 (6.25)	42.15 (7.69)	41.30 (6.97)	p=0.407	p=0.463	p=0.790
Session 3	41.95 (5.94)	42.70 (5.89)	42.33 (5.85)			
Group Average	41.13 (5.95)	42.48 (6.64)				
Stroop Test						
Total Score						
Session 1	52.95 (10.86)	52.90 (7.90)	52.93 (9.37)	$F_{2,76}$=96.851	$F_{1,38}$=0.033	$F_{2,76}$=0.306
Session 2	59.95 (11.28)	61.20 (10.50)	60.58 (10.77)	p<0.0005*	p=0.857	p=0.737
Session 3	63.95 (12.23)	64.55 (11.82)	64.25 (11.87)			
Group Average	58.95 (12.17)	59.55 (11.18)				

*P-value significant at the 0.05 level

Table 7. Main Effects and Interaction Effects for ImPACT Composite Scores (N=40)

	High School Mean (SD)	College Mean (SD)	Session Average Mean (SD)	Main Effect of Time	Main Effect of Age	Interaction Effect
Verbal Memory						
Session 1	89.20 (7.73)	90.05 (6.48)	89.63 (7.05)	$F_{2,76}$=0.373	$F_{1,38}$=0.331	$F_{2,76}$=1.278
Session 2	86.65 (8.44)	90.30 (7.35)	88.48 (8.03)	p=0.690	p=0.569	p=0.284
Session 3	89.10 (7.67)	87.85 (10.79)	88.48 (9.26)			
Group Average	(88.32) 7.91	89.40 (8.34)				
Visual Memory						
Session 1	78.40 (9.34)	79.50 (10.45)	78.95 (11.20)	$F_{2,76}$=1.629	$F_{1,38}$=0.795	$F_{2,76}$=0.188
Session 2	79.95 (10.45)	82.95 (9.73)	81.45 (10.08)	p=0.203	p=0.378	p=0.829
Session 3	80.30 (7.46)	83.00 (9.67)	81.65 (8.63)			
Group Average	79.55 (9.05)	81.82 (10.86)				
Processing Speed						
Session 1	39.43 (7.88)	45.81 (6.03)	42.62 (7.64)	$F_{2,76}$=5.806	$F_{1,38}$=5.029	$F_{2,76}$=2.233
Session 2	43.03 (7.36)	46.86 (7.09)	44.95 (7.39)	p=0.005*	p=0.031*	p=0.114
Session 3	43.58 (6.45)	46.65 (6.55)	45.11 (6.60)			
Group Average	42.01 (7.34)	46.44 (6.48)				

*P-value significant at the 0.05 level

Table 7 (cont.). Main Effects and Interaction Effects for ImPACT Composite Scores (N=40)

	High School Mean	(SD)	College Mean	(SD)	Session Average Mean	(SD)	Main Effect of Time	Main Effect of Age	Interaction Effect
Reaction Time									
Session 1	0.55	(0.06)	0.52	(0.06)	0.53	(0.06)	$F_{2,76}$=2.012	$F_{1,38}$=1.206	$F_{2,76}$=0.118
Session 2	0.52	(0.06)	0.51	(0.08)	0.52	(0.07)	p=0.141	p=0.279	p=0.889
Session 3	0.53	(0.08)	0.51	(0.07)	0.52	(0.08)			
Group Average	0.53	(0.07)	0.51	(0.07)					
Impulse Control									
Session 1	9.20	(5.40)	6.20	(4.31)	7.70	(5.05)	$F_{2,76}$=0.039	$F_{1,38}$=2.531	$F_{2,76}$=0.390
Session 2	8.85	(7.51)	6.65	(4.13)	7.75	(6.09)	p=0.961	p=0.120	p=0.678
Session 3	8.75	(4.51)	7.05	(5.29)	7.90	(4.92)			
Group Average	8.93	(5.84)	6.63	(4.54)					

*P-value significant at the 0.05 level

APPENDIX 2:
GRADED SYMPTOM CHECKLIST

Graded Symptom Checklist Subject______ Date________

Based on how you feel right now, rate your symptoms…

	None						Severe
Headache	0	1	2	3	4	5	6
Nausea	0	1	2	3	4	5	6
Vomiting	0	1	2	3	4	5	6
Balance Problems	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Fatigue	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
Sleeping more than usual	0	1	2	3	4	5	6
Sleeping less than usual	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervousness	0	1	2	3	4	5	6
Feeling more emotional	0	1	2	3	4	5	6
Numbness or tingling	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling mentally foggy	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Visual Problems	0	1	2	3	4	5	6

Total Symptom Score ______

APPENDIX 3A:
HOPKINS VERBAL LEARNING TEST (FORM 1)

Hopkins Verbal Learning Test **Version 1**

Name______________________ Testing Session: Pr D1 D3 D5 D10 Po

ParT A: Free Recall

	Trial 1	Trial 2	Trial 3
LION	______	______	______
EMERALD	______	______	______
HORSE	______	______	______
TENT	______	______	______
SAPPHIRE	______	______	______
HOTEL	______	______	______
CAVE	______	______	______
OPAL	______	______	______
TIGER	______	______	______
PEARL	______	______	______
COW	______	______	______
HUT	______	______	______
Number Correct	______	______	______

Part B: Recognition

HORSE	ruby	CAVE	balloon	coffee	LION
House	OPAL	TIGER	boat	scarf	PEARL
HUT	EMERALD	SAPPHIRE	dog	apartment	penny
TENT	mountain	cat	HOTEL	COW	diamond

True Positives: ______/12

False-Positive Errors, Related:______/6 Unrelated:______/6

Discrimination Index: (#True-Positives)-(False-Positives)=______

Hopkins Verbal Learning Test | **Version 1**

Name:________________________ BL D1 D2 D3 D4 D5 ....

Date:________________________

Part B: Delayed Recall

LION	_____
EMERALD	_____
HORSE	_____
TENT	_____
SAPPHIRE	_____
HOTEL	_____
CAVE	_____
OPAL	_____
TIGER	_____
PEARL	_____
COW	_____
HUT	_____

Delayed Recall Total Score	

Part C: Recognition

HORSE	ruby	CAVE	balloon	coffee	LION
house	OPAL	TIGER	boat	scarf	PEARL
HUT	EMERALD	SAPPHIRE	dog	apartment	penny
TENT	mountain	cat	HOTEL	COW	diamond

True Positives: _____/12

False Positive Errors, Related: _____/6 Unrelated: _____/6

Discrimination Index: (# True Positives) – (# False Positives) = _____

APPENDIX 3B:
HOPKINS VERBAL LEARNING TEST (FORM 2)

Hopkins Verbal Learning Test **Version 2**

Name_____________________________ Testing Session: Pr D1 D3 D5 D10 Po

Part A: Free Recall

	Trial 1	Trial 2	Trial 3
FORK	______	______	______
RUM	______	______	______
PAN	______	______	______
PISTOL	______	______	______
SWORD	______	______	______
SPATULA	______	______	______
BOURBON	______	______	______
VODKA	______	______	______
POT	______	______	______
BOMB	______	______	______
RIFLE	______	______	______
WINE	______	______	______
Number Correct	______	______	______

Part B: Recognition

spoon	PISTOL	doll	whiskey	FORK	POT
harmonica	can opener	SWORD	pencil	gun	VODKA
knife	RUM	trout	BOMB	PAN	gold
WINE	lemon	SPATULA	BOURBON	beer	RIFLE

True Positives: _____/12

False-Positive Errors, Related:____/6 Unrelated:_____/6

Discrimination Index: (#True-Positives) - (False-Positives)= _______

Hopkins Verbal Learning Test **Version 2**

Name:________________________ BL D1 D2 D3 D4 D5 ....

Date:_________________________

Part B: Delayed Recall

FORK	____
RUM	____
PAN	____
PISTOL	____
SWORD	____
SPATULA	____
BOURBON	____
VODKA	____
POT	____
BOMB	____
RIFLE	____
WINE	____

Delayed Recall Total Score	

Part C: Recognition

spoon	PISTOL	doll	whiskey	FORK	POT
harmonica	can opener	SWORD	pencil	gun	VODKA
knife	RUM	trout	BOMB	PAN	gold
WINE	lemon	SPATULA	BOURBON	beer	RIFLE

True Positives: _____/12

False Positive Errors, Related: _____/6 Unrelated: _____/6

Discrimination Index: (# True Positives) – (# False Positives) = _____

APPENDIX 3C:
HOPKINS VERBAL LEARNING TEST (FORM 3)

Hopkins Verbal Learning Test **Version 3**

Name____________________________ Testing Session: Pr D1 D3 D5 D10 Po

Part A: Free Recall

	Trial 1	Trial 2	Trial 3
SUGAR	______	______	______
TRUMPET	______	______	______
VIOLIN	______	______	______
COAL	______	______	______
GARLIC	______	______	______
KEROSINE	______	______	______
VANILLA	______	______	______
WOOD	______	______	______
CLARINET	______	______	______
FLUTE	______	______	______
CINNAMON	______	______	______
GASOLINE	______	______	______
Number Correct	______	______	______

Part B: Recognition

pepper	GARLIC	WOOD	drum	oil	SUGAR
ball	salt	priest	chair	COAL	CLARINET
TRUMPET	basement	CINNAMON	FLUTE	electricity	moon
KEROSINE	VANILLA	GASOLINE	sand	piano	VIOLIN

True Positives: _____/12

False-Positive Errors, Related:____/6 Unrelated:_____/6

Discrimination Index: (#True-Positives) - (False-Positives)= _______

Hopkins Verbal Learning Test **Version 3**

Name:_______________________ BL D1 D2 D3 D4 D5 ....

Date:_______________________

Part B: Delayed Recall

SUGAR	____
TRUMPET	____
VIOLIN	____
COAL	____
GARLIC	____
KEROSINE	____
VANILLA	____
WOOD	____
CLARINET	____
FLUTE	____
CINNAMON	____
GASOLINE	____

Delayed Recall Total Score	

Part C: Recognition

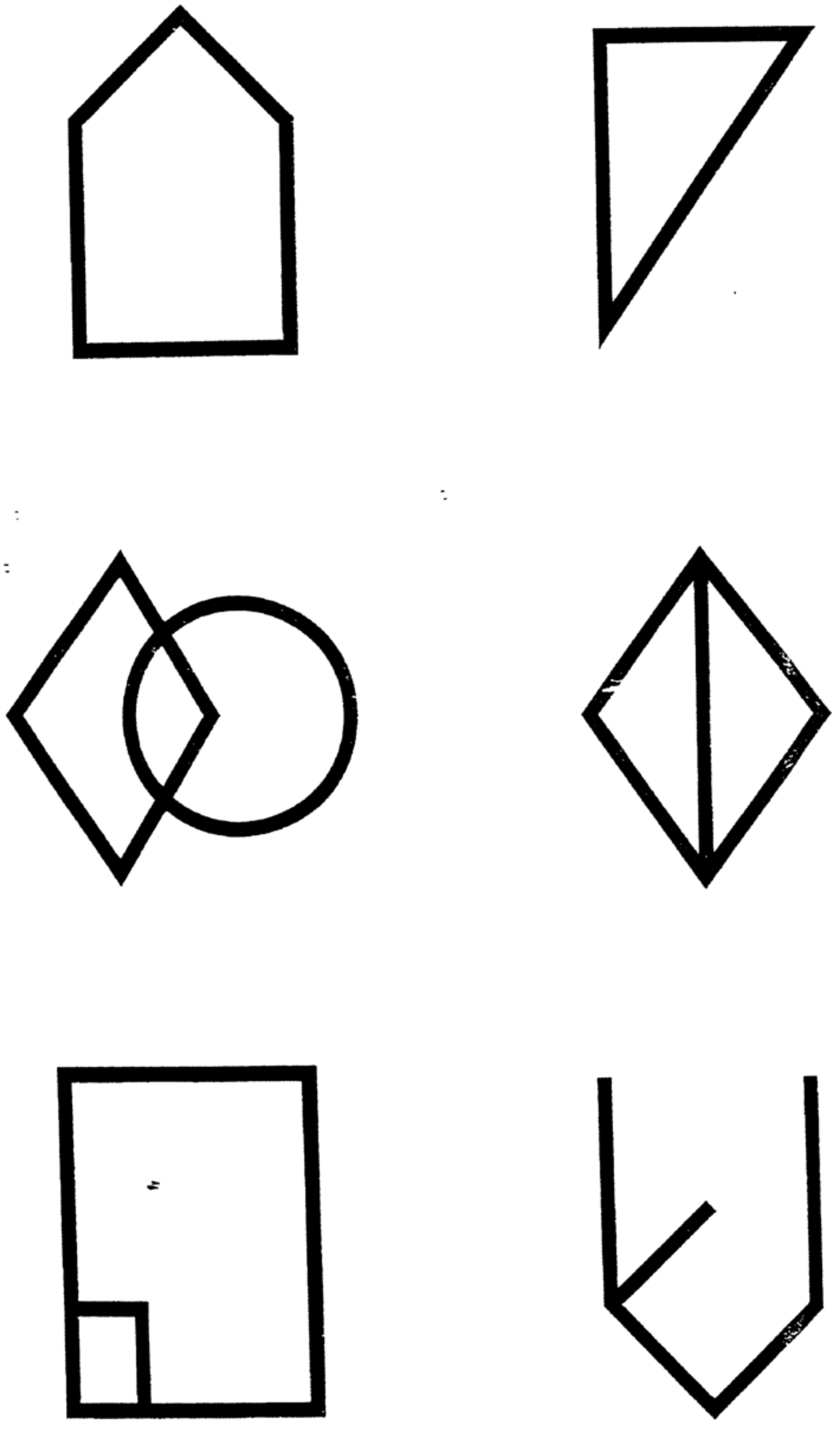
pepper	GARLIC	WOOD	drum	oil	SUGAR
ball	salt	priest	chair	COAL	CLARINET
TRUMPET	basement	CINNAMON	FLUTE	electricity	moon
KEROSINE	VANILLA	GASOLINE	sand	piano	VIOLIN

True Positives: _____/12

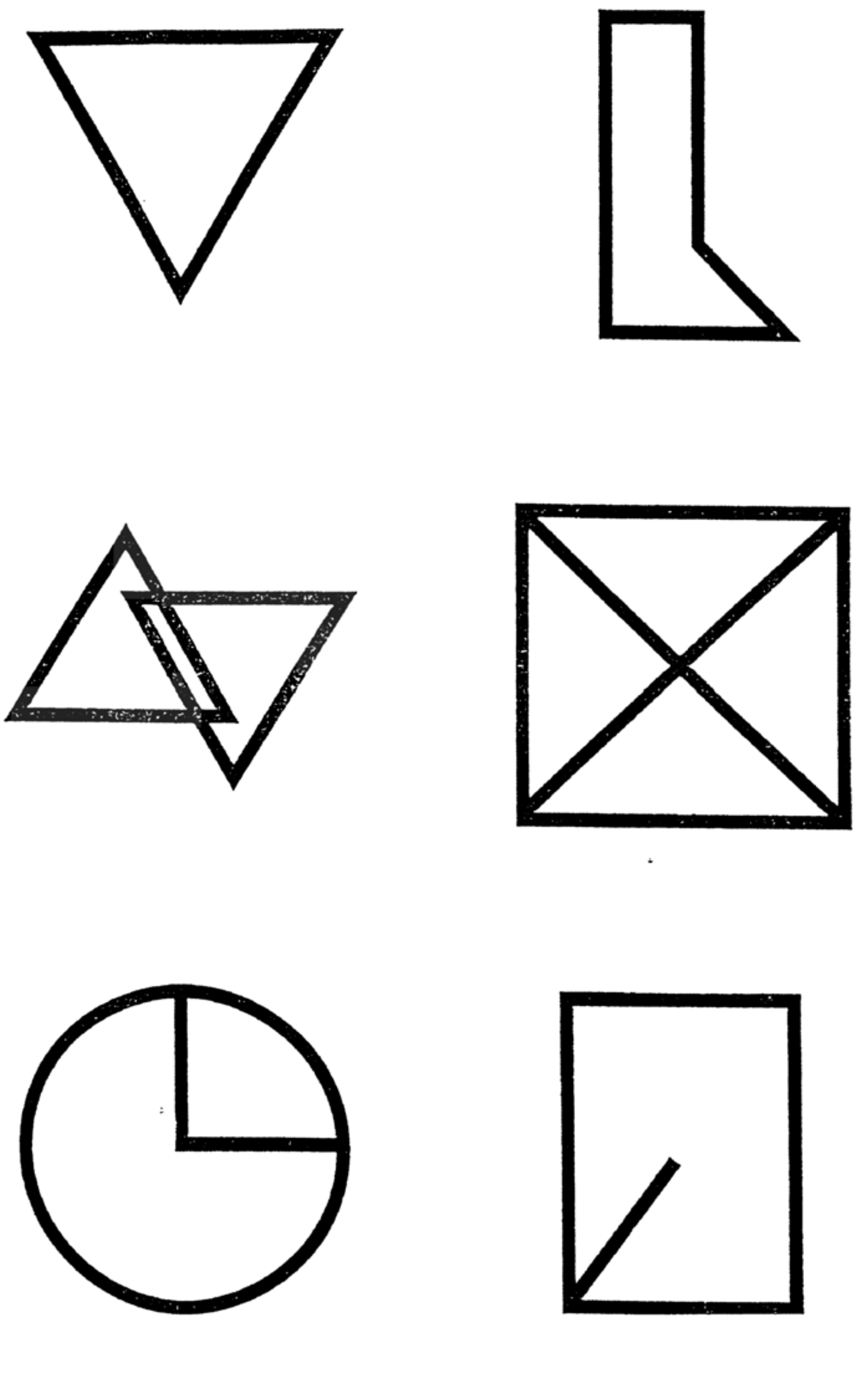
False Positive Errors, Related: _____/6 Unrelated: _____/6

