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EXAMINING THE EQUIVALENCE OF STORY MEMORY TEST FORMS IN ASSESSING VERBAL MEMORY IN CONCUSSED COLLEGE ATHLETES

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Abstract

Concussions are the most common form of mild traumatic brain injury (mTBI), and it is estimated that at least 300,000 athletes sustain sports-related concussions each year in the United States (Moser et al., 2007). Neuropsychological testing is commonly used in both the diagnosis of concussions and in tracking recovery. The present study aims to validate one of the paper-and-pencil tests included in the neuropsychological concussion testing battery for the Penn State Sports Concussion Program. This test, the Rivermead Behavioural Memory Test (RBMT), was developed by Wilson et al. (1989) in order to screen for everyday memory problems. This test has been found to be a good measure of verbal memory, and verbal memory deficits are quite sensitive to concussion (Bruce & Echemendia, 2003). The present study used a sample of 162 collegiate athletes from The Pennsylvania State University to evaluate the equivalence of four forms of one of the subtests of the RBMT. It was found that performance on forms A and B of the RBMT was significantly better than performance on forms C and D. Convergent and discriminant validity measures were also performed, and the RBMT was found to be most significantly correlated with other tests of the Penn State Sports Concussion Program neuropsychological testing battery that measure memory. Thus, although the RBMT forms were not found to be equivalent, the RBMT was validated as being sensitive to verbal memory. The implications for these findings in the future of the Penn State Sports Concussion Program are discussed.

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Introduction

Introductory statement

Concussions are the most common form of traumatic brain injury (TBI), and TBI is one of the leading causes of injury and death among the young population (Giza & Hovda, 2004). In fact, it is estimated by the Centers for Disease Control and Prevention (CDCP) that at least 300,000 athletes sustain sports-related concussions each year in the United States (Moser et al., 2007). As concussions often go by undiagnosed and can be difficult to detect, the actual number of concussions sustained each year is estimated to be much greater.

Neuropsychological testing is commonly used in both the diagnosis of concussions and in tracking concussion recovery. Neuropsychological testing batteries are often extensive, and some utilize both traditional paper-and-pencil tests as well as computerized tests. These batteries assess domains of cognition that are likely to be affected by concussion, especially memory, attention, reaction time, and information processing speed. As athletes may be quite likely to experience concussions, many sports programs require athletes to undergo a baseline neuropsychological testing battery before the beginning of the training season. After sustaining a concussion, clinical neuropsychologists are then able to compare athletes' individual performances at baseline with the post-injury performance (Moser et al., 2007).

Purpose of study

This is primarily a validity study of one of the paper-and-pencil tests included in the neuropsychological concussion testing battery for the Penn State Sports Concussion Program. This test, the Rivermead Behavioural Memory Test (RBMT), was developed as a screening test for everyday memory problems (Wilson et al., 1989). As memory is one of the key cognitive domains affected by concussion, the need for a valid memory screening test is important. The original RBMT is composed of twelve different tests. One of the tests that will be validated in this study involves a short prose passage that is read aloud to the participant. This RBMT test has four different forms (A, B, C, and D), each with a different passage. Previous literature has not the equivalence between these four different forms in a collegiate athlete population, and that is what this study aims to determine. This study will also verify the validity of the RBMT by evaluating its convergent and discriminant validity with other tests that comprise common neuropsychological testing batteries for sports-related concussion. Convergent validity will be determined by correlating the RBMT with other cognitive measures of verbal and visual memory, while discriminant validity will be determined by correlating the RBMT with measures that are thought to be less associated with memory.

The introduction to this study will begin by providing some background information about the physiology, symptomatology, and diagnosis of concussions. Next, several elements of neuropsychological testing batteries will be discussed, including those involved in the convergent and discriminant validity analyses, and the RBMT will be described in more detail. The introduction will conclude with the hypotheses concerning the research questions.

Background: Concussions

Definition and Epidemiology

There has been ongoing debate regarding the precise definition of concussions among clinicians and neuropsychologists. A concussion has previously been defined as "…a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" and "a temporary alteration in consciousness not necessarily with loss of consciousness" (Rosenbaum, Arnett, Bailey, & Echemendia, 2006). While there may not be a particular definition that universally satisfies everyone's concept of a concussion, the definitions mentioned here seem to have been the most widely accepted (Wills & Arnett, 2008).