Discrimination Index: (# True Positives) – (# False Positives) = _____

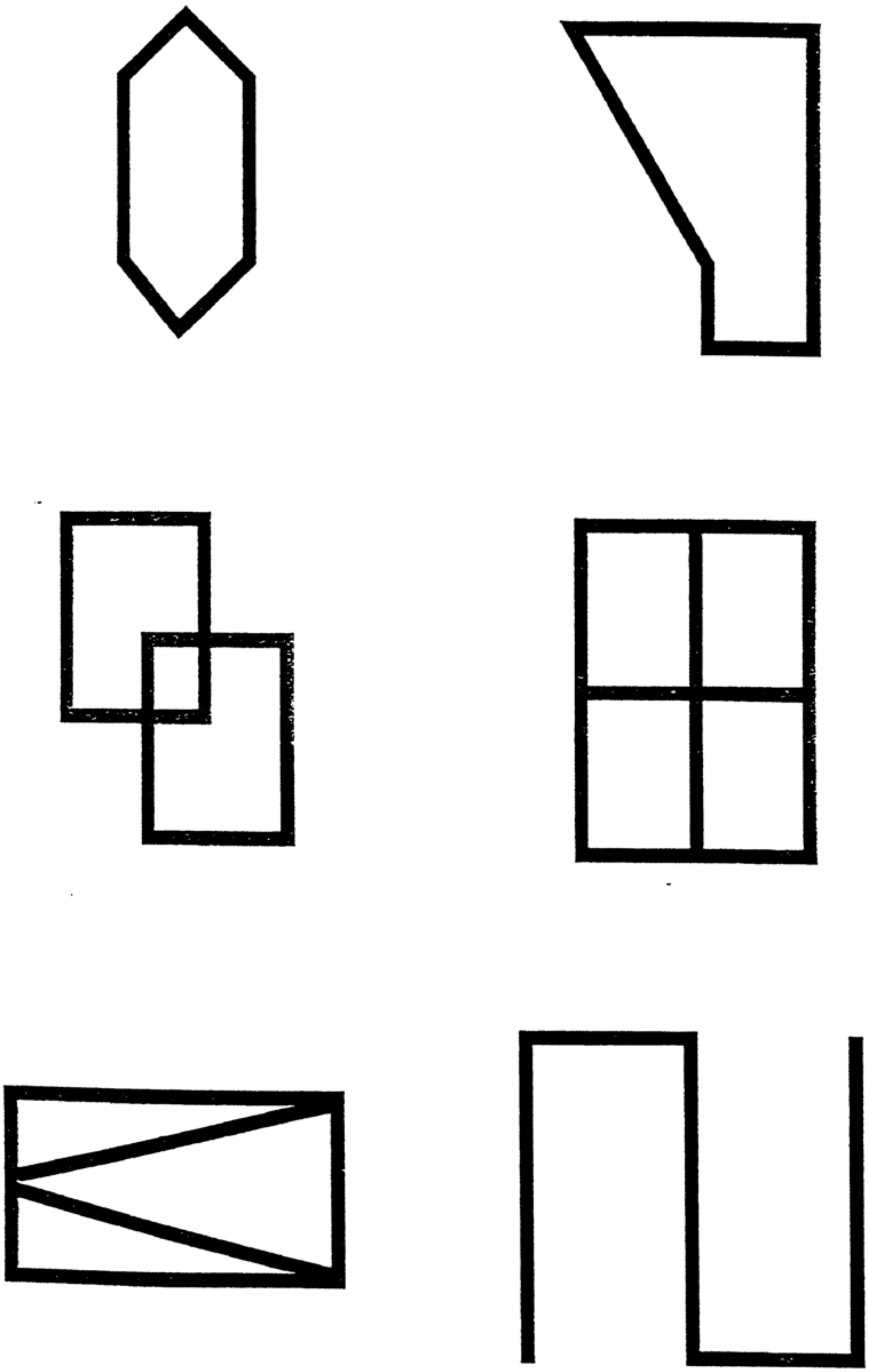
APPENDIX 4A:
BRIEF VISUOSPATIAL MEMORY TEST (FORM 1)



APPENDIX 4B:
BRIEF VISUOSPATIAL MEMORY TEST (FORM 2)



APPENDIX 4C:
BRIEF VISUOSPATIAL MEMORY TEST (FORM 3)



APPENDIX 5:
TRAIL MAKING TEST FORM B

Subject:______________________________

Internal Use Only,
ID No. :_______________

Examiner: ______________________________

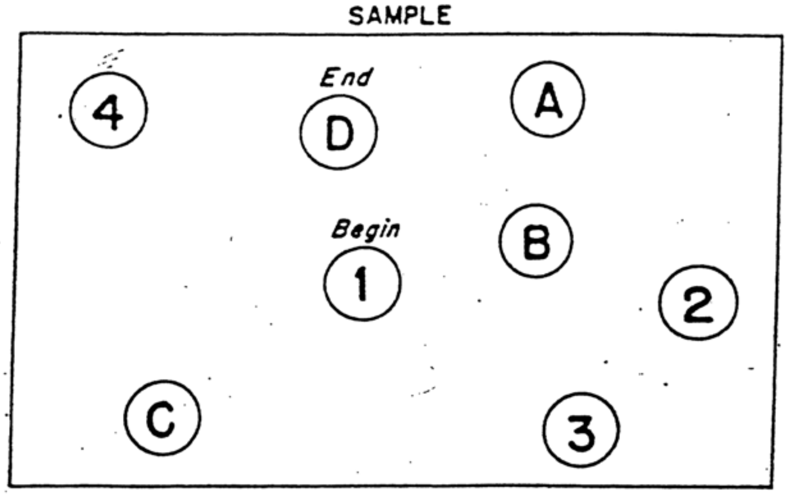
Date: ______ Time: ______ AM PM Testing Session: BL D1 D2 D3 D4 D5 ......

Trail Making Test Part B

Instructions for sample item: This test is somewhat like a connect the dots puzzle. You are to connect the circles in order, alternating between numbers and letters. For example, you draw a line from 1 to A, A to 2, 2 to B and so on (examiner goes through motions of task while explaining instructions out loud).

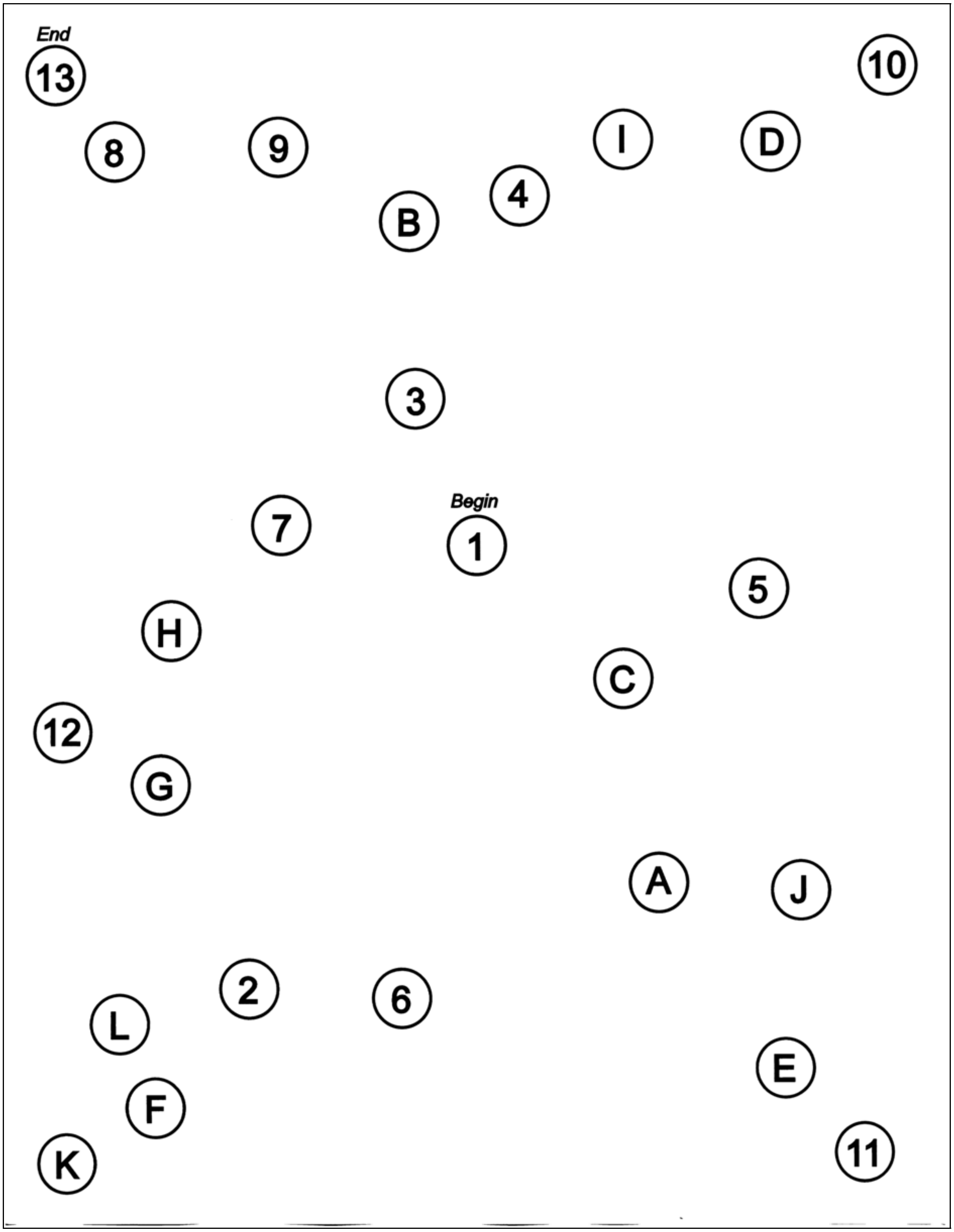
Test Instructions: This is the pattern I want you to follow when we begin the test. Connect the circles in order, alternating from number to letter each time. I want you to work as fast as you can connecting the circles, trying not to make any mistakes, and trying not to lift your pencil from the paper. Remember, you're to go from a number to a letter to a number to a letter until the end.

SAMPLE

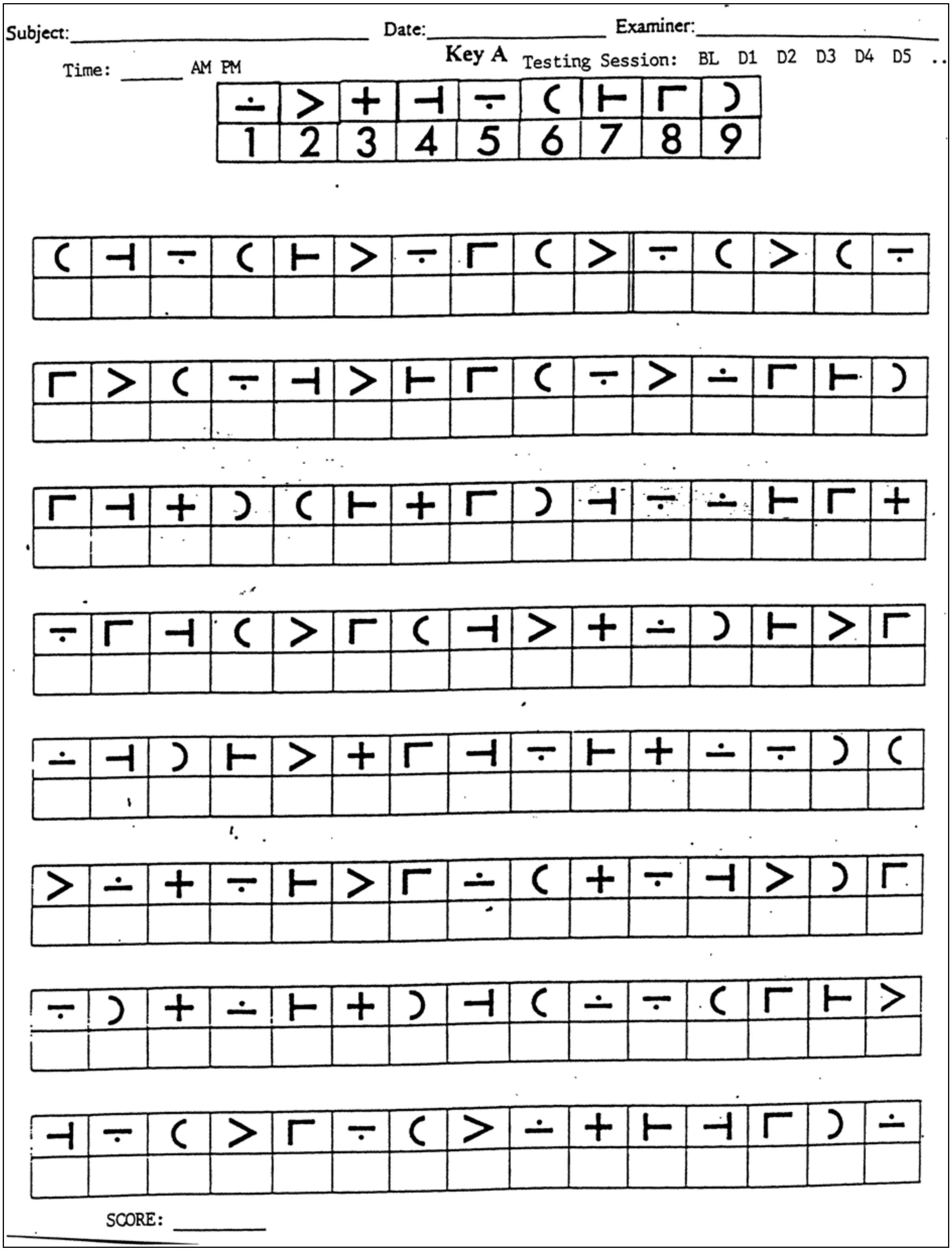


Total Time:_______________ Total Errors:___________

SCORE:__________

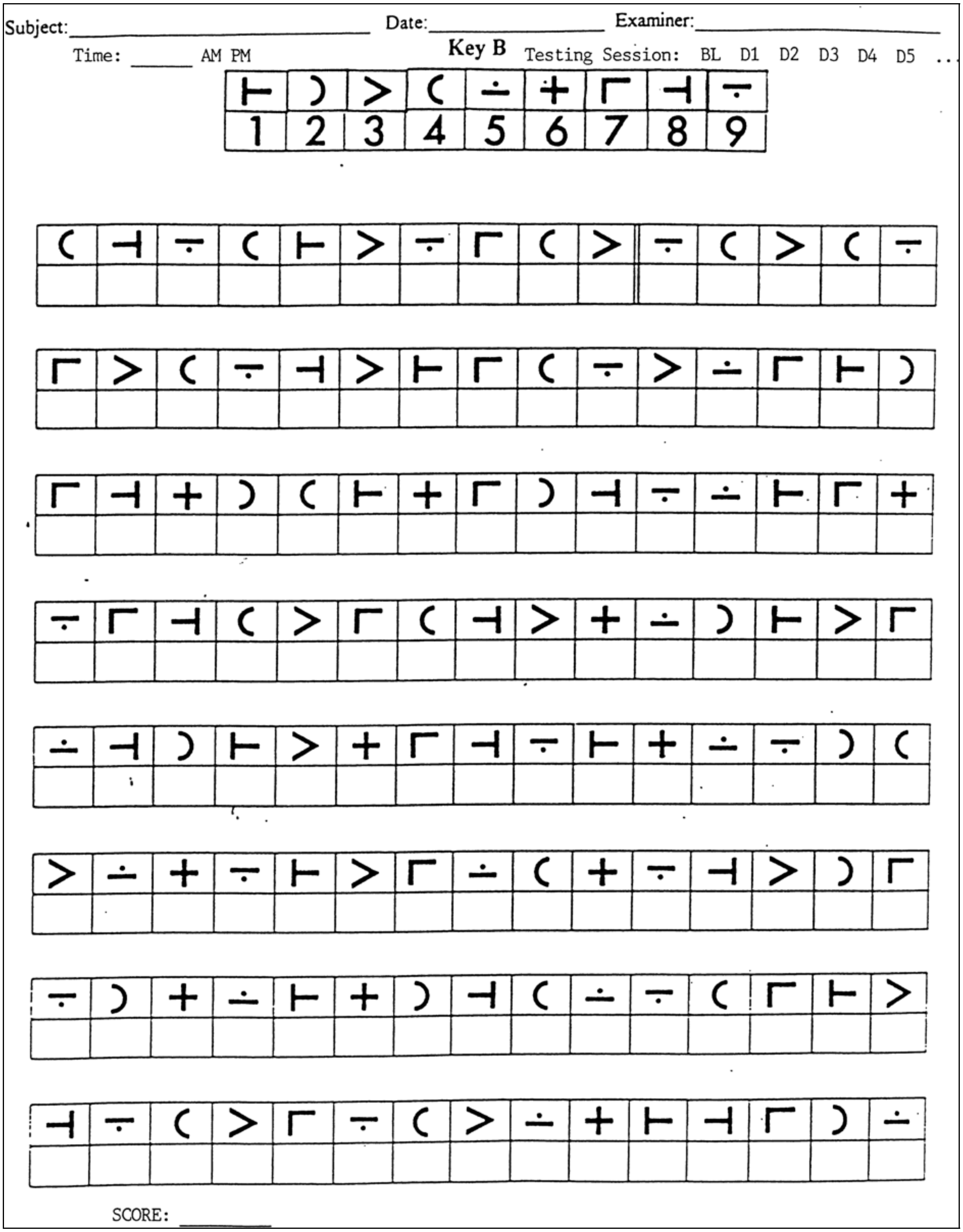

End
13
10
8
9
I
D
4
B
3
Begin
1
7
5
H
C
12
G
A
J
2
6
L
E
F
11
K

APPENDIX 6A:
SYMBOL DIGIT MODALITIES TEST (FORM A)



APPENDIX 6B:

SYMBOL DIGIT MODALITIES TEST (FORM B)


Subject:__________ Date:__________ Examiner:__________

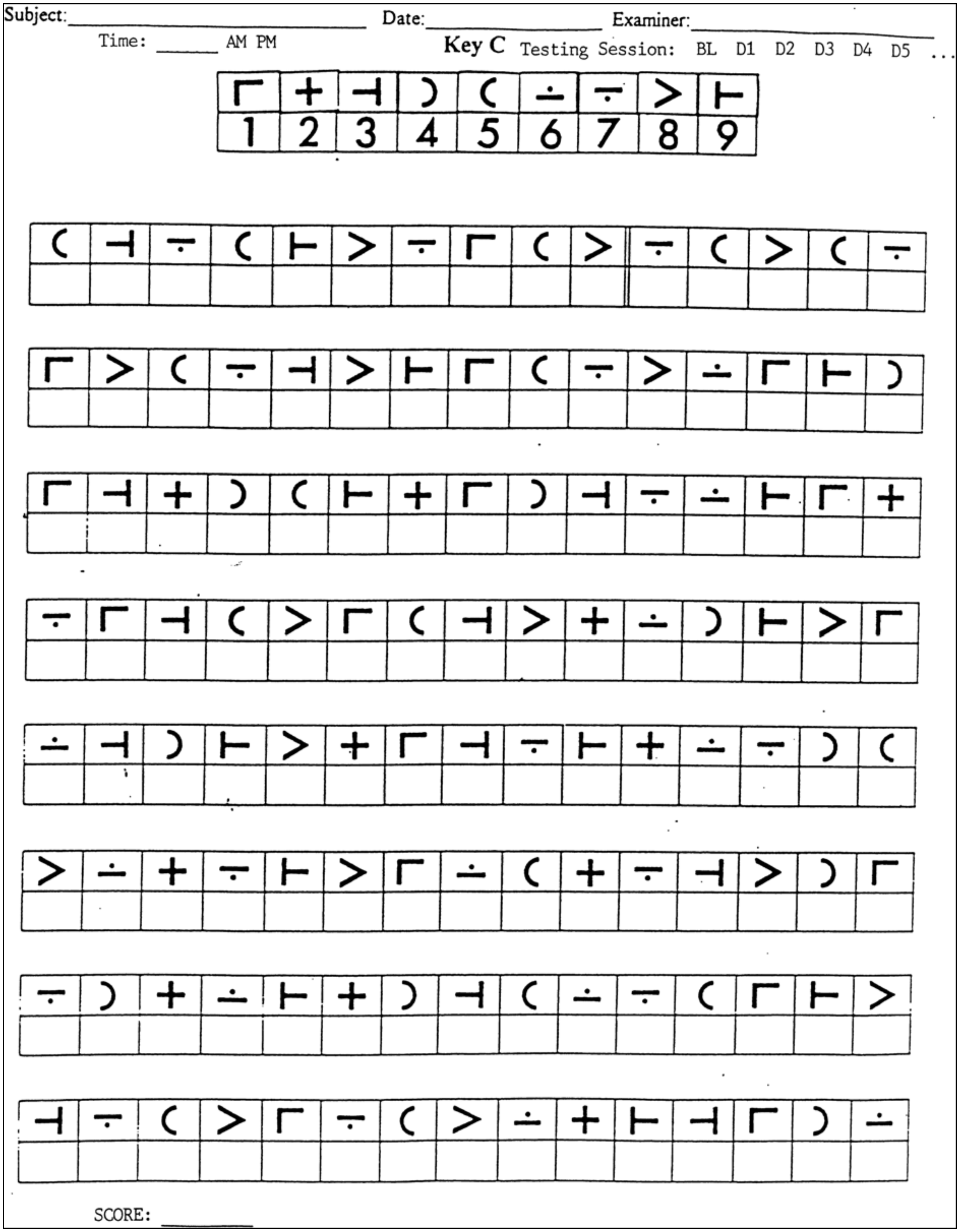
Time: _____ AM PM Key B Testing Session: BL D1 D2 D3 D4 D5 ...

1 2 3 4 5 6 7 8 9

SCORE: ________

APPENDIX 6C:

SYMBOL DIGIT MODALITIES TEST (FORM C)


Subject:______________ Date:__________ Examiner:__________

Time: ______ AM PM

Key C Testing Session: BL D1 D2 D3 D4 D5 ...

1 2 3 4 5 6 7 8 9

SCORE: ________

APPENDIX 7A:
STROOP TEST (SCORE SHEET)

Name: ____________________ Date: _______ Time: ________ AM PM
Examiner: _________________

Testing Session: BL D1 D2 D3 D4 D5 ......

Stroop Color Word Test

<u>Instructions:</u> Place Color-Word card in front of subject and say: **This is a test of how fast you can read the color of ink in which the words on this page are written. When I say go, begin reading down the columns starting with the leftmost column, then going to the second column and so on.** Point to the first and second columns <u>**I want you to name the color of the ink the words are printed in, ignoring the word spelled out.**</u> Point to the first item **This is the first item: what would you say?** If the response is correct go on. If the response is incorrect, say **"No, that is the word spelled out, I want you to say the color of the ink, now try again." Read until I say stop. If you finish reading all the words before I say stop, return to the first column and begin again. Ready, Go ahead.**
Time the subject for <u>45 seconds</u> and say **Stop**.

Below is a key of correct responses for use by the examiner. Each numbered item in the columns corresponds to the correct response to be provided by the subject. If the subject makes a mistake, say **No**, then allow the subject to correct the response. To score, mark the last item completed and enter that number below as the Total Score.

1.	BLUE	21.	RED	41.	BLUE	61.	GREEN	81.	RED
2.	RED	22.	BLUE	42.	GREEN	62.	RED	82.	BLUE
3.	GREEN	23.	GREEN	43.	RED	63.	BLUE	83.	GREEN
4.	BLUE	24.	RED	44.	BLUE	64.	GREEN	84.	RED
5.	GREEN	25.	GREEN	45.	RED	65.	RED	85.	BLUE
6.	RED	26.	BLUE	46.	GREEN	66.	BLUE	86.	GREEN
7.	GREEN	27.	GREEN	47.	RED	67.	GREEN	87.	RED
8.	RED	28.	RED	48.	BLUE	68.	RED	88.	BLUE
9.	BLUE	29.	BLUE	49.	GREEN	69.	BLUE	89.	GREEN
10.	RED	30.	RED	50.	RED	70.	GREEN	90.	BLUE
11.	BLUE	31.	BLUE	51.	GREEN	71.	BLUE	91.	GREEN
12.	GREEN	32.	GREEN	52.	BLUE	72.	RED	92.	RED
13.	RED	33.	BLUE	53.	RED	73.	BLUE	93.	BLUE
14.	GREEN	34.	GREEN	54.	GREEN	74.	RED	94.	GREEN
15.	BLUE	35.	RED	55.	BLUE	75.	GREEN	95.	RED
16.	GREEN	36.	GREEN	56.	GREEN	76.	BLUE	96.	BLUE
17.	BLUE	37.	RED	57.	RED	77.	GREEN	97.	RED
18.	RED	38.	BLUE	58.	BLUE	78.	RED	98.	GREEN
19.	GREEN	39.	RED	59.	GREEN	79.	BLUE	99.	BLUE
20.	BLUE	40.	GREEN	60.	BLUE	80.	RED	100.	RED

Total Score in 45 Seconds: ___________

APPENDIX 7B:
STROOP TEST (WORD SHEET)

RED	BLUE	GREEN	RED	BLUE
GREEN	GREEN	RED	BLUE	GREEN
BLUE	RED	BLUE	GREEN	RED
GREEN	BLUE	RED	RED	BLUE
RED	RED	GREEN	BLUE	GREEN
BLUE	GREEN	BLUE	GREEN	RED
RED	BLUE	GREEN	BLUE	GREEN
BLUE	GREEN	RED	GREEN	RED
GREEN	RED	BLUE	RED	BLUE
BLUE	GREEN	GREEN	BLUE	GREEN
GREEN	RED	BLUE	RED	RED
RED	BLUE	RED	GREEN	BLUE
GREEN	RED	BLUE	RED	GREEN
BLUE	BLUE	RED	GREEN	RED
RED	GREEN	GREEN	BLUE	BLUE
BLUE	BLUE	RED	GREEN	RED
RED	GREEN	BLUE	RED	GREEN
GREEN	RED	GREEN	BLUE	BLUE
RED	BLUE	RED	GREEN	RED
GREEN	RED	GREEN	BLUE	GREEN

APPENDIX 8A:
STATISTICAL ANALYSES – SUBJECT DESCRIPTIVES

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Age	40	6.00	15.00	21.00	18.0000	2.18386
Height (cm)	40	36.48	151.48	187.96	172.5383	9.57294
Weight (kg)	40	52.52	45.00	97.52	70.9808	12.80886
Valid N (listwise)	40					

Descriptive Statistics[a]

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Age	20	2.00	15.00	17.00	16.0000	.85840
Height (cm)	20	33.02	154.94	187.96	171.7675	9.54725
Weight (kg)	20	40.50	45.00	85.50	66.1580	11.83462
Valid N (listwise)	20					

a. Grade = High School

Descriptive Statistics[a]

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Age	20	2.00	19.00	21.00	20.0000	.79472
Height (cm)	20	33.94	151.48	185.42	173.3090	9.78288
Weight (kg)	20	46.72	50.80	97.52	75.8035	12.15503
Valid N (listwise)	20					

a. Grade = College

APPENDIX 8B:
STATISTICAL ANALYSES – OUTCOME MEASURE DESCRIPTIVES (AGE GROUP)

Descriptive Statistics[a]

	N	Minimum	Maximum	Mean	Std. Deviation
HVLT Total Recall	60	21.00	33.00	27.4167	3.56200
HVLT Discrimination Index	60	11.00	12.00	11.8000	.40338
HVLT-D Delayed Recall	60	4.00	12.00	9.8500	2.17712
HVLT-D Discrimination Index	60	8.00	12.00	11.4333	.78905
BVMT Total Recall	60	26.00	36.00	32.9500	2.24307
BVMT Delayed	60	9.00	12.00	11.8000	.54617
TMTB Total Time	60	26.85	91.28	49.6628	14.50246
SDMT Score	60	26.00	56.00	41.1333	5.94742
Stroop Score	60	27.00	89.00	58.9500	12.16890
ImPACT Verbal Memory Composite	60	67.00	100.00	88.3167	7.90943
ImPACT Visual Memory Composite	60	55.00	94.00	79.5500	9.04682
ImPACT Visual Motor Speed Composite	60	24.88	53.65	42.0128	7.36805
ImPACT Reaction Time Composite	60	.41	.68	.5330	.06858
ImPACT Impulse Control Composite	60	.00	33.00	8.9333	5.84218
Valid N (listwise)	60				

a. Grade = High School

Descriptive Statistics[a]

	N	Minimum	Maximum	Mean	Std. Deviation
HVLT Total Recall	60	19.00	35.00	27.2333	3.30570
HVLT Discrimination Index	60	9.00	12.00	11.5667	.76727
HVLT-D Delayed Recall	60	5.00	12.00	10.3333	1.97155
HVLT-D Discrimination Index	60	7.00	12.00	11.3167	1.21421
BVMT Total Recall	60	18.00	36.00	32.4667	3.80217
BVMT Delayed	60	9.00	12.00	11.6833	.74769
TMTB Total Time	60	18.72	79.48	41.4628	13.71495
SDMT Score	60	31.00	59.00	42.4833	6.63706
Stroop Score	60	35.00	85.00	59.5500	11.17871
ImPACT Verbal Memory Composite	60	61.00	100.00	89.4000	8.34266
ImPACT Visual Memory Composite	60	48.00	98.00	81.8167	10.86199
ImPACT Visual Motor Speed Composite	60	31.70	54.75	46.4388	6.47568
ImPACT Reaction Time Composite	60	.39	.76	.5117	.06921
ImPACT Impulse Control Composite	60	.00	19.00	6.6333	4.53972
Valid N (listwise)	60				

a. Grade = College

APPENDIX 8C:
STATISTICAL ANALYSES – 2x3 MIXED MODEL ANOVAs
AGE EFFECTS & PRACTICE EFFECTS

HVLT-R Total Recalled (immediate)

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	HV_total.1.00
2	HV_total.2.00
3	HV_total.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
HV_total.1.00: HVLT Total Recall	High School	26.3000	3.79889	20
	College	27.2000	3.48833	20
	Total	26.7500	3.62859	40
HV_total.2.00: HVLT Total Recall	High School	28.2000	3.25415	20
	College	27.6000	2.77963	20
	Total	27.9000	3.00256	40
HV_total.3.00: HVLT Total Recall	High School	27.7500	3.50751	20
	College	26.9000	3.71200	20
	Total	27.3250	3.59050	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.936	2.441	2	.295	.940	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	26.450	2	13.225	2.676	.075
	Greenhouse-Geisser	26.450	1.880	14.069	2.676	.079
	Huynh-Feldt	26.450	2.000	13.225	2.676	.075
	Lower-bound	26.450	1.000	26.450	2.676	.110
session * Grade	Sphericity Assumed	17.917	2	8.958	1.812	.170
	Greenhouse-Geisser	17.917	1.880	9.530	1.812	.173
	Huynh-Feldt	17.917	2.000	8.958	1.812	.170
	Lower-bound	17.917	1.000	17.917	1.812	.186
Error(session)	Sphericity Assumed	375.633	76	4.943		
	Greenhouse-Geisser	375.633	71.440	5.258		
	Huynh-Feldt	375.633	76.000	4.943		
	Lower-bound	375.633	38.000	9.885		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	89598.675	1	89598.675	3498.090	.000
Grade	1.008	1	1.008	.039	.844
Error	973.317	38	25.614		

HVLT-R Discrimination Index (immediate)

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	HV_discr.1.00
2	HV_discr.2.00
3	HV_discr.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
HV_discr.1.00: HVLT Discrimination Index	High School	11.7500	.44426	20
	College	11.5000	.76089	20
	Total	11.6250	.62788	40
HV_discr.2.00: HVLT Discrimination Index	High School	11.8000	.41039	20
	College	11.6500	.58714	20
	Total	11.7250	.50574	40
HV_discr.3.00: HVLT Discrimination Index	High School	11.8500	.36635	20
	College	11.5500	.94451	20
	Total	11.7000	.72324	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.999	.055	2	.973	.999	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	.217	2	.108	.633	.534
	Greenhouse-Geisser	.217	1.997	.108	.633	.533
	Huynh-Feldt	.217	2.000	.108	.633	.534
	Lower-bound	.217	1.000	.217	.633	.431
session * Grade	Sphericity Assumed	.117	2	.058	.341	.712
	Greenhouse-Geisser	.117	1.997	.058	.341	.712
	Huynh-Feldt	.117	2.000	.058	.341	.712
	Lower-bound	.117	1.000	.117	.341	.563
Error(session)	Sphericity Assumed	13.000	76	.171		
	Greenhouse-Geisser	13.000	75.888	.171		
	Huynh-Feldt	13.000	76.000	.171		
	Lower-bound	13.000	38.000	.342		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	16380.033	1	16380.033	20078.751	.000
Grade	1.633	1	1.633	2.002	.165
Error	31.000	38	.816		

HVLT-R Total Recalled (delayed)

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	HVD_rec.1.00
2	HVD_rec.2.00
3	HVD_rec.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
HVD_rec.1.00: HVLT-D Delayed Recall	High School	9.8000	1.85245	20
	College	10.4000	2.13739	20
	Total	10.1000	1.99743	40
HVD_rec.2.00: HVLT-D Delayed Recall	High School	9.8500	2.10950	20
	College	10.4000	1.72901	20
	Total	10.1250	1.92404	40
HVD_rec.3.00: HVLT-D Delayed Recall	High School	9.9000	2.61373	20
	College	10.2000	2.11760	20
	Total	10.0500	2.35285	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.998	.089	2	.956	.998	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	.117	2	.058	.031	.969
	Greenhouse-Geisser	.117	1.995	.058	.031	.969
	Huynh-Feldt	.117	2.000	.058	.031	.969
	Lower-bound	.117	1.000	.117	.031	.860
session * Grade	Sphericity Assumed	.517	2	.258	.139	.871
	Greenhouse-Geisser	.517	1.995	.259	.139	.870
	Huynh-Feldt	.517	2.000	.258	.139	.871
	Lower-bound	.517	1.000	.517	.139	.711
Error(session)	Sphericity Assumed	141.367	76	1.860		
	Greenhouse-Geisser	141.367	75.817	1.865		
	Huynh-Feldt	141.367	76.000	1.860		
	Lower-bound	141.367	38.000	3.720		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	12221.008	1	12221.008	1265.448	.000
Grade	7.008	1	7.008	.726	.400
Error	366.983	38	9.657		

HVLT-R Discrimination Index (delayed)

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	HVD_discr.1.00
2	HVD_discr.2.00
3	HVD_discr.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
HVD_discr.1.00: HVLT-D Discrimination Index	High School	11.6000	.59824	20
	College	11.3000	1.30182	20
	Total	11.4500	1.01147	40
HVD_discr.2.00: HVLT-D Discrimination Index	High School	11.1500	1.03999	20
	College	11.2500	1.29269	20
	Total	11.2000	1.15913	40
HVD_discr.3.00: HVLT-D Discrimination Index	High School	11.5500	.60481	20
	College	11.4000	1.09545	20
	Total	11.4750	.87669	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.838	6.538	2	.038	.861	.921	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	1.850	2	.925	1.369	.260
	Greenhouse-Geisser	1.850	1.721	1.075	1.369	.260
	Huynh-Feldt	1.850	1.843	1.004	1.369	.260
	Lower-bound	1.850	1.000	1.850	1.369	.249
session * Grade	Sphericity Assumed	.817	2	.408	.605	.549
	Greenhouse-Geisser	.817	1.721	.474	.605	.525
	Huynh-Feldt	.817	1.843	.443	.605	.536
	Lower-bound	.817	1.000	.817	.605	.442
Error(session)	Sphericity Assumed	51.333	76	.675		
	Greenhouse-Geisser	51.333	65.405	.785		
	Huynh-Feldt	51.333	70.019	.733		
	Lower-bound	51.333	38.000	1.351		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	15526.875	1	15526.875	8463.131	.000
Grade	.408	1	.408	.223	.640
Error	69.717	38	1.835		

BVMT-R Total Recalled (immediate)

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	BV_tot.1.00
2	BV_tot.2.00
3	BV_tot.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
BV_tot.1.00: BVMT Total Recall	High School	32.7500	2.78860	20
	College	32.2500	3.98517	20
	Total	32.5000	3.40437	40
BV_tot.2.00: BVMT Total Recall	High School	33.4500	1.46808	20
	College	33.3500	2.77726	20
	Total	33.4000	2.19323	40
BV_tot.3.00: BVMT Total Recall	High School	32.6500	2.30046	20
	College	31.8000	4.46743	20
	Total	32.2250	3.53363	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.948	1.964	2	.375	.951	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	30.217	2	15.108	3.199	.046
	Greenhouse-Geisser	30.217	1.902	15.889	3.199	.049
	Huynh-Feldt	30.217	2.000	15.108	3.199	.046
	Lower-bound	30.217	1.000	30.217	3.199	.082
session * Grade	Sphericity Assumed	2.817	2	1.408	.298	.743
	Greenhouse-Geisser	2.817	1.902	1.481	.298	.732
	Huynh-Feldt	2.817	2.000	1.408	.298	.743
	Lower-bound	2.817	1.000	2.817	.298	.588
Error(session)	Sphericity Assumed	358.967	76	4.723		
	Greenhouse-Geisser	358.967	72.265	4.967		
	Huynh-Feldt	358.967	76.000	4.723		
	Lower-bound	358.967	38.000	9.446		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	128380.208	1	128380.208	6437.787	.000
Grade	7.008	1	7.008	.351	.557
Error	757.783	38	19.942		