It has been estimated that 90% of those who sustain concussions do not experience loss of consciousness (Moser et al., 2007). In the event of a concussion, a hit or a blow causes abrupt acceleration and deceleration of the brain, and rotational or linear motion causes the brain to hit against the skull. This may cause structural damage and may trigger a neurometabolic cascade, which may lead to neurocognitive and neurobehavioral impairments. Between 250,000 and 300,000 hospitalizations each year are attributed to concussions (Rosenbaum et al., 2006). Concussions are commonly sustained by athletes, and it is estimated that 5.1% of collegiate football and soccer players have been concussed at some point in their careers. However, these numbers are likely to be underestimates, as concussions are often undiagnosed (2006).

Neurometabolic Cascade

There have been several suggested mechanisms to describe the neurometabolic cascade implicated in concussion. These may include the effects of decreased cerebral blood flow (CBF), ionic and metabolic events, decreased neurotransmission, and affected vascular reactivity (Giza & Hovda, 2007). Giza and Hovda have proposed a physiological mechanism for the effects of concussion. They propose that after concussion, mechanical membrane disruption and axonal stretching causes the release of potassium ions from cells through voltage-gated potassium channels on the membrane. Non-specific depolarization causes cells to release the excitatory neurotransmitter glutamate, which activates N-methyl-D-aspartate (NMDA) and d-amino-3-hydroxy-5-methyl-4-isoxazole-propionic acid (AMPA) receptors. These receptors open cation ion channels, and thus trigger the further release of potassium and influx of calcium. Although glial cells normally function in the uptake of potassium, in the case of concussion there is too large an efflux for all of the ions to be sequestered. Thus, sodium-potassium ATPase pump, which works to maintain normal resting potential of cells, works harder to attempt to restore the membrane potential. This active pump requires energy in the form of ATP, and the increased demands of ATP cause an increase in glucose metabolism and a period of hyperglycolysis. However, the increased metabolic demands of the brain following concussion are coupled with diminished cerebral blood flow, causing a mismatch in energy availability and demand. This "energy crisis" is thought to be one of the reasons that having one concussion makes one more susceptible to further injury (Giza & Hovda, 2004). As the brain has fewer energy resources to meet the increased metabolic demands of recovery from concussion, there are even fewer available resources that would be able to meet the added demands of a second concussion. This theory may also contribute to the effects of second impact syndrome (SIS).

The effects of calcium influx may also play a role in the neurometabolic cascade following concussion. Excess calcium is sequestered in the mitochondria, where it halts oxidative phosphorylation and thus decreases the ability of the cell to undergo aerobic metabolism. Additionally, excess calcium is thought to destroy microtubules and neurofilaments, impairing neural connections. As microtubules are essential in organelle transport down the axon, organelles thus accumulate in the axon, causing axonal swelling and eventual axonomy. As an important second messenger, increased levels of intracellular calcium may cause cell death by initiating the action of phospholipases, protein kinases, and nitric oxide synthase, and can lead to apoptosis.

SIS occurs when a second brain trauma is sustained when the brain has not yet fully recovered from the initial TBI. SIS may lead to rapid neural degeneration, cerebral edema, and eventual death. It is thought that the brain is more susceptible to subsequent head injuries after the first has been sustained, making SIS more likely. Also, with each subsequent concussion, there is an increased risk for permanent neuronal damage (Giza & Hovda, 2004).

Symptomatology

Typical symptoms of concussion may be physical, cognitive, or affective in nature (Rosenbaum et al., 2006). Common physical symptoms include headache, dizziness, nausea, fatigue, problems with balance, and sleep disturbances. Cognitive symptoms may include confusion, memory difficulties, mental fogginess, nervousness, and problems with attention and concentration (Moser et al., 2007). Depression and anxiety are the most common affective symptoms (Rosenbaum et al., 2006). Empirical studies in athletes have shown that most symptoms tend to dissipate within a span of 7-10 days; however, if the athlete sustain a second injury before all the symptoms have completely disappeared, there is a heightened risk for SIS. It is crucial for symptoms to be closely monitored in patients who have suffered from concussions in order to prevent permanent neuronal damage.