BVMT-R Total Recalled (delayed)

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	BV_del.1.00
2	BV_del.2.00
3	BV_del.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
BV_del.1.00: BVMT Delayed	High School	11.8500	.48936	20
	College	11.7500	.78640	20
	Total	11.8000	.64847	40
BV_del.2.00: BVMT Delayed	High School	11.9000	.30779	20
	College	11.8500	.36635	20
	Total	11.8750	.33493	40
BV_del.3.00: BVMT Delayed	High School	11.6500	.74516	20
	College	11.4500	.94451	20
	Total	11.5500	.84580	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.808	7.900	2	.019	.839	.896	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	2.317	2	1.158	3.356	.040
	Greenhouse-Geisser	2.317	1.677	1.381	3.356	.049
	Huynh-Feldt	2.317	1.792	1.293	3.356	.046
	Lower-bound	2.317	1.000	2.317	3.356	.075
session * Grade	Sphericity Assumed	.117	2	.058	.169	.845
	Greenhouse-Geisser	.117	1.677	.070	.169	.807
	Huynh-Feldt	.117	1.792	.065	.169	.822
	Lower-bound	.117	1.000	.117	.169	.683
Error(session)	Sphericity Assumed	26.233	76	.345		
	Greenhouse-Geisser	26.233	63.745	.412		
	Huynh-Feldt	26.233	68.106	.385		
	Lower-bound	26.233	38.000	.690		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	16544.008	1	16544.008	28684.668	.000
Grade	.408	1	.408	.708	.405
Error	21.917	38	.577		

TMT-B Total Time

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	TM_time.1.00
2	TM_time.2.00
3	TM_time.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
TM_time.1.00: TMTB Total Time	High School	61.4290	13.79373	20
	College	50.0395	14.52637	20
	Total	55.7343	15.12475	40
TM_time.2.00: TMTB Total Time	High School	47.3565	9.49168	20
	College	40.6120	12.12984	20
	Total	43.9843	11.27984	40
TM_time.3.00: TMTB Total Time	High School	40.2030	11.27906	20
	College	33.7370	9.21566	20
	Total	36.9700	10.68051	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.846	6.204	2	.045	.866	.928	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	7191.457	2	3595.729	73.432	.000
	Greenhouse-Geisser	7191.457	1.733	4150.826	73.432	.000
	Huynh-Feldt	7191.457	1.856	3875.339	73.432	.000
	Lower-bound	7191.457	1.000	7191.457	73.432	.000
session * Grade	Sphericity Assumed	152.981	2	76.491	1.562	.216
	Greenhouse-Geisser	152.981	1.733	88.299	1.562	.219
	Huynh-Feldt	152.981	1.856	82.439	1.562	.218
	Lower-bound	152.981	1.000	152.981	1.562	.219
Error(session)	Sphericity Assumed	3721.476	76	48.967		
	Greenhouse-Geisser	3721.476	65.836	56.526		
	Huynh-Feldt	3721.476	70.517	52.775		
	Lower-bound	3721.476	38.000	97.934		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	249116.614	1	249116.614	760.910	.000
Grade	2017.200	1	2017.200	6.161	.018
Error	12440.929	38	327.393		

SDMT Total Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	SDMT.1.00
2	SDMT.2.00
3	SDMT.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
SDMT.1.00: SDMT Score	High School	41.0000	5.84898	20
	College	42.6000	6.54860	20
	Total	41.8000	6.18186	40
SDMT.2.00: SDMT Score	High School	40.4500	6.25321	20
	College	42.1500	7.68645	20
	Total	41.3000	6.96953	40
SDMT.3.00: SDMT Score	High School	41.9500	5.94249	20
	College	42.7000	5.88575	20
	Total	42.3250	5.85021	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.945	2.096	2	.351	.948	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	21.017	2	10.508	.909	.407
	Greenhouse-Geisser	21.017	1.896	11.087	.909	.403
	Huynh-Feldt	21.017	2.000	10.508	.909	.407
	Lower-bound	21.017	1.000	21.017	.909	.346
session * Grade	Sphericity Assumed	5.450	2	2.725	.236	.790
	Greenhouse-Geisser	5.450	1.896	2.875	.236	.779
	Huynh-Feldt	5.450	2.000	2.725	.236	.790
	Lower-bound	5.450	1.000	5.450	.236	.630
Error(session)	Sphericity Assumed	878.200	76	11.555		
	Greenhouse-Geisser	878.200	72.033	12.192		
	Huynh-Feldt	878.200	76.000	11.555		
	Lower-bound	878.200	38.000	23.111		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	209752.408	1	209752.408	2107.925	.000
Grade	54.675	1	54.675	.549	.463
Error	3781.250	38	99.507		

Stroop Test Total Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	Stroop.1.00
2	Stroop.2.00
3	Stroop.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
Stroop.1.00: Stroop Score	High School	52.9500	10.85539	20
	College	52.9000	7.90003	20
	Total	52.9250	9.37095	40
Stroop.2.00: Stroop Score	High School	59.9500	11.27865	20
	College	61.2000	10.49611	20
	Total	60.5750	10.77244	40
Stroop.3.00: Stroop Score	High School	63.9500	12.22799	20
	College	64.5500	11.82092	20
	Total	64.2500	11.87488	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.871	5.124	2	.077	.885	.950	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	2670.450	2	1335.225	96.851	.000
	Greenhouse-Geisser	2670.450	1.771	1507.908	96.851	.000
	Huynh-Feldt	2670.450	1.900	1405.431	96.851	.000
	Lower-bound	2670.450	1.000	2670.450	96.851	.000
session * Grade	Sphericity Assumed	8.450	2	4.225	.306	.737
	Greenhouse-Geisser	8.450	1.771	4.771	.306	.710
	Huynh-Feldt	8.450	1.900	4.447	.306	.726
	Lower-bound	8.450	1.000	8.450	.306	.583
Error(session)	Sphericity Assumed	1047.767	76	13.786		
	Greenhouse-Geisser	1047.767	67.297	15.569		
	Huynh-Feldt	1047.767	72.204	14.511		
	Lower-bound	1047.767	38.000	27.573		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	421267.500	1	421267.500	1292.750	.000
Grade	10.800	1	10.800	.033	.857
Error	12383.033	38	325.869		

ImPACT Verbal Memory Composite Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	ImP_verb.1.00
2	ImP_verb.2.00
3	ImP_verb.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
ImP_verb.1.00: ImPACT Verbal Memory Composite	High School	89.2000	7.72964	20
	College	90.0500	6.47648	20
	Total	89.6250	7.05178	40
ImP_verb.2.00: ImPACT Verbal Memory Composite	High School	86.6500	8.44347	20
	College	90.3000	7.34919	20
	Total	88.4750	8.02875	40
ImP_verb.3.00: ImPACT Verbal Memory Composite	High School	89.1000	7.67017	20
	College	87.8500	10.78632	20
	Total	88.4750	9.25975	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.983	.646	2	.724	.983	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	35.267	2	17.633	.373	.690
	Greenhouse-Geisser	35.267	1.966	17.939	.373	.686
	Huynh-Feldt	35.267	2.000	17.633	.373	.690
	Lower-bound	35.267	1.000	35.267	.373	.545
session * Grade	Sphericity Assumed	120.867	2	60.433	1.278	.284
	Greenhouse-Geisser	120.867	1.966	61.480	1.278	.284
	Huynh-Feldt	120.867	2.000	60.433	1.278	.284
	Lower-bound	120.867	1.000	120.867	1.278	.265
Error(session)	Sphericity Assumed	3593.200	76	47.279		
	Greenhouse-Geisser	3593.200	74.706	48.098		
	Huynh-Feldt	3593.200	76.000	47.279		
	Lower-bound	3593.200	38.000	94.558		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	947496.408	1	947496.408	8894.372	.000
Grade	35.208	1	35.208	.331	.569
Error	4048.050	38	106.528		

ImPACT Visual Memory Composite Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	ImP_vis.1.00
2	ImP_vis.2.00
3	ImP_vis.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
ImP_vis.1.00: ImPACT Visual Memory Composite	High School	78.4000	9.33809	20
	College	79.5000	13.02831	20
	Total	78.9500	11.20199	40
ImP_vis.2.00: ImPACT Visual Memory Composite	High School	79.9500	10.45026	20
	College	82.9500	9.72504	20
	Total	81.4500	10.07905	40
ImP_vis.3.00: ImPACT Visual Memory Composite	High School	80.3000	7.45583	20
	College	83.0000	9.67362	20
	Total	81.6500	8.63371	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.956	1.666	2	.435	.958	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	181.067	2	90.533	1.629	.203
	Greenhouse-Geisser	181.067	1.916	94.519	1.629	.204
	Huynh-Feldt	181.067	2.000	90.533	1.629	.203
	Lower-bound	181.067	1.000	181.067	1.629	.210
session * Grade	Sphericity Assumed	20.867	2	10.433	.188	.829
	Greenhouse-Geisser	20.867	1.916	10.893	.188	.820
	Huynh-Feldt	20.867	2.000	10.433	.188	.829
	Lower-bound	20.867	1.000	20.867	.188	.667
Error(session)	Sphericity Assumed	4222.733	76	55.562		
	Greenhouse-Geisser	4222.733	72.795	58.008		
	Huynh-Feldt	4222.733	76.000	55.562		
	Lower-bound	4222.733	38.000	111.125		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	781176.033	1	781176.033	4030.417	.000
Grade	154.133	1	154.133	.795	.378
Error	7365.167	38	193.820		

ImPACT Processing Speed Composite Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	ImP_mot.1.00
2	ImP_mot.2.00
3	ImP_mot.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
ImP_mot.1.00: ImPACT Visual Motor Speed Composite	High School	39.4285	7.88060	20
	College	45.8050	6.02695	20
	Total	42.6168	7.64053	40
ImP_mot.2.00: ImPACT Visual Motor Speed Composite	High School	43.0335	7.36348	20
	College	46.8645	7.09152	20
	Total	44.9490	7.39450	40
ImP_mot.3.00: ImPACT Visual Motor Speed Composite	High School	43.5765	6.44623	20
	College	46.6470	6.55320	20
	Total	45.1118	6.60176	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.882	4.643	2	.098	.895	.960	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	155.879	2	77.939	5.806	.005
	Greenhouse-Geisser	155.879	1.789	87.131	5.806	.006
	Huynh-Feldt	155.879	1.921	81.146	5.806	.005
	Lower-bound	155.879	1.000	155.879	5.806	.021
session * Grade	Sphericity Assumed	59.959	2	29.979	2.233	.114
	Greenhouse-Geisser	59.959	1.789	33.515	2.233	.120
	Huynh-Feldt	59.959	1.921	31.213	2.233	.116
	Lower-bound	59.959	1.000	59.959	2.233	.143
Error(session)	Sphericity Assumed	1020.305	76	13.425		
	Greenhouse-Geisser	1020.305	67.982	15.008		
	Huynh-Feldt	1020.305	72.997	13.977		
	Lower-bound	1020.305	38.000	26.850		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	234710.920	1	234710.920	2008.337	.000
Grade	587.684	1	587.684	5.029	.031
Error	4440.995	38	116.868		

ImPACT Reaction Time Composite Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	ImP_rt.1.00
2	ImP_rt.2.00
3	ImP_rt.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
ImP_rt.1.00: ImPACT Reaction Time Composite	High School	.5450	.06460	20
	College	.5200	.05903	20
	Total	.5325	.06238	40
ImP_rt.2.00: ImPACT Reaction Time Composite	High School	.5235	.06192	20
	College	.5070	.07908	20
	Total	.5153	.07060	40
ImP_rt.3.00: ImPACT Reaction Time Composite	High School	.5305	.07964	20
	College	.5080	.07090	20
	Total	.5193	.07529	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.905	3.679	2	.159	.914	.983	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	.007	2	.003	2.012	.141
	Greenhouse-Geisser	.007	1.827	.004	2.012	.145
	Huynh-Feldt	.007	1.965	.003	2.012	.142
	Lower-bound	.007	1.000	.007	2.012	.164
session * Grade	Sphericity Assumed	.000	2	.000	.118	.889
	Greenhouse-Geisser	.000	1.827	.000	.118	.872
	Huynh-Feldt	.000	1.965	.000	.118	.886
	Lower-bound	.000	1.000	.000	.118	.733
Error(session)	Sphericity Assumed	.123	76	.002		
	Greenhouse-Geisser	.123	69.429	.002		
	Huynh-Feldt	.123	74.674	.002		
	Lower-bound	.123	38.000	.003		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	32.740	1	32.740	2893.110	.000
Grade	.014	1	.014	1.206	.279
Error	.430	38	.011		

ImPACT Impulse Control Composite Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	ImP_imp.1.00
2	ImP_imp.2.00
3	ImP_imp.3.00

Between-Subjects Factors

		Value Label	N
Grade	1.00	High School	20
	2.00	College	20

Descriptive Statistics

	Grade	Mean	Std. Deviation	N
ImP_imp.1.00: ImPACT Impulse Control Composite	High School	9.2000	5.39590	20
	College	6.2000	4.31155	20
	Total	7.7000	5.05457	40
ImP_imp.2.00: ImPACT Impulse Control Composite	High School	8.8500	7.51332	20
	College	6.6500	4.13299	20
	Total	7.7500	6.08803	40
ImP_imp.3.00: ImPACT Impulse Control Composite	High School	8.7500	4.50584	20
	College	7.0500	5.28628	20
	Total	7.9000	4.92404	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.963	1.399	2	.497	.964	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept+Grade
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	.867	2	.433	.039	.961
	Greenhouse-Geisser	.867	1.928	.449	.039	.958
	Huynh-Feldt	.867	2.000	.433	.039	.961
	Lower-bound	.867	1.000	.867	.039	.844
session * Grade	Sphericity Assumed	8.600	2	4.300	.390	.678
	Greenhouse-Geisser	8.600	1.928	4.460	.390	.671
	Huynh-Feldt	8.600	2.000	4.300	.390	.678
	Lower-bound	8.600	1.000	8.600	.390	.536
Error(session)	Sphericity Assumed	837.200	76	11.016		
	Greenhouse-Geisser	837.200	73.280	11.425		
	Huynh-Feldt	837.200	76.000	11.016		
	Lower-bound	837.200	38.000	22.032		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	7269.633	1	7269.633	115.924	.000
Grade	158.700	1	158.700	2.531	.120
Error	2383.000	38	62.711		

APPENDIX 8D:

STATISTICAL ANALYSES – $ICC_{2,1}$ and SEM
PERFORMANCE CONSISTENCY

Formulas

$$ICC(2,1) = \frac{BMS - EMS}{BMS + (k-1)EMS + \frac{k(WMS - EMS)}{n}}$$

$$SEM = S\sqrt{1 - ICC}$$

HVLT-R Total Recalled (immediate)

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	HV_total.1.00
2	HV_total.2.00
3	HV_total.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
HV_total.1.00: HVLT Total Recall	26.7500	3.62859	40
HV_total.2.00: HVLT Total Recall	27.9000	3.00256	40
HV_total.3.00: HVLT Total Recall	27.3250	3.59050	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.919	3.201	2	.202	.925	.969	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	26.450	2	13.225	2.621	.079
	Greenhouse-Geisser	26.450	1.851	14.293	2.621	.084
	Huynh-Feldt	26.450	1.939	13.643	2.621	.081
	Lower-bound	26.450	1.000	26.450	2.621	.114
Error(session)	Sphericity Assumed	393.550	78	5.046		
	Greenhouse-Geisser	393.550	72.170	5.453		
	Huynh-Feldt	393.550	75.608	5.205		
	Lower-bound	393.550	39.000	10.091		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	89598.675	1	89598.675	3586.430	.000
Error	974.325	39	24.983		

HVLT-R Discrimination Index (immediate)

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	HV_discr.1.00
2	HV_discr.2.00
3	HV_discr.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
HV_discr.1.00: HVLT Discrimination Index	11.6250	.62788	40
HV_discr.2.00: HVLT Discrimination Index	11.7250	.50574	40
HV_discr.3.00: HVLT Discrimination Index	11.7000	.72324	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.999	.055	2	.973	.999	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	.217	2	.108	.644	.528
	Greenhouse-Geisser	.217	1.997	.108	.644	.528
	Huynh-Feldt	.217	2.000	.108	.644	.528
	Lower-bound	.217	1.000	.217	.644	.427
Error(session)	Sphericity Assumed	13.117	78	.168		
	Greenhouse-Geisser	13.117	77.888	.168		
	Huynh-Feldt	13.117	78.000	.168		
	Lower-bound	13.117	39.000	.336		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	16380.033	1	16380.033	19575.729	.000
Error	32.633	39	.837		

HVLT-R Total Recalled (delayed)

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	HVD_rec.1.00
2	HVD_rec.2.00
3	HVD_rec.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
HVD_rec.1.00: HVLT-D Delayed Recall	10.1000	1.99743	40
HVD_rec.2.00: HVLT-D Delayed Recall	10.1250	1.92404	40
HVD_rec.3.00: HVLT-D Delayed Recall	10.0500	2.35285	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.998	.079	2	.961	.998	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	.117	2	.058	.032	.968
	Greenhouse-Geisser	.117	1.996	.058	.032	.968
	Huynh-Feldt	.117	2.000	.058	.032	.968
	Lower-bound	.117	1.000	.117	.032	.859
Error(session)	Sphericity Assumed	141.883	78	1.819		
	Greenhouse-Geisser	141.883	77.839	1.823		
	Huynh-Feldt	141.883	78.000	1.819		
	Lower-bound	141.883	39.000	3.638		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	12221.008	1	12221.008	1274.412	.000
Error	373.992	39	9.590		

HVLT-R Discrimination Index (delayed)

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	HVD_discr.1.00
2	HVD_discr.2.00
3	HVD_discr.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
HVD_discr.1.00: HVLT-D Discrimination Index	11.4500	1.01147	40
HVD_discr.2.00: HVLT-D Discrimination Index	11.2000	1.15913	40
HVD_discr.3.00: HVLT-D Discrimination Index	11.4750	.87669	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.831	7.021	2	.030	.856	.891	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	1.850	2	.925	1.384	.257
	Greenhouse-Geisser	1.850	1.711	1.081	1.384	.257
	Huynh-Feldt	1.850	1.782	1.038	1.384	.257
	Lower-bound	1.850	1.000	1.850	1.384	.247
Error(session)	Sphericity Assumed	52.150	78	.669		
	Greenhouse-Geisser	52.150	66.740	.781		
	Huynh-Feldt	52.150	69.501	.750		
	Lower-bound	52.150	39.000	1.337		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	15526.875	1	15526.875	8635.267	.000
Error	70.125	39	1.798		

BVMT-R Total Recalled (immediate)

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	BV_tot.1.00
2	BV_tot.2.00
3	BV_tot.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
BV_tot.1.00: BVMT Total Recall	32.5000	3.40437	40
BV_tot.2.00: BVMT Total Recall	33.4000	2.19323	40
BV_tot.3.00: BVMT Total Recall	32.2250	3.53363	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.949	2.003	2	.367	.951	.999	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	30.217	2	15.108	3.257	.044
	Greenhouse-Geisser	30.217	1.902	15.884	3.257	.046
	Huynh-Feldt	30.217	1.997	15.129	3.257	.044
	Lower-bound	30.217	1.000	30.217	3.257	.079
Error(session)	Sphericity Assumed	361.783	78	4.638		
	Greenhouse-Geisser	361.783	74.190	4.876		
	Huynh-Feldt	361.783	77.892	4.645		
	Lower-bound	361.783	39.000	9.276		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	128380.208	1	128380.208	6546.656	.000
Error	764.792	39	19.610		

BVMT-R Total Recalled (delayed)

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	BV_del.1.00
2	BV_del.2.00
3	BV_del.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
BV_del.1.00: BVMT Delayed	11.8000	.64847	40
BV_del.2.00: BVMT Delayed	11.8750	.33493	40
BV_del.3.00: BVMT Delayed	11.5500	.84580	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.806	8.184	2	.017	.838	.871	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	2.317	2	1.158	3.429	.037
	Greenhouse-Geisser	2.317	1.675	1.383	3.429	.046
	Huynh-Feldt	2.317	1.742	1.330	3.429	.044
	Lower-bound	2.317	1.000	2.317	3.429	.072
Error(session)	Sphericity Assumed	26.350	78	.338		
	Greenhouse-Geisser	26.350	65.341	.403		
	Huynh-Feldt	26.350	67.934	.388		
	Lower-bound	26.350	39.000	.676		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	16544.008	1	16544.008	28901.067	.000
Error	22.325	39	.572		

TMT-B Total Time

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	TM_time.1.00
2	TM_time.2.00
3	TM_time.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
TM_time.1.00: TMTB Total Time	55.7343	15.12475	40
TM_time.2.00: TMTB Total Time	43.9843	11.27984	40
TM_time.3.00: TMTB Total Time	36.9700	10.68051	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.828	7.153	2	.028	.854	.889	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	7191.457	2	3595.729	72.389	.000
	Greenhouse-Geisser	7191.457	1.707	4212.666	72.389	.000
	Huynh-Feldt	7191.457	1.777	4046.070	72.389	.000
	Lower-bound	7191.457	1.000	7191.457	72.389	.000
Error(session)	Sphericity Assumed	3874.458	78	49.673		
	Greenhouse-Geisser	3874.458	66.577	58.195		
	Huynh-Feldt	3874.458	69.318	55.894		
	Lower-bound	3874.458	39.000	99.345		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	249116.614	1	249116.614	671.978	.000
Error	14458.129	39	370.721		

SDMT Total Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	SDMT.1.00
2	SDMT.2.00
3	SDMT.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
SDMT.1.00: SDMT Score	41.8000	6.18186	40
SDMT.2.00: SDMT Score	41.3000	6.96953	40
SDMT.3.00: SDMT Score	42.3250	5.85021	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Epsilon[a] Huynh-Feldt	Epsilon[a] Lower-bound
session	.944	2.205	2	.332	.947	.993	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	21.017	2	10.508	.928	.400
	Greenhouse-Geisser	21.017	1.893	11.101	.928	.396
	Huynh-Feldt	21.017	1.987	10.577	.928	.399
	Lower-bound	21.017	1.000	21.017	.928	.341
Error(session)	Sphericity Assumed	883.650	78	11.329		
	Greenhouse-Geisser	883.650	73.837	11.968		
	Huynh-Feldt	883.650	77.492	11.403		
	Lower-bound	883.650	39.000	22.658		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	209752.408	1	209752.408	2132.561	.000
Error	3835.925	39	98.357		

Stroop Test Total Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	Stroop.1.00
2	Stroop.2.00
3	Stroop.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
Stroop.1.00: Stroop Score	52.9250	9.37095	40
Stroop.2.00: Stroop Score	60.5750	10.77244	40
Stroop.3.00: Stroop Score	64.2500	11.87488	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.876	5.049	2	.080	.889	.929	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	2670.450	2	1335.225	98.604	.000
	Greenhouse-Geisser	2670.450	1.779	1501.367	98.604	.000
	Huynh-Feldt	2670.450	1.858	1437.480	98.604	.000
	Lower-bound	2670.450	1.000	2670.450	98.604	.000
Error(session)	Sphericity Assumed	1056.217	78	13.541		
	Greenhouse-Geisser	1056.217	69.368	15.226		
	Huynh-Feldt	1056.217	72.451	14.578		
	Lower-bound	1056.217	39.000	27.082		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	421267.500	1	421267.500	1325.613	.000
Error	12393.833	39	317.791		

ImPACT Verbal Memory Composite Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	ImP_verb.1.00
2	ImP_verb.2.00
3	ImP_verb.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
ImP_verb.1.00: ImPACT Verbal Memory Composite	89.6250	7.05178	40
ImP_verb.2.00: ImPACT Verbal Memory Composite	88.4750	8.02875	40
ImP_verb.3.00: ImPACT Verbal Memory Composite	88.4750	9.25975	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.975	.976	2	.614	.975	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	35.267	2	17.633	.370	.692
	Greenhouse-Geisser	35.267	1.951	18.081	.370	.686
	Huynh-Feldt	35.267	2.000	17.633	.370	.692
	Lower-bound	35.267	1.000	35.267	.370	.546
Error(session)	Sphericity Assumed	3714.067	78	47.616		
	Greenhouse-Geisser	3714.067	76.071	48.824		
	Huynh-Feldt	3714.067	78.000	47.616		
	Lower-bound	3714.067	39.000	95.232		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	947496.408	1	947496.408	9049.724	.000
Error	4083.258	39	104.699		

ImPACT Visual Memory Composite Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	ImP_vis.1.00
2	ImP_vis.2.00
3	ImP_vis.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
ImP_vis.1.00: ImPACT Visual Memory Composite	78.9500	11.20199	40
ImP_vis.2.00: ImPACT Visual Memory Composite	81.4500	10.07905	40
ImP_vis.3.00: ImPACT Visual Memory Composite	81.6500	8.63371	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.955	1.734	2	.420	.957	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	181.067	2	90.533	1.664	.196
	Greenhouse-Geisser	181.067	1.915	94.571	1.664	.197
	Huynh-Feldt	181.067	2.000	90.533	1.664	.196
	Lower-bound	181.067	1.000	181.067	1.664	.205
Error(session)	Sphericity Assumed	4243.600	78	54.405		
	Greenhouse-Geisser	4243.600	74.670	56.832		
	Huynh-Feldt	4243.600	78.000	54.405		
	Lower-bound	4243.600	39.000	108.810		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	781176.033	1	781176.033	4051.689	.000
Error	7519.300	39	192.803		

ImPACT Processing Speed Composite Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	ImP_mot.1.00
2	ImP_mot.2.00
3	ImP_mot.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
ImP_mot.1.00: ImPACT Visual Motor Speed Composite	42.6168	7.64053	40
ImP_mot.2.00: ImPACT Visual Motor Speed Composite	44.9490	7.39450	40
ImP_mot.3.00: ImPACT Visual Motor Speed Composite	45.1118	6.60176	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.881	4.805	2	.090	.894	.934	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	155.879	2	77.939	5.628	.005
	Greenhouse-Geisser	155.879	1.788	87.197	5.628	.007
	Huynh-Feldt	155.879	1.868	83.454	5.628	.006
	Lower-bound	155.879	1.000	155.879	5.628	.023
Error(session)	Sphericity Assumed	1080.263	78	13.850		
	Greenhouse-Geisser	1080.263	69.719	15.495		
	Huynh-Feldt	1080.263	72.845	14.830		
	Lower-bound	1080.263	39.000	27.699		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	234710.920	1	234710.920	1820.304	.000
Error	5028.679	39	128.940		

ImPACT Reaction Time Composite Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	ImP_rt.1.00
2	ImP_rt.2.00
3	ImP_rt.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
ImP_rt.1.00: ImPACT Reaction Time Composite	.5325	.06238	40
ImP_rt.2.00: ImPACT Reaction Time Composite	.5153	.07060	40
ImP_rt.3.00: ImPACT Reaction Time Composite	.5193	.07529	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.908	3.683	2	.159	.915	.958	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	.007	2	.003	2.059	.134
	Greenhouse-Geisser	.007	1.831	.004	2.059	.139
	Huynh-Feldt	.007	1.917	.003	2.059	.137
	Lower-bound	.007	1.000	.007	2.059	.159
Error(session)	Sphericity Assumed	.124	78	.002		
	Greenhouse-Geisser	.124	71.405	.002		
	Huynh-Feldt	.124	74.744	.002		
	Lower-bound	.124	39.000	.003		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	32.740	1	32.740	2877.872	.000
Error	.444	39	.011		

ImPACT Impulse Control Composite Score

Within-Subjects Factors

Measure: MEASURE_1

session	Dependent Variable
1	ImP_imp.1.00
2	ImP_imp.2.00
3	ImP_imp.3.00

Descriptive Statistics

	Mean	Std. Deviation	N
ImP_imp.1.00: ImPACT Impusle Control Composite	7.7000	5.05457	40
ImP_imp.2.00: ImPACT Impusle Control Composite	7.7500	6.08803	40
ImP_imp.3.00: ImPACT Impusle Control Composite	7.9000	4.92404	40

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
session	.967	1.280	2	.527	.968	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: session

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
session	Sphericity Assumed	.867	2	.433	.040	.961
	Greenhouse-Geisser	.867	1.936	.448	.040	.957
	Huynh-Feldt	.867	2.000	.433	.040	.961
	Lower-bound	.867	1.000	.867	.040	.843
Error(session)	Sphericity Assumed	845.800	78	10.844		
	Greenhouse-Geisser	845.800	75.500	11.203		
	Huynh-Feldt	845.800	78.000	10.844		
	Lower-bound	845.800	39.000	21.687		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	7269.633	1	7269.633	111.546	.000
Error	2541.700	39	65.172		

APPENDIX 8E:
STATISTICAL ANALYSES – LINEAR REGRESSIONS
PREDICTIVE ABILITY

HVLT-R Percent Recognized (immediate) &
ImPACT Word Memory Learning Percent Correct

Session 1

Descriptive Statistics[a]

	Mean	Std. Deviation	N
HVLT % Recongized	98.4370	2.61626	40
ImPACT Word Memory Learning % Correct	98.0000	3.26599	40

a. Test Day = Day 1

Correlations[a]

		HVLT % Recongized	ImPACT Word Memory Learning % Correct
Pearson Correlation	HVLT % Recongized	1.000	.175
	ImPACT Word Memory Learning % Correct	.175	1.000
Sig. (1-tailed)	HVLT % Recongized	.	.140
	ImPACT Word Memory Learning % Correct	.140	.
N	HVLT % Recongized	40	40
	ImPACT Word Memory Learning % Correct	40	40

a. Test Day = Day 1

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Word Memory Learning % Correct[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: HVLT % Recongized

c. Test Day = Day 1

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.175[a]	.031	.005	2.60961

a. Predictors: (Constant), ImPACT Word Memory Learning % Correct

b. Test Day = Day 1

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8.165	1	8.165	1.199	.280[a]
	Residual	258.783	38	6.810		
	Total	266.948	39			

a. Predictors: (Constant), ImPACT Word Memory Learning % Correct

b. Dependent Variable: HVLT % Recongized

c. Test Day = Day 1

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	84.708	12.546		6.752	.000
	ImPACT Word Memory Learning % Correct	.140	.128	.175	1.095	.280

a. Dependent Variable: HVLT % Recongized

b. Test Day = Day 1

HVLT-R Percent Recognized (immediate) &
ImPACT Word Memory Learning Percent Correct

Session 2

Descriptive Statistics[a]

	Mean	Std. Deviation	N
HVLT % Recongized	98.8535	2.10805	40
ImPACT Word Memory Learning % Correct	94.6000	6.46410	40

a. Test Day = Day 2

Correlations[a]

		HVLT % Recongized	ImPACT Word Memory Learning % Correct
Pearson Correlation	HVLT % Recongized	1.000	-.019
	ImPACT Word Memory Learning % Correct	-.019	1.000
Sig. (1-tailed)	HVLT % Recongized	.	.454
	ImPACT Word Memory Learning % Correct	.454	.
N	HVLT % Recongized	40	40
	ImPACT Word Memory Learning % Correct	40	40

a. Test Day = Day 2

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Word Memory Learning % Correct[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: HVLT % Recongized

c. Test Day = Day 2

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.019[a]	.000	-.026	2.13523

a. Predictors: (Constant), ImPACT Word Memory Learning % Correct

b. Test Day = Day 2

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.061	1	.061	.013	.909[a]
	Residual	173.250	38	4.559		
	Total	173.311	39			

a. Predictors: (Constant), ImPACT Word Memory Learning % Correct

b. Dependent Variable: HVLT % Recongized

c. Test Day = Day 2

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	99.431	5.015		19.826	.000
	ImPACT Word Memory Learning % Correct	-.006	.053	-.019	-.115	.909

a. Dependent Variable: HVLT % Recongized

b. Test Day = Day 2

HVLT-R Percent Recognized (immediate) &
ImPACT Word Memory Learning Percent Correct

Session 3

Descriptive Statistics[a]

	Mean	Std. Deviation	N
HVLT % Recongized	98.7495	3.01400	40
ImPACT Word Memory Learning % Correct	94.3750	6.73943	40

a. Test Day = Day 3

Correlations[a]

		HVLT % Recongized	ImPACT Word Memory Learning % Correct
Pearson Correlation	HVLT % Recongized	1.000	.413
	ImPACT Word Memory Learning % Correct	.413	1.000
Sig. (1-tailed)	HVLT % Recongized	.	.004
	ImPACT Word Memory Learning % Correct	.004	.
N	HVLT % Recongized	40	40
	ImPACT Word Memory Learning % Correct	40	40

a. Test Day = Day 3

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Word Memory Learning % Correct[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: HVLT % Recongized

c. Test Day = Day 3

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.413[a]	.171	.149	2.78077

a. Predictors: (Constant), ImPACT Word Memory Learning % Correct

b. Test Day = Day 3

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	60.442	1	60.442	7.816	.008[a]
	Residual	293.842	38	7.733		
	Total	354.283	39			

a. Predictors: (Constant), ImPACT Word Memory Learning % Correct

b. Dependent Variable: HVLT % Recongized

c. Test Day = Day 3

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	81.317	6.251		13.009	.000
	ImPACT Word Memory Learning % Correct	.185	.066	.413	2.796	.008

a. Dependent Variable: HVLT % Recongized

b. Test Day = Day 3

HVLT-R Percent Recognized (delayed) &
ImPACT Word Memory Delayed Memory Percent Correct

Session 1

Descriptive Statistics[a]

	Mean	Std. Deviation	N
HVLT-D % Recognized	97.7078	4.21423	40
ImPACT Word Memory Delayed Memory % Correct	92.4000	5.99059	40

a. Test Day = Day 1

Correlations[a]

		HVLT-D % Recognized	ImPACT Word Memory Delayed Memory % Correct
Pearson Correlation	HVLT-D % Recognized	1.000	.156
	ImPACT Word Memory Delayed Memory % Correct	.156	1.000
Sig. (1-tailed)	HVLT-D % Recognized	.	.169
	ImPACT Word Memory Delayed Memory % Correct	.169	.
N	HVLT-D % Recognized	40	40
	ImPACT Word Memory Delayed Memory % Correct	40	40

a. Test Day = Day 1

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Word Memory Delayed Memory % Correct[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: HVLT-D % Recognized

c. Test Day = Day 1

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.156[a]	.024	-.001	4.21725

a. Predictors: (Constant), ImPACT Word Memory Delayed Memory % Correct

b. Test Day = Day 1

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16.792	1	16.792	.944	.337[a]
	Residual	675.837	38	17.785		
	Total	692.629	39			

a. Predictors: (Constant), ImPACT Word Memory Delayed Memory % Correct

b. Dependent Variable: HVLT-D % Recognized

c. Test Day = Day 1

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	87.587	10.437		8.392	.000
	ImPACT Word Memory Delayed Memory % Correct	.110	.113	.156	.972	.337

a. Dependent Variable: HVLT-D % Recognized

b. Test Day = Day 1

HVLT-R Percent Recognized (delayed) &
ImPACT Word Memory Delayed Memory Percent Correct

Session 2

Descriptive Statistics[a]

	Mean	Std. Deviation	N
HVLT-D % Recognized	96.6660	4.82947	40
ImPACT Word Memory Delayed Memory % Correct	85.2500	11.66355	40

a. Test Day = Day 2

Correlations[a]

		HVLT-D % Recognized	ImPACT Word Memory Delayed Memory % Correct
Pearson Correlation	HVLT-D % Recognized	1.000	.243
	ImPACT Word Memory Delayed Memory % Correct	.243	1.000
Sig. (1-tailed)	HVLT-D % Recognized	.	.066
	ImPACT Word Memory Delayed Memory % Correct	.066	.
N	HVLT-D % Recognized	40	40
	ImPACT Word Memory Delayed Memory % Correct	40	40

a. Test Day = Day 2

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Word Memory Delayed Memory % Correct[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: HVLT-D % Recognized

c. Test Day = Day 2

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.243[a]	.059	.034	4.74617

a. Predictors: (Constant), ImPACT Word Memory Delayed Memory % Correct

b. Test Day = Day 2

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	53.635	1	53.635	2.381	.131[a]
	Residual	855.993	38	22.526		
	Total	909.628	39			

a. Predictors: (Constant), ImPACT Word Memory Delayed Memory % Correct

b. Dependent Variable: HVLT-D % Recognized

c. Test Day = Day 2

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	88.095	5.605		15.716	.000
	ImPACT Word Memory Delayed Memory % Correct	.101	.065	.243	1.543	.131

a. Dependent Variable: HVLT-D % Recognized

b. Test Day = Day 2

HVLT-R Percent Recognized (delayed) &
ImPACT Word Memory Delayed Memory Percent Correct