Diagnosis and Neuropsychological Testing

A variety of neuroimaging techniques have been used in the study of the brain of the concussed individual, including plain radiographs, computerized tomography (CT), magnetic resonance imaging (MRI), electroencephalography (EEG), near-infrared spectroscopy, single-photon emission computed tomography (SPECT), magnetic resonance angiography, and diffusion weighted magnetic resonance imaging (Echemendia, Putukian, Mackin, Julian, & Shoss, 2001). These techniques are useful in the detection of gross structural abnormalities and vascular changes, but have only recently been shown to be useful in the diagnosis or study of mTBI. The structural and metabolic changes that occur during concussion had previously been thought to be too microscopic to be detected, but other studies have shown that certain neuroimaging techniques, especially functional magnetic resonance imaging (fMRI) and oxygen-15 positron emission tomography (O-15 PET), may be sensitive to TBI.

In a study by Ricker, Hillary, and DeLuca (2001), O-15 PET was utilized as a measure of cognition in a study that involved a paradigm comparing performance of TBI patients to controls on a cognition paradigm. TBI patients were given tasks that required free recall, cued recall, and recognition, and the brain regions involved in memory retrieval were noted. The study concluded that TBI patients need to utilize more neural resources and put forth a greater effort than controls in more cognitively-demanding tasks in order to achieve the same levels of performance. The researchers also employed fMRI studies to investigate cognition post-TBI, and found that TBI patients had increased blood flow and more diffuse cortical activation than controls during working memory tasks, as well as increased activation in the right hemisphere. The overall conclusions from this study were that TBI patients may process information less efficiently for both working memory and episodic memory recall. Following injury, there is a possibility of functional reallocation of brain substrates, which may indicate neural plasticity in neurorehabilitation. Ricker et al. concluded that brain reorganization, as well as the use of various compensatory mechanisms, may be responsible for differences in neuroimaging in TBI patients (2001).

Another study by McAllister et al. (2001) involved the use of fMRI to investigate increased working memory (WM) processing loads in mild TBI (mTBI) patients. Patients with mTBI showed increased activation during moderate WM processing loads, but decreased activation during high WM processing loads, as compared to controls. The regions of increased activation in mTBI patients were in the bilateral frontal and parietal brain regions. There was also a different pattern of allocation of processing resources in mTBI patients during the high

WM load condition. One given explanation was that in mTBI, there are problems in the ability to match the amount of resources recruited to the level of processing load; therefore, the brain may not be able to allocate more resources for the highest-load task. Overall, McAllister et al. concluded that changes in the abilities to utilize WM processing resources may be contributing factors to memory deficits seen in TBI patients (2001).

The previous two studies show promising advances in functional neuroimaging in the diagnosis and management of concussions. However, despite the recent advances in neuroimaging techniques in their sensitivity to TBI, neuropsychological testing is still considered the gold standard clinically for assessing cognitive changes that occur with mTBI.

Neuropsychological testing has been shown to be helpful in both the diagnosis and follow-up of mTBI (Echemendia, Putukian, Mackin, Julian, & Shoss, 2001). Cognitive domains such as memory recall, concentration, attention, information processing speed, visual tracking, reaction time, and the ability to problem-solve are often measured by neuropsychological concussion test batteries. The use of neuropsychological testing in the head-injured American football player has been most widely studied; however, there is less information regarding female athletes and male athletes in other types of sports (Echemendia, Putukian, Mackin, Julian, & Shoss, 2001). The neuropsychological assessment for athletes who have experienced concussion is usually comprised of both baseline and post-concussion assessments—this testing paradigm has been adapted by many high school, collegiate, and professional athletic programs (Moser et al., 2007). Neuropsychological assessments of sports-related concussion can be used to both diagnose and track recovery of concussions, and is distinct from traditional methods of neuropsychological assessment. These assessments are usually quite lengthy and extensive. They aim to assess several cognitive domains affected by concussion, especially memory, attention, information processing speed, and reaction time (Moser et al., 2007). Before the playing season, athletes are given a battery of neuropsychological tests that serve as a baseline measurement. The tests may be either paper-and-pencil tests, computerized tests, or a combination of the two. Then, if an athlete suffers a concussion, a series of similar neuropsychological tests are given in a series. Most of the time, athletes are considered to be able to return to play safely when their performance on post-concussion evaluations is comparable to their baseline performance levels. Clinical neuropsychologists are qualified to interpret the test data from neuropsychological evaluations.