Session 3

Descriptive Statistics[a]

	Mean	Std. Deviation	N
HVLT-D % Recognized	97.8115	3.65364	40
ImPACT Word Memory Delayed Memory % Correct	86.5750	12.69542	40

a. Test Day = Day 3

Correlations[a]

		HVLT-D % Recognized	ImPACT Word Memory Delayed Memory % Correct
Pearson Correlation	HVLT-D % Recognized	1.000	-.103
	ImPACT Word Memory Delayed Memory % Correct	-.103	1.000
Sig. (1-tailed)	HVLT-D % Recognized	.	.263
	ImPACT Word Memory Delayed Memory % Correct	.263	.
N	HVLT-D % Recognized	40	40
	ImPACT Word Memory Delayed Memory % Correct	40	40

a. Test Day = Day 3

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Word Memory Delayed Memory % Correct[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: HVLT-D % Recognized

c. Test Day = Day 3

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.103[a]	.011	-.015	3.68152

a. Predictors: (Constant), ImPACT Word Memory Delayed Memory % Correct

b. Test Day = Day 3

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.576	1	5.576	.411	.525[a]
	Residual	515.037	38	13.554		
	Total	520.613	39			

a. Predictors: (Constant), ImPACT Word Memory Delayed Memory % Correct

b. Dependent Variable: HVLT-D % Recognized

c. Test Day = Day 3

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	100.390	4.062		24.714	.000
	ImPACT Word Memory Delayed Memory % Correct	-.030	.046	-.103	-.641	.525

a. Dependent Variable: HVLT-D % Recognized

b. Test Day = Day 3

BVMT-R Percent Recalled (immediate) &
ImPACT Design Memory Learning Percent Correct

Session 1

Descriptive Statistics[a]

	Mean	Std. Deviation	N
BVMT % Recalled	90.2775	9.45617	40
ImPACT Design Memory Learning % Correct	84.3500	9.69681	40

a. Test Day = Day 1

Correlations[a]

		BVMT % Recalled	ImPACT Design Memory Learning % Correct
Pearson Correlation	BVMT % Recalled	1.000	.498
	ImPACT Design Memory Learning % Correct	.498	1.000
Sig. (1-tailed)	BVMT % Recalled	.	.001
	ImPACT Design Memory Learning % Correct	.001	.
N	BVMT % Recalled	40	40
	ImPACT Design Memory Learning % Correct	40	40

a. Test Day = Day 1

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Design Memory Learning % Correct[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: BVMT % Recalled

c. Test Day = Day 1

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.498[a]	.248	.228	8.30792

a. Predictors: (Constant), ImPACT Design Memory Learning % Correct

b. Test Day = Day 1

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	864.526	1	864.526	12.525	.001[a]
	Residual	2622.820	38	69.022		
	Total	3487.346	39			

a. Predictors: (Constant), ImPACT Design Memory Learning % Correct

b. Dependent Variable: BVMT % Recalled

c. Test Day = Day 1

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	49.322	11.647		4.235	.000
	ImPACT Design Memory Learning % Correct	.486	.137	.498	3.539	.001

a. Dependent Variable: BVMT % Recalled

b. Test Day = Day 1

BVMT-R Percent Recalled (immediate) &
ImPACT Design Memory Learning Percent Correct

Session 2

Descriptive Statistics[a]

	Mean	Std. Deviation	N
BVMT % Recalled	92.7765	6.09189	40
ImPACT Design Memory Learning % Correct	85.3000	9.05312	40

a. Test Day = Day 2

Correlations[a]

		BVMT % Recalled	ImPACT Design Memory Learning % Correct
Pearson Correlation	BVMT % Recalled	1.000	.348
	ImPACT Design Memory Learning % Correct	.348	1.000
Sig. (1-tailed)	BVMT % Recalled	.	.014
	ImPACT Design Memory Learning % Correct	.014	.
N	BVMT % Recalled	40	40
	ImPACT Design Memory Learning % Correct	40	40

a. Test Day = Day 2

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Design Memory Learning % Correct[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: BVMT % Recalled

c. Test Day = Day 2

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.348[a]	.121	.098	5.78644

a. Predictors: (Constant), ImPACT Design Memory Learning % Correct

b. Test Day = Day 2

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	174.987	1	174.987	5.226	.028[a]
	Residual	1272.349	38	33.483		
	Total	1447.336	39			

a. Predictors: (Constant), ImPACT Design Memory Learning % Correct

b. Dependent Variable: BVMT % Recalled

c. Test Day = Day 2

Coefficients[a,b]

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	72.818	8.778		8.295	.000
	ImPACT Design Memory Learning % Correct	.234	.102	.348	2.286	.028

a. Dependent Variable: BVMT % Recalled

b. Test Day = Day 2

BVMT-R Percent Recalled (immediate) &
ImPACT Design Memory Learning Percent Correct

Session 3

Descriptive Statistics[a]

	Mean	Std. Deviation	N
BVMT % Recalled	89.5128	9.81402	40
ImPACT Design Memory Learning % Correct	89.2750	8.89248	40

a. Test Day = Day 3

Correlations[a]

		BVMT % Recalled	ImPACT Design Memory Learning % Correct
Pearson Correlation	BVMT % Recalled	1.000	.356
	ImPACT Design Memory Learning % Correct	.356	1.000
Sig. (1-tailed)	BVMT % Recalled	.	.012
	ImPACT Design Memory Learning % Correct	.012	.
N	BVMT % Recalled	40	40
	ImPACT Design Memory Learning % Correct	40	40

a. Test Day = Day 3

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Design Memory Learning % Correct[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: BVMT % Recalled

c. Test Day = Day 3

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.356[a]	.127	.104	9.29011

a. Predictors: (Constant), ImPACT Design Memory Learning % Correct

b. Test Day = Day 3

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	476.653	1	476.653	5.523	.024[a]
	Residual	3279.631	38	86.306		
	Total	3756.284	39			

a. Predictors: (Constant), ImPACT Design Memory Learning % Correct

b. Dependent Variable: BVMT % Recalled

c. Test Day = Day 3

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	54.415	15.007		3.626	.001
	ImPACT Design Memory Learning % Correct	.393	.167	.356	2.350	.024

a. Dependent Variable: BVMT % Recalled

b. Test Day = Day 3

BVMT-R Percent Recalled (delayed) &
ImPACT Design Memory Delayed Memory Percent Correct

Session 1

Descriptive Statistics[a]

	Mean	Std. Deviation	N
BVMT % Delayed Recall	98.3333	5.40428	40
ImPACT Design Memory Delayed Memory % Correct	81.1000	11.40355	40

a. Test Day = Day 1

Correlations[a]

		BVMT % Delayed Recall	ImPACT Design Memory Delayed Memory % Correct
Pearson Correlation	BVMT % Delayed Recall	1.000	.353
	ImPACT Design Memory Delayed Memory % Correct	.353	1.000
Sig. (1-tailed)	BVMT % Delayed Recall	.	.013
	ImPACT Design Memory Delayed Memory % Correct	.013	.
N	BVMT % Delayed Recall	40	40
	ImPACT Design Memory Delayed Memory % Correct	40	40

a. Test Day = Day 1

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Design Memory Delayed Memory % Correct[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: BVMT % Delayed Recall

c. Test Day = Day 1

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.353[a]	.125	.102	5.12244

a. Predictors: (Constant), ImPACT Design Memory Delayed Memory % Correct

b. Test Day = Day 1

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	141.947	1	141.947	5.410	.025[a]
	Residual	997.098	38	26.239		
	Total	1139.044	39			

a. Predictors: (Constant), ImPACT Design Memory Delayed Memory % Correct

b. Dependent Variable: BVMT % Delayed Recall

c. Test Day = Day 1

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	84.765	5.889		14.393	.000
	ImPACT Design Memory Delayed Memory % Correct	.167	.072	.353	2.326	.025

a. Dependent Variable: BVMT % Delayed Recall

b. Test Day = Day 1

BVMT-R Percent Recalled (delayed) &
ImPACT Design Memory Delayed Memory Percent Correct

Session 2

Descriptive Statistics[a]

	Mean	Std. Deviation	N
BVMT % Delayed Recall	98.9588	2.78998	40
ImPACT Design Memory Delayed Memory % Correct	82.2750	9.37259	40

a. Test Day = Day 2

Correlations[a]

		BVMT % Delayed Recall	ImPACT Design Memory Delayed Memory % Correct
Pearson Correlation	BVMT % Delayed Recall	1.000	-.013
	ImPACT Design Memory Delayed Memory % Correct	-.013	1.000
Sig. (1-tailed)	BVMT % Delayed Recall	.	.468
	ImPACT Design Memory Delayed Memory % Correct	.468	.
N	BVMT % Delayed Recall	40	40
	ImPACT Design Memory Delayed Memory % Correct	40	40

a. Test Day = Day 2

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Design Memory Delayed Memory % Correct[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: BVMT % Delayed Recall

c. Test Day = Day 2

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.013[a]	.000	-.026	2.82621

a. Predictors: (Constant), ImPACT Design Memory Delayed Memory % Correct

b. Test Day = Day 2

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.053	1	.053	.007	.935[a]
	Residual	303.523	38	7.987		
	Total	303.576	39			

a. Predictors: (Constant), ImPACT Design Memory Delayed Memory % Correct

b. Dependent Variable: BVMT % Delayed Recall

c. Test Day = Day 2

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	99.284	3.998		24.835	.000
	ImPACT Design Memory Delayed Memory % Correct	-.004	.048	-.013	-.082	.935

a. Dependent Variable: BVMT % Delayed Recall

b. Test Day = Day 2

BVMT-R Percent Recalled (delayed) &
ImPACT Design Memory Delayed Memory Percent Correct

Session 3

Descriptive Statistics[a]

	Mean	Std. Deviation	N
BVMT % Delayed Recall	96.2503	7.04850	40
ImPACT Design Memory Delayed Memory % Correct	85.0500	10.53188	40

a. Test Day = Day 3

Correlations[a]

		BVMT % Delayed Recall	ImPACT Design Memory Delayed Memory % Correct
Pearson Correlation	BVMT % Delayed Recall	1.000	.230
	ImPACT Design Memory Delayed Memory % Correct	.230	1.000
Sig. (1-tailed)	BVMT % Delayed Recall	.	.077
	ImPACT Design Memory Delayed Memory % Correct	.077	.
N	BVMT % Delayed Recall	40	40
	ImPACT Design Memory Delayed Memory % Correct	40	40

a. Test Day = Day 3

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Design Memory Delayed Memory % Correct[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: BVMT % Delayed Recall

c. Test Day = Day 3

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.230[a]	.053	.028	6.94922

a. Predictors: (Constant), ImPACT Design Memory Delayed Memory % Correct

b. Test Day = Day 3

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	102.492	1	102.492	2.122	.153[a]
	Residual	1835.083	38	48.292		
	Total	1937.575	39			

a. Predictors: (Constant), ImPACT Design Memory Delayed Memory % Correct

b. Dependent Variable: BVMT % Delayed Recall

c. Test Day = Day 3

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	83.159	9.053		9.186	.000
	ImPACT Design Memory Delayed Memory % Correct	.154	.106	.230	1.457	.153

a. Dependent Variable: BVMT % Delayed Recall

b. Test Day = Day 3

TMT-B Total Time &
ImPACT Three Letters Average Counted Correctly

Session 1

Descriptive Statistics[a]

	Mean	Std. Deviation	N
TMTB Total Time	55.7343	15.12475	40
ImPACT Three Letters Avg Counted Correctly	17.6200	4.80914	40

a. Test Day = Day 1

Correlations[a]

		TMTB Total Time	ImPACT Three Letters Avg Counted Correctly
Pearson Correlation	TMTB Total Time	1.000	-.694
	ImPACT Three Letters Avg Counted Correctly	-.694	1.000
Sig. (1-tailed)	TMTB Total Time	.	.000
	ImPACT Three Letters Avg Counted Correctly	.000	.
N	TMTB Total Time	40	40
	ImPACT Three Letters Avg Counted Correctly	40	40

a. Test Day = Day 1

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Three Letters Avg Counted Correctly[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: TMTB Total Time

c. Test Day = Day 1

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.694[a]	.481	.468	11.03638

a. Predictors: (Constant), ImPACT Three Letters Avg Counted Correctly

b. Test Day = Day 1

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4293.106	1	4293.106	35.247	.000[a]
	Residual	4628.463	38	121.802		
	Total	8921.569	39			

a. Predictors: (Constant), ImPACT Three Letters Avg Counted Correctly

b. Dependent Variable: TMTB Total Time

c. Test Day = Day 1

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	94.175	6.706		14.044	.000
	ImPACT Three Letters Avg Counted Correctly	-2.182	.367	-.694	-5.937	.000

a. Dependent Variable: TMTB Total Time

b. Test Day = Day 1

TMT-B Total Time &
ImPACT Three Letters Average Counted Correctly

Session 2

Descriptive Statistics[a]

	Mean	Std. Deviation	N
TMTB Total Time	43.9843	11.27984	40
ImPACT Three Letters Avg Counted Correctly	19.1000	4.65684	40

a. Test Day = Day 2

Correlations[a]

		TMTB Total Time	ImPACT Three Letters Avg Counted Correctly
Pearson Correlation	TMTB Total Time	1.000	-.415
	ImPACT Three Letters Avg Counted Correctly	-.415	1.000
Sig. (1-tailed)	TMTB Total Time	.	.004
	ImPACT Three Letters Avg Counted Correctly	.004	.
N	TMTB Total Time	40	40
	ImPACT Three Letters Avg Counted Correctly	40	40

a. Test Day = Day 2

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Three Letters Avg Counted Correctly[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: TMTB Total Time

c. Test Day = Day 2

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.415[a]	.172	.150	10.39891

a. Predictors: (Constant), ImPACT Three Letters Avg Counted Correctly

b. Test Day = Day 2

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	852.941	1	852.941	7.888	.008[a]
	Residual	4109.218	38	108.137		
	Total	4962.159	39			

a. Predictors: (Constant), ImPACT Three Letters Avg Counted Correctly

b. Dependent Variable: TMTB Total Time

c. Test Day = Day 2

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	63.165	7.025		8.992	.000
	ImPACT Three Letters Avg Counted Correctly	-1.004	.358	-.415	-2.808	.008

a. Dependent Variable: TMTB Total Time

b. Test Day = Day 2

TMT-B Total Time &
ImPACT Three Letters Average Counted Correctly

Session 3

Descriptive Statistics[a]

	Mean	Std. Deviation	N
TMTB Total Time	36.9700	10.68051	40
ImPACT Three Letters Avg Counted Correctly	19.2250	4.04442	40

a. Test Day = Day 3

Correlations[a]

		TMTB Total Time	ImPACT Three Letters Avg Counted Correctly
Pearson Correlation	TMTB Total Time	1.000	-.410
	ImPACT Three Letters Avg Counted Correctly	-.410	1.000
Sig. (1-tailed)	TMTB Total Time	.	.004
	ImPACT Three Letters Avg Counted Correctly	.004	.
N	TMTB Total Time	40	40
	ImPACT Three Letters Avg Counted Correctly	40	40

a. Test Day = Day 3

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Three Letters Avg Counted Correctly[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: TMTB Total Time

c. Test Day = Day 3

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.410[a]	.168	.146	9.86957

a. Predictors: (Constant), ImPACT Three Letters Avg Counted Correctly

b. Test Day = Day 3

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	747.340	1	747.340	7.672	.009[a]
	Residual	3701.518	38	97.408		
	Total	4448.858	39			

a. Predictors: (Constant), ImPACT Three Letters Avg Counted Correctly

b. Dependent Variable: TMTB Total Time

c. Test Day = Day 3

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	57.778	7.673		7.530	.000
	ImPACT Three Letters Avg Counted Correctly	-1.082	.391	-.410	-2.770	.009

a. Dependent Variable: TMTB Total Time

b. Test Day = Day 3

SDMT Total Score &
ImPACT Symbol Match Average Correct Reaction Time

Session 1

Descriptive Statistics[a]

	Mean	Std. Deviation	N
SDMT Score	41.8000	6.18186	40
ImPACT Symbol Match Avg Correct RT (visible)	1.3560	.21990	40

a. Test Day = Day 1

Correlations[a]

		SDMT Score	ImPACT Symbol Match Avg Correct RT (visible)
Pearson Correlation	SDMT Score	1.000	-.479
	ImPACT Symbol Match Avg Correct RT (visible)	-.479	1.000
Sig. (1-tailed)	SDMT Score	.	.001
	ImPACT Symbol Match Avg Correct RT (visible)	.001	.
N	SDMT Score	40	40
	ImPACT Symbol Match Avg Correct RT (visible)	40	40

a. Test Day = Day 1

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Symbol Match Avg Correct RT (visible)[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: SDMT Score

c. Test Day = Day 1

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.479[a]	.229	.209	5.49897

a. Predictors: (Constant), ImPACT Symbol Match Avg Correct RT (visible)

b. Test Day = Day 1

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	341.332	1	341.332	11.288	.002[a]
	Residual	1149.068	38	30.239		
	Total	1490.400	39			

a. Predictors: (Constant), ImPACT Symbol Match Avg Correct RT (visible)

b. Dependent Variable: SDMT Score

c. Test Day = Day 1

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	60.042	5.499		10.919	.000
	ImPACT Symbol Match Avg Correct RT (visible)	-13.453	4.004	-.479	-3.360	.002

a. Dependent Variable: SDMT Score

b. Test Day = Day 1

SDMT Total Score &
ImPACT Symbol Match Average Correct Reaction Time

Session 2

Descriptive Statistics[a]

	Mean	Std. Deviation	N
SDMT Score	41.3000	6.96953	40
ImPACT Symbol Match Avg Correct RT (visible)	1.3713	.24798	40

a. Test Day = Day 2

Correlations[a]

		SDMT Score	ImPACT Symbol Match Avg Correct RT (visible)
Pearson Correlation	SDMT Score	1.000	-.587
	ImPACT Symbol Match Avg Correct RT (visible)	-.587	1.000
Sig. (1-tailed)	SDMT Score	.	.000
	ImPACT Symbol Match Avg Correct RT (visible)	.000	.
N	SDMT Score	40	40
	ImPACT Symbol Match Avg Correct RT (visible)	40	40

a. Test Day = Day 2

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Symbol Match Avg Correct RT (visible)[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: SDMT Score

c. Test Day = Day 2

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.587[a]	.345	.327	5.71626

a. Predictors: (Constant), ImPACT Symbol Match Avg Correct RT (visible)

b. Test Day = Day 2

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	652.725	1	652.725	19.976	.000[a]
	Residual	1241.675	38	32.676		
	Total	1894.400	39			

a. Predictors: (Constant), ImPACT Symbol Match Avg Correct RT (visible)

b. Dependent Variable: SDMT Score

c. Test Day = Day 2

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	63.922	5.142		12.432	.000
	ImPACT Symbol Match Avg Correct RT (visible)	-16.498	3.691	-.587	-4.469	.000

a. Dependent Variable: SDMT Score

b. Test Day = Day 2

SDMT Total Score &
ImPACT Symbol Match Average Correct Reaction Time

Session 3

Descriptive Statistics[a]

	Mean	Std. Deviation	N
SDMT Score	42.3250	5.85021	40
ImPACT Symbol Match Avg Correct RT (visible)	1.4390	.37214	40

a. Test Day = Day 3

Correlations[a]

		SDMT Score	ImPACT Symbol Match Avg Correct RT (visible)
Pearson Correlation	SDMT Score	1.000	-.427
	ImPACT Symbol Match Avg Correct RT (visible)	-.427	1.000
Sig. (1-tailed)	SDMT Score	.	.003
	ImPACT Symbol Match Avg Correct RT (visible)	.003	.
N	SDMT Score	40	40
	ImPACT Symbol Match Avg Correct RT (visible)	40	40

a. Test Day = Day 3

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Symbol Match Avg Correct RT (visible)[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: SDMT Score

c. Test Day = Day 3

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.427[a]	.182	.160	5.36049

a. Predictors: (Constant), ImPACT Symbol Match Avg Correct RT (visible)

b. Test Day = Day 3

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	242.850	1	242.850	8.451	.006[a]
	Residual	1091.925	38	28.735		
	Total	1334.775	39			

a. Predictors: (Constant), ImPACT Symbol Match Avg Correct RT (visible)

b. Dependent Variable: SDMT Score

c. Test Day = Day 3

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	51.974	3.426		15.172	.000
	ImPACT Symbol Match Avg Correct RT (visible)	-6.705	2.307	-.427	-2.907	.006

a. Dependent Variable: SDMT Score

b. Test Day = Day 3

Stroop Test Total Score &
ImPACT Color Match Average Correct Reaction Time

Session 1

Descriptive Statistics[a]

	Mean	Std. Deviation	N
Stroop Score	52.9250	9.37095	40
ImPACT Color Match Avg Correct RT	.7670	.12083	40

a. Test Day = Day 1

Correlations[a]

		Stroop Score	ImPACT Color Match Avg Correct RT
Pearson Correlation	Stroop Score	1.000	-.506
	ImPACT Color Match Avg Correct RT	-.506	1.000
Sig. (1-tailed)	Stroop Score	.	.000
	ImPACT Color Match Avg Correct RT	.000	.
N	Stroop Score	40	40
	ImPACT Color Match Avg Correct RT	40	40

a. Test Day = Day 1

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Color Match Avg Correct RT[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Stroop Score

c. Test Day = Day 1

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.506[a]	.256	.236	8.18924

a. Predictors: (Constant), ImPACT Color Match Avg Correct RT

b. Test Day = Day 1

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	876.354	1	876.354	13.067	.001[a]
	Residual	2548.421	38	67.064		
	Total	3424.775	39			

a. Predictors: (Constant), ImPACT Color Match Avg Correct RT

b. Dependent Variable: Stroop Score

c. Test Day = Day 1

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	83.014	8.424		9.855	.000
	ImPACT Color Match Avg Correct RT	-39.230	10.852	-.506	-3.615	.001

a. Dependent Variable: Stroop Score

b. Test Day = Day 1

Stroop Test Total Score &
ImPACT Color Match Average Correct Reaction Time

Session 2

Descriptive Statistics[a]

	Mean	Std. Deviation	N
Stroop Score	60.5750	10.77244	40
ImPACT Color Match Avg Correct RT	.7160	.13670	40

a. Test Day = Day 2

Correlations[a]

		Stroop Score	ImPACT Color Match Avg Correct RT
Pearson Correlation	Stroop Score	1.000	-.363
	ImPACT Color Match Avg Correct RT	-.363	1.000
Sig. (1-tailed)	Stroop Score	.	.011
	ImPACT Color Match Avg Correct RT	.011	.
N	Stroop Score	40	40
	ImPACT Color Match Avg Correct RT	40	40

a. Test Day = Day 2

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Color Match Avg Correct RT[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Stroop Score

c. Test Day = Day 2

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.363[a]	.132	.109	10.16731

a. Predictors: (Constant), ImPACT Color Match Avg Correct RT

b. Test Day = Day 2

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	597.554	1	597.554	5.780	.021[a]
	Residual	3928.221	38	103.374		
	Total	4525.775	39			

a. Predictors: (Constant), ImPACT Color Match Avg Correct RT

b. Dependent Variable: Stroop Score

c. Test Day = Day 2

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	81.078	8.678		9.343	.000
	ImPACT Color Match Avg Correct RT	-28.635	11.910	-.363	-2.404	.021

a. Dependent Variable: Stroop Score

b. Test Day = Day 2

Stroop Test Total Score &
ImPACT Color Match Average Correct Reaction Time

Session 3

Descriptive Statistics[a]

	Mean	Std. Deviation	N
Stroop Score	64.2500	11.87488	40
ImPACT Color Match Avg Correct RT	.7020	.11034	40

a. Test Day = Day 3

Correlations[a]

		Stroop Score	ImPACT Color Match Avg Correct RT
Pearson Correlation	Stroop Score	1.000	-.225
	ImPACT Color Match Avg Correct RT	-.225	1.000
Sig. (1-tailed)	Stroop Score	.	.081
	ImPACT Color Match Avg Correct RT	.081	.
N	Stroop Score	40	40
	ImPACT Color Match Avg Correct RT	40	40

a. Test Day = Day 3

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	ImPACT Color Match Avg Correct RT[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Stroop Score

c. Test Day = Day 3

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.225[a]	.051	.026	11.72099

a. Predictors: (Constant), ImPACT Color Match Avg Correct RT

b. Test Day = Day 3

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	278.999	1	278.999	2.031	.162[a]
	Residual	5220.501	38	137.382		
	Total	5499.500	39			

a. Predictors: (Constant), ImPACT Color Match Avg Correct RT

b. Dependent Variable: Stroop Score

c. Test Day = Day 3

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	81.266	12.084		6.725	.000
	ImPACT Color Match Avg Correct RT	-24.240	17.009	-.225	-1.425	.162

a. Dependent Variable: Stroop Score

b. Test Day = Day 3

APPENDIX 9A:
PARTICIPATION CONSENT FORM (ADULT)

THIS CONSENT DOCUMENT SHOULD BE USED ONLY
BETWEEN 12-12-06 AND 12-11-07
APPROVED BY
INSTITUTIONAL REVIEW BOARD, UNC-CHAPEL HILL

University of North Carolina-Chapel Hill
Consent to Participate in a Research Study
Adult Participants
Social Behavioral Form

IRB Study # 06-0856
Consent Form Version Date: ______________

Title of Study: EFFECT OF AGE ON VALIDITY AND PRACTICE EFFECTS OF ImPACT AND TRADITIONAL PAPER-PENCIL NEUROPSYCHOLOGICAL TESTS

Principal Investigator: Daniel L. Kontos, ATC
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Funding Source: NA

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Faculty Advisor telephone number: 919.962.5175
Faculty Advisor email: gus@email.unc.edu

What are some general things you should know about research studies?
You are being asked to take part in a research study. To join the study is voluntary.
You may refuse to join, or you may withdraw your consent to be in the study, for any reason, without penalty.

Research studies are designed to obtain new knowledge. This new information may help people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study.
You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?
To date, there is a lack of evidence to support that computerized testing of athletes after they have had a concussion is a valid measurement of attention, memory, concentration, information processing, and reaction time. Also, there is insufficient research on whether or not age has an affect on an individual's performance during testing of athletes after they have had a concussion. Finally, literature shows that there are some practice effects that occur for traditional paper-pencil testing of athletes after they have had a concussion, but that these practice effects do not occur for computerized testing of athletes after they have had a concussion.

Page 1 of 4

Therefore, using healthy (i.e. non-concussed) participants, the purposes of this research study are to determine 1) the validity of ImPACT (a computerized concussion test) as a tool for testing athletes after they have had a concussion based on comparisons with traditional paper-pencil concussion tests, 2) if age significantly affects performance on concussion tests, and 3) if practice effects significantly affect performance on concussion tests following repeated test sessions.

Are there any reasons you should not be in this study?
You should not be in this study if you have suffered a concussion in the last 5 years, have a known neurocognitive deficit or disorder (such as headaches or migraines, visual disturbances, dizziness, or insomnia), have a known psychological condition or disorder, suffer from color blindness, or if you are (or will be) 18 years of age at the time of participation.

How many people will take part in this study?
If you decide to be in this study, you will be one of approximately 40 people in this research study.

How long will your part in this study last?
You will need to report for testing every other day for a total of three visits. Each testing session will last approximately one hour.

What will happen if you take part in the study?
You will report to the UNC Sports Medicine Research Laboratory (SMRL) every other day for a total of three visits. Each testing session will last for approximately one hour. Prior to participation you will need to sign an approved informed consent form.

During each testing session:

- You will complete both the ImPACT computerized concussion test and a brief series of paper-pencil concussion tests in order to measure attention, memory, concentration, information processing, and reaction time.
- You will be given a five minute rest period between the computerized concussion test and the paper-pencil concussion tests.
- Upon completion of both concussion tests, you will be released from the SMRL.

After all participants have completed all test sessions, test scores will be released in person only to interested individuals.

What are the possible benefits from being in this study?
Research is designed to benefit society by gaining new knowledge. You may not benefit personally from being in this research study.

What are the possible risks or discomforts involved from being in this study?
Potential risks of this study include mental and/or physical fatigue similar in nature to any test taking experience. The risk of mental and/or physical fatigue will be minimized through the allotment of a five minute rest period between test batteries.

There may be uncommon or previously unknown risks. You should report any problems to the researcher.

How will your privacy be protected?
Privacy and confidentiality will be protected through the following measures:

- ID numbers will be used rather than names
- The linkage file for ID numbers and names as well as any file containing individually identifiable data will be secured in a locked file cabinet in a locked office.
- All electronic information will be secured by password protection.
- All individually identifiable data will be accessible solely by the Principal Investigator.

Participants *will not* be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

Will you receive anything for being in this study?
You will not receive anything for taking part in this study.

Will it cost you anything to be in this study?
There will be no costs for being in the study other than your time to participate.

What if you are a UNC student?
You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

What if you are a UNC employee?
Taking part in this research is not a part of your University duties, and refusing will not affect your job. You will not be offered or receive any special job-related consideration if you take part in this research.

What if you have questions about this study?
You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or concerns, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research participant?
All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

Participant's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

______________________________________ ________________
Signature of Research Participant Date

____
Printed Name of Research Participant

______________________________________ ________________
Signature of Person Obtaining Consent Date

____
Printed Name of Person Obtaining Consent

APPENDIX 9B:
PARTICIPATION CONSENT FORM (CHILD)

University of North Carolina-Chapel Hill
Assent to Participate in a Research Study
Adolescent Participants age 15-17
Social Behavioral Form

THIS CONSENT DOCUMENT SHOULD BE USED ONLY BETWEEN 12-12-06 AND 12-11-07
APPROVED BY INSTITUTIONAL REVIEW BOARD, UNC-CHAPEL HILL

IRB Study # 06-0856
Assent Form Version Date: ______________

Title of Study: EFFECT OF AGE ON VALIDITY AND PRACTICE EFFECTS OF ImPACT AND TRADITIONAL PAPER-PENCIL NEUROPSYCHOLOGICAL TESTS

Principal Investigator: Daniel L. Kontos, ATC
UNC-Chapel Hill Department: EXSS
UNC-Chapel Hill Phone number: 919.843.9674
Faculty Advisor: Kevin M. Guskiewicz, PhD
Funding Source: NA

Study Contact telephone number: 919.843.9674
Study Contact email: kontos@email.unc.edu
Faculty Advisor telephone number: 919.962.5175
Faculty Advisor email: gus@email.unc.edu

What are some general things you should know about research studies?
You are being asked to take part in a research study. Your parent, or guardian, needs to give permission for you to be in this study. You do not have to be in this study if you don't want to, even if your parent has already given permission. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason, without penalty.

Research studies are designed to obtain new knowledge. This new information may help people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?
To date, there is a lack of evidence to support that computerized testing of athletes after they have had a concussion is a valid measurement of attention, memory, concentration, information processing, and reaction time. Also, there is insufficient research on whether or not age has an affect on an individual's performance during testing of athletes after they have had a concussion. Finally, literature shows that there are some practice effects that occur for traditional paper-

Page 1 of 4

pencil testing of athletes after they have had a concussion, but that these practice effects do not occur for computerized testing of athletes after they have had a concussion.

Therefore, using healthy (i.e. non-concussed) participants, the purposes of this research study are to determine 1) the validity of ImPACT (a computerized concussion test) as a tool for testing athletes after they have had a concussion based on comparisons with traditional paper-pencil concussion tests, 2) if age significantly affects performance on concussion tests, and 3) if practice effects significantly affect performance on concussion tests following repeated test sessions.

Are there any reasons you should not be in this study?

You should not be in this study if you have suffered a concussion in the last 5 years, have a known neurocognitive deficit or disorder (such as headaches or migraines, visual disturbances, dizziness, or insomnia), have a known psychological condition or disorder, suffer from color blindness, or if you are (or will be) 18 years of age at the time of participation.

How many people will take part in this study?

If you decide to be in this study, you will be one of approximately 40 people in this research study.

How long will your part in this study last?

You will need to report for testing every other day for a total of three visits. Each testing session will last approximately one hour.

What will happen if you take part in the study?

You will report to the computer lab at your high school every other day for a total of three visits. Each testing session will last for approximately one hour. Prior to participation you will need to sign an approved informed assent form.

During each testing session:

- You will complete both the ImPACT computerized concussion test and a brief series of paper-pencil concussion tests in order to measure attention, memory, concentration, information processing, and reaction time.
- You will be given a five minute rest period between the computerized concussion test and the paper-pencil concussion tests.
- Upon completion of both concussion tests, you will be released from the testing site.

After all participants have completed all test sessions, test scores will be released in person only to interested individuals.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. You may not benefit personally from being in this research study.

What are the possible risks or discomforts involved from being in this study?

Potential risks of this study include mental and/or physical fatigue similar in nature to any test taking experience. The risk of mental and/or physical fatigue will be minimized through the allotment of a five minute rest period between test batteries.

There may be uncommon or previously unknown risks. You should report any problems to the researcher.

How will your privacy be protected?
Privacy and confidentiality will be protected through the following measures:

- ID numbers will be used rather than names
- The linkage file for ID numbers and names as well as any file containing individually identifiable data will be secured in a locked file cabinet in a locked office.
- All electronic information will be secured by password protection.
- All individually identifiable data will be accessible solely by the Principal Investigator.

Participants *will not* be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

Will you receive anything for being in this study?
You will not receive anything for taking part in this study.

What if you have questions about this study?
You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or concerns, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research participant?
All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

Participant's Agreement:
I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

________________________________ ______________
Your signature if you agree to be in the study Date

____
Printed name if you agree to be in the study

________________________________ ______________
Signature of Person Obtaining Assent Date

____
Printed Name of Person Obtaining Assent

APPENDIX 9C:
PARTICIPATION CONSENT FORM (PARENT)

THIS CONSENT DOCUMENT SHOULD BE USED ONLY
BETWEEN 12-12-06 AND 12-11-07
APPROVED BY
INSTITUTIONAL REVIEW BOARD, UNC-CHAPEL HILL

University of North Carolina-Chapel Hill
Parental Permission for a Minor Child to Participate in a Research Study
Social Behavioral Form

IRB Study # 06-0856
Consent Form Version Date: ____________

Title of Study: EFFECT OF AGE ON VALIDITY AND PRACTICE EFFECTS OF ImPACT AND TRADITIONAL PAPER-PENCIL NEUROPSYCHOLOGICAL TESTS

Principal Investigator: Daniel L. Kontos, ATC
UNC-Chapel Hill Department: EXSS
UNC-Chapel Hill Phone number: 919.843.9674
Faculty Advisor: Kevin M. Guskiewicz, PhD
Funding Source: NA

Study Contact telephone number: 919.843.9674
Study Contact email: kontos@email.unc.edu
Faculty Advisor telephone number: 919.962.5175
Faculty Advisor email: gus@email.unc.edu

What are some general things you should know about research studies?
You are being asked to allow your child to take part in a research study. To join the study is voluntary. You may refuse to give permission, or you may withdraw your permission for your child to be in the study, for any reason. Even if you give your permission, your child can decide not to be in the study or to leave the study early.

Research studies are designed to obtain new knowledge. This new information may help people in the future. Your child may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this study are discussed below. It is important that you understand this information so that you and your child can make an informed choice about being in this research study. You will be given a copy of this permission form. You and your child should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?
To date, there is a lack of evidence to support that computerized testing of athletes after they have had a concussion is a valid measurement of attention, memory, concentration, information processing, and reaction time. Also, there is insufficient research on whether or not age has an affect on an individual's performance during testing of athletes after they have had a concussion. Finally, literature shows that there are some practice effects that occur for traditional paper-

pencil testing of athletes after they have had a concussion, but that these practice effects do not occur for computerized testing of athletes after they have had a concussion.

Therefore, using healthy (i.e. non-concussed) participants, the purposes of this research study are to determine 1) the validity of ImPACT (a computerized concussion test) as a tool for testing athletes after they have had a concussion based on comparisons with traditional paper-pencil concussion tests, 2) if age significantly affects performance on concussion tests, and 3) if practice effects significantly affect performance on concussion tests following repeated test sessions.

Are there any reasons your child should not be in this study?
Your child should not be in this study if he/she has suffered a concussion in the last 5 years, has a known neurocognitive deficit or disorder (such as headaches or migraines, visual disturbances, dizziness, or insomnia), has a known psychological condition or disorder, suffers from color blindness, or if your child is (or will be) 18 years of age at the time of participation.

How many people will take part in this study?
If your child is in this study, your child will be one of approximately 40 people in this research study.

How long will your child's part in this study last?
Your child will need to report for testing every other day for a total of three visits. Each testing session will last approximately one hour.

What will happen if your child takes part in the study?
Your child will report to the computer lab at his/her high school every other day for a total of three visits. Each testing session will last for approximately one hour. Prior to your child's participation you will need to sign an approved informed consent form and your child will need to sign an approved informed assent form.

During each testing session:

- Your child will complete both the ImPACT computerized concussion test and a brief series of paper-pencil concussion tests in order to measure attention, memory, concentration, information processing, and reaction time.
- Your child will be given a five minute rest period between the computerized concussion test and the paper-pencil concussion tests.
- Upon completion of both concussion tests, your child will be released from the testing site.

After all participants have completed all test sessions, test scores will be released in person only to interested individuals.

What are the possible benefits from being in this study?
Research is designed to benefit society by gaining new knowledge. Your child may not benefit personally from being in this research study.

What are the possible risks or discomforts involved from being in this study?
Potential risks of this study include mental and/or physical fatigue similar in nature to any test taking experience. The risk of mental and/or physical fatigue will be minimized through the allotment of a five minute rest period between test batteries.

There may be uncommon or previously unknown risks. You should report any problems to the researcher.

How will your child's privacy be protected?
Privacy and confidentiality will be protected through the following measures:

- ID numbers will be used rather than names
- The linkage file for ID numbers and names as well as any file containing individually identifiable data will be secured in a locked file cabinet in a locked office.
- All electronic information will be secured by password protection.
- All individually identifiable data will be accessible solely by the Principal Investigator.

Participants *will not* be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

Will your child receive anything for being in this study?
Your child will not receive anything for taking part in this study.

Will it cost you anything for your child to be in this study?
There will be no costs for being in the study other than your child's time to participate.

What if you or your child has questions about this study?
You and your child have the right to ask, and have answered, any questions you may have about this research. If you have questions, or concerns, you should contact the researchers listed on the first page of this form.

What if you or your child has questions about your child's rights as a research participant?
All research on human volunteers is reviewed by a committee that works to protect your child's rights and welfare. If you or your child has questions or concerns about your child's rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

Parent's Agreement:
I have read the information provided above. I have asked all the questions I have at this time. I voluntarily give permission to allow my child to participate in this research study.

____
Printed Name of Research Participant (Child)

____ _________________
Signature of Parent Date

____
Printed Name of Parent

APPENDIX 10:
RECRUITMENT FLYER

APPROVED - IRB, UNC-CH

DEC 1 2 2006

Would You Like to Participate in a Research Study for Concussion Testing?

<u>You may qualify to participate if you…</u>

- Are between the ages of 15-17 or 19-21,
- Are athletically active (engage in athletics 4 or more days of the week),
- Have <u>not</u> had a concussion in the last 5 years,
- Do <u>not</u> have any known neurocognitive deficits or disorders,
- Do <u>not</u> have any known psychological disorders or conditions, and
- Do <u>not</u> suffer from color blindness.

<u>Participants will be asked to…</u>

- Report for testing on 3 separate occasions for approximately 1 hour each visit,
- Complete a brief series of traditional, paper-pencil concussion tests, and
- Complete a computerized concussion test.

If you are interested in participating and meet the qualifications for this study, Please contact Daniel Kontos at kontos@email.unc.edu

This research study was approved by the UNC-CH Behavioral Institutional Review Board on 12/12/2006. IRB Study number: 06-0856.

REFERENCES

Alexander, M. P. (1995). Mild traumatic brain injury: pathophysiology, natural history, and clinical management. *Neurology, 45*(7), 1253-1260.

Aubry, M., Cantu, R., Dvorak, J., Graf-Baumann, T., Johnston, K., Kelly, J., et al. (2002). Summary and agreement statement of the First International Conference on Concussion in Sport, Vienna 2001. Recommendations for the improvement of safety and health of athletes who may suffer concussive injuries. *Br J Sports Med, 36*(1), 6-10.

Barr, W. B. (2001). Methodologic Issues in Neuropsychological Testing. *J Athl Train, 36*(3), 297-302.

Barr, W. B., & McCrea, M. (2001). Sensitivity and specificity of standardized neurocognitive testing immediately following sports concussion. *J Int Neuropsychol Soc, 7*(6), 693-702.

Barth, J. T., Diamond, R., & Errico, A. (1996). Mild head injury and post concussion syndrome: does anyone really suffer? *Clin Electroencephalogr, 27*(4), 183-186.

Barth, J. T., Freeman, J. R., Broshek, D. K., & Varney, R. N. (2001). Acceleration-Deceleration Sport-Related Concussion: The Gravity of It All. *J Athl Train, 36*(3), 253-256.

Benedict, R. H., & Zgaljardic, D. J. (1998). Practice effects during repeated administrations of memory tests with and without alternate forms. *J Clin Exp Neuropsychol, 20*(3), 339-352.

Binder, L. M. (1986). Persisting symptoms after mild head injury: a review of the postconcussive syndrome. *J Clin Exp Neuropsychol, 8*(4), 323-346.

Bruce, D. A., Alavi, A., Bilaniuk, L., Dolinskas, C., Obrist, W., & Uzzell, B. (1981). Diffuse cerebral swelling following head injuries in children: the syndrome of "malignant brain edema". *J Neurosurg, 54*(2), 170-178.

Butcher, J. N., Perry, J., & Hahn, J. (2004). Computers in clinical assessment: historical developments, present status, and future challenges. *J Clin Psychol, 60*(3), 331-345.

Buzzini, S. R., & Guskiewicz, K. M. (2006). Sport-related concussion in the young athlete. *Curr Opin Pediatr, 18*(4), 376-382.

Cantu, R. C. (1996). Head injuries in sport. *Br J Sports Med, 30*(4), 289-296.

Collie, A., Darby, D., & Maruff, P. (2001). Computerised cognitive assessment of athletes with sports related head injury. *Br J Sports Med, 35*(5), 297-302.

Collie, A., Maruff, P., Darby, D. G., & McStephen, M. (2003). The effects of practice on the cognitive test performance of neurologically normal individuals assessed at brief test-retest intervals. *J Int Neuropsychol Soc, 9*(3), 419-428.

Collins, M. W., Field, M., Lovell, M. R., Iverson, G., Johnston, K. M., Maroon, J., et al. (2003). Relationship between postconcussion headache and neuropsychological test performance in high school athletes. *Am J Sports Med, 31*(2), 168-173.

Collins, M. W., Grindel, S. H., Lovell, M. R., Dede, D. E., Moser, D. J., Phalin, B. R., et al. (1999). Relationship between concussion and neuropsychological performance in college football players. *Jama, 282*(10), 964-970.

Collins, M. W., Iverson, G. L., Lovell, M. R., McKeag, D. B., Norwig, J., & Maroon, J. (2003). On-field predictors of neuropsychological and symptom deficit following sports-related concussion. *Clin J Sport Med, 13*(4), 222-229.

Collins, M. W., Lovell, M. R., & McKeag, D. B. (1999). Current issues in managing sports-related concussion. *Jama, 282*(24), 2283-2285.

Committee on Head Injury Nomenclature of the Congress of Neurological Surgeons. (1966). Glossary of head injury including some definitions of injury to the cervical spine. *Clin Neurosurg, 12*, 386-394.

Echemendia, R. J., Putukian, M., Mackin, R. S., Julian, L., & Shoss, N. (2001). Neuropsychological test performance prior to and following sports-related mild traumatic brain injury. *Clin J Sport Med, 11*(1), 23-31.

Ettlin, T. M., Kischka, U., Reichmann, S., Radii, E. W., Heim, S., Wengen, D., et al. (1992). Cerebral symptoms after whiplash injury of the neck: a prospective clinical and neuropsychological study of whiplash injury. *J Neurol Neurosurg Psychiatry, 55*(10), 943-948.

Ferrara, M. S., McCrea, M., Peterson, C. L., & Guskiewicz, K. M. (2001). A Survey of Practice Patterns in Concussion Assessment and Management. *J Athl Train, 36*(2), 145-149.

Field, M., Collins, M. W., Lovell, M. R., & Maroon, J. (2003). Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *J Pediatr, 142*(5), 546-553.

Giza, C. C., Griesbach, G. S., & Hovda, D. A. (2005). Experience-dependent behavioral plasticity is disturbed following traumatic injury to the immature brain. *Behav Brain Res, 157*(1), 11-22.

Giza, C. C., & Hovda, D. A. (2001). The Neurometabolic Cascade of Concussion. *J Athl Train, 36*(3), 228-235.

Gottschalk, L. A., Bechtel, R. J., Maguire, G. A., Harrington, D. E., Levinson, D. M., Franklin, D. L., et al. (2000). Computerized measurement of cognitive impairment and associated neuropsychiatric dimensions. *Compr Psychiatry, 41*(5), 326-333.

Grindel, S. H., Lovell, M. R., & Collins, M. W. (2001). The assessment of sport-related concussion: the evidence behind neuropsychological testing and management. *Clin J Sport Med, 11*(3), 134-143.

Guskiewicz, K. M. (2001). Postural stability assessment following concussion: one piece of the puzzle. *Clin J Sport Med, 11*(3), 182-189.

Guskiewicz, K. M., Bruce, S. L., Cantu, R. C., Ferrara, M. S., Kelly, J. P., McCrea, M., et al. (2004). National Athletic Trainers' Association Position Statement: Management of Sport-Related Concussion. *J Athl Train, 39*(3), 280-297.

Guskiewicz, K. M., Ross, S. E., & Marshall, S. W. (2001). Postural Stability and Neuropsychological Deficits After Concussion in Collegiate Athletes. *J Athl Train, 36*(3), 263-273.

Guskiewicz, K. M., Weaver, N. L., Padua, D. A., & Garrett, W. E., Jr. (2000). Epidemiology of concussion in collegiate and high school football players. *Am J Sports Med, 28*(5), 643-650.

Hepler, D. J., Olton, D. S., Wenk, G. L., & Coyle, J. T. (1985). Lesions in nucleus basalis magnocellularis and medial septal area of rats produce qualitatively similar memory impairments. *J Neurosci, 5*(4), 866-873.

Hollnagel, H., & Norrelund, N. (1980). [Headache among 40-year-olds in Glostrup. An epidemiological study]. *Ugeskr Laeger, 142*(46), 3071-3077.

Iverson, G. L., Franzen, M. D., Lovell, M. R., & Collins, M. W. (2004). Construct validity of ImPACT in athletes with concussions. *Arch Clin Neuropsychol, 19*(7), 961.

Iverson, G. L., Lovell, M. R., & Collins, M. W. (2003a). Immediate post-concussion assessment and cognitive test (ImPACT): Normative data. Retrieved May 2, 2007, from http://www.impacttest.com/ArticlesPage_images/Articles_Docs/7ImPACTNormativeDataversion%202.pdf

Iverson, G. L., Lovell, M. R., & Collins, M. W. (2003b). Interpreting change on ImPACT following sport concussion. *Clin Neuropsychol, 17*(4), 460-467.

Iverson, G. L., Lovell, M. R., & Collins, M. W. (2005). Validity of ImPACT for measuring processing speed following sports-related concussion. *J Clin Exp Neuropsychol, 27*(6), 683-689.

Kelly, J. P. (2000). Concussion in sports and recreation. *Semin Neurol, 20*(2), 165-171.

Krupnick, J. L., & Horowitz, M. J. (1981). Stress response syndromes. Recurrent themes. *Arch Gen Psychiatry, 38*(4), 428-435.

Leininger, B. E., Gramling, S. E., Farrell, A. D., Kreutzer, J. S., & Peck, E. A., 3rd. (1990). Neuropsychological deficits in symptomatic minor head injury patients after concussion and mild concussion. *J Neurol Neurosurg Psychiatry, 53*(4), 293-296.

Levin, H. S. (1994). A guide to clinical neuropsychological testing. *Arch Neurol, 51*(9), 854-859.

Lovell, M. R., & Collins, M. W. (1998). Neuropsychological assessment of the college football player. *J Head Trauma Rehabil, 13*(2), 9-26.

Lovell, M. R., Collins, M. W., Iverson, G. L., Field, M., Maroon, J. C., Cantu, R., et al. (2003). Recovery from mild concussion in high school athletes. *J Neurosurg, 98*(2), 296-301.

Lovell, M. R., Collins, M. W., Iverson, G. L., Johnston, K. M., & Bradley, J. P. (2004). Grade 1 or "ding" concussions in high school athletes. *Am J Sports Med, 32*(1), 47-54.

Macciocchi, S. N., Barth, J. T., Alves, W., Rimel, R. W., & Jane, J. A. (1996). Neuropsychological functioning and recovery after mild head injury in collegiate athletes. *Neurosurgery, 39*(3), 510-514.

Macciocchi, S. N., Barth, J. T., Littlefield, L., & Cantu, R. C. (2001). Multiple Concussions and Neuropsychological Functioning in Collegiate Football Players. *J Athl Train, 36*(3), 303-306.

Makdissi, M., Collie, A., Maruff, P., Darby, D. G., Bush, A., McCrory, P., et al. (2001). Computerised cognitive assessment of concussed Australian Rules footballers. *Br J Sports Med, 35*(5), 354-360.

Maroon, J. C., Lovell, M. R., Norwig, J., Podell, K., Powell, J. W., & Hartl, R. (2000). Cerebral concussion in athletes: evaluation and neuropsychological testing. *Neurosurgery, 47*(3), 659-669; discussion 669-672.

Matser, E. J., Kessels, A. G., Lezak, M. D., Jordan, B. D., & Troost, J. (1999). Neuropsychological impairment in amateur soccer players. *Jama, 282*(10), 971-973.

McClincy, M. P., Lovell, M. R., Pardini, J., Collins, M. W., & Spore, M. K. (2006). Recovery from sports concussion in high school and collegiate athletes. *Brain Inj, 20*(1), 33-39.

McCrea, M., Barr, W. B., Guskiewicz, K., Randolph, C., Marshall, S. W., Cantu, R., et al. (2005). Standard regression-based methods for measuring recovery after sport-related concussion. *J Int Neuropsychol Soc, 11*(1), 58-69.

McCrea, M., Guskiewicz, K. M., Marshall, S. W., Barr, W., Randolph, C., Cantu, R. C., et al. (2003). Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study. *Jama, 290*(19), 2556-2563.

McCrea, M., Kelly, J. P., Randolph, C., Kluge, J., Bartolic, E., Finn, G., et al. (1998). Standardized assessment of concussion (SAC): on-site mental status evaluation of the athlete. *J Head Trauma Rehabil, 13*(2), 27-35.

McCrory, P., Johnston, K., Meeuwisse, W., Aubry, M., Cantu, R., Dvorak, J., et al. (2005). Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. *Br J Sports Med, 39*(4), 196-204.

McCrory, P., Makdissi, M., Davis, G., & Collie, A. (2005). Value of neuropsychological testing after head injuries in football. *Br J Sports Med, 39 Suppl 1*, i58-63.

Miyamoto, M., Kato, J., Narumi, S., & Nagaoka, A. (1987). Characteristics of memory impairment following lesioning of the basal forebrain and medial septal nucleus in rats. *Brain Res, 419*(1-2), 19-31.

Notebaert, A. J., & Guskiewicz, K. M. (2005). Current trends in athletic training practice for concussion assessment and management. *J Athl Train, 40*(4), 320-325.

Powell, J. W. (2001). Cerebral Concussion: Causes, Effects, and Risks in Sports. *J Athl Train, 36*(3), 307-311.

Powell, J. W., & Barber-Foss, K. D. (1999). Traumatic brain injury in high school athletes. *Jama, 282*(10), 958-963.

Randolph, C. (2001). Implementation of Neuropsychological Testing Models for the High School, Collegiate, and Professional Sport Settings. *J Athl Train, 36*(3), 288-296.

Randolph, C., McCrea, M., & Barr, W. B. (2005). Is neuropsychological testing useful in the management of sport-related concussion? *J Athl Train, 40*(3), 139-152.

Rutland-Brown, W., Langlois, J. A., Thomas, K. E., & Xi, Y. L. (2006). Incidence of traumatic brain injury in the United States, 2003. *J Head Trauma Rehabil, 21*(6), 544-548.

Schatz, P., & Browndyke, J. (2002). Applications of computer-based neuropsychological assessment. *J Head Trauma Rehabil, 17*(5), 395-410.

Schatz, P., Pardini, J. E., Lovell, M. R., Collins, M. W., & Podell, K. (2006). Sensitivity and specificity of the ImPACT Test Battery for concussion in athletes. *Arch Clin Neuropsychol, 21*(1), 91-99.

Schulz, M. R., Marshall, S. W., Mueller, F. O., Yang, J., Weaver, N. L., Kalsbeek, W. D., et al. (2004). Incidence and risk factors for concussion in high school athletes, North Carolina, 1996-1999. *Am J Epidemiol, 160*(10), 937-944.

Shaw, N. A. (2002). The neurophysiology of concussion. *Prog Neurobiol, 67*(4), 281-344.

Snoek, J. W., Minderhoud, J. M., & Wilmink, J. T. (1984). Delayed deterioration following mild head injury in children. *Brain, 107 (Pt 1)*, 15-36.

Sosin, D. M., Sniezek, J. E., & Thurman, D. J. (1996). Incidence of mild and moderate brain injury in the United States, 1991. *Brain Inj, 10*(1), 47-54.

Thurman, D. J., Branche, C. M., & Sniezek, J. E. (1998). The epidemiology of sports-related traumatic brain injuries in the United States: recent developments. *J Head Trauma Rehabil, 13*(2), 1-8.

Valovich McLeod, T. C. (2005). The Prediction of Intracranial Injury After Minor Head Trauma in the Pediatric Population. *J Athl Train, 40*(2), 123-125.

Weingartner, H., Cohen, R. M., Murphy, D. L., Martello, J., & Gerdt, C. (1981). Cognitive processes in depression. *Arch Gen Psychiatry, 38*(1), 42-47.