Description of Neuropsychological Tests

The Penn State Sports Concussion Program utilizes an extensive testing battery for athletes who have suffered from concussions. The test battery is a combination of computerized and pencil-and-paper tasks, which aim to show performance changes in several cognitive constructs typically affected in concussion. For the purposes of this paper, only a subset of the tests that are included in the testing battery will be described: the Hopkins Verbal Learning Test-Revised (HVLT-R) a paper-and-pencil task that reflects verbal memory (Brandt & Benedict, 2001); the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) Test Battery, which consists of demographic data, a series of neuropsychological tests, and a Post-Concussion Symptom Scale (PCSS) (Lovell, Collins, Podell, Powell, and Maroon, 2000); the Brief Visuospatial Memory Test – Revised (BVMT-R), which assess changes in visuospatial memory (Benedict and Groninger, 1995); the Symbol Digit Modalities Test (Smith, 1982), which measures information processing speed (Landro, Celius, & Sletvold, 2003); and the Stroop Color-Word Test, which measures attention, information processing speed, and visual tracking (Bailey, Echemendia, & Arnett, 2006). Two tests in the battery that are used to provide information about intelligence and the affective nature of the athletes will also be included in the analysis—these tests are the Weschler Test of Adult Reading (WTAR, The Psychological Corporation, 2001), which was designed as a pre-morbid estimate of intelligence, and the Beck Depression Inventory—Fast Screen (BDI-FS) (Beck, Steer, & Brown, 2000), which is used to evaluate depression.

The main focus of this study is the Rivermead Behavioral Memory Test (RBMT). This task has been found to be a good measure of verbal memory, and verbal memory deficits are quite sensitive to concussion (Bruce & Echemendia, 2003). As previously mentioned, the RBMT is a test that was developed by Wilson, Cockburn, and Baddeley (1985) to accompany previously-existing memory tests in order to provide more insight about memory problems in everyday life (Wilson et al., 1989). The RBMT is comprised of 12 different subtests, and one subtest in particular will be the focus of this study. There are four different forms of this subtest, and it is the validation of this subtest that is of interest.

Predictions

Hypothesis 1: The four forms of the RBMT will not be equivalent

The RBMT has been shown to accurately predict everyday memory problems (de Wall, Wilson, & Baddeley, 1994). However, the four unique stories of the RBMT subtest of interest may not all be equivalent at predicting memory deficits associated with mTBI. Because the subject matter and vocabulary in the stories differ in complexity between tests, it is hypothesized that there will be significant differences in RBMT immediate and delayed recall memory scores for athletes.

Hypothesis 2: The RBMT accurately reflects verbal memory and will be highly correlated with other measures of verbal memory used in the Penn State University concussion battery.

If the RBMT is a good indicator of verbal memory, then it should be highly correlated with other tasks that also measure a similar construct. Four tasks in the Penn State Sports Concussion Program testing battery that are meant to measure memory are the HVLT-R, the ImPACT verbal and visual memory composites, and the BVMT-R. It is expected that correlations will be higher with verbal than with nonverbal memory tasks.

Hypothesis 3: The RBMT accurately reflects verbal memory and will be weakly correlated with measures in the Penn State University concussion battery that are thought to be least associated with verbal memory.

If the RBMT is a good measure of verbal memory, then it should be less correlated with other tasks that are not thought to measure memory. Four tasks in the Penn State Sports Concussion Program testing battery that are thought to measure constructs other than memory are the Symbol Digit Modalities Test (SDMT), the Stroop Test, and the Visual Motor Speed Composite and Reaction Time Composite of the ImPACT. These tasks are more likely to measure information processing speed and reaction time. Because research suggests that performance on any cognitive task is likely to be correlated within individuals to some degree, the correlations between the RBMT and these tasks are expected to be lower, though not uncorrelated, compared with the RBMT and memory tasks.

Method

Participants

The participants involved in the current study were Penn State University student athletes who were administered the Penn State neuropsychological concussion testing battery between September 2003 and October 2009. There were 162 student athletes who participated in the study. Table 1 in Appendix A contains more detailed descriptions of these subjects. The athletes were recruited from various sports teams, including football, men's and women's soccer, men's and women's lacrosse, wrestling, men's ice hockey, and men and women's basketball.

For both baseline and post-concussion assessments, athletes were administered the Penn State Sports Concussion Program neuropsychological testing battery, which includes the tests described below, as well as several other pencil-and-paper and computerized tests. Athletes were first given a baseline testing battery before the start of the season, and then, in the case of a concussion, were given the battery again—ideally, within the first 48-72 hours of injury. The battery was often administered several more times within the first two weeks following concussion. The batteries were administered by a clinical neuropsychologist, a clinical neuropsychology graduate student, or a trained undergraduate student under the supervision of a graduate student. The battery lasted approximately two hours for both the baseline and post-concussion assessments. The following section will serve to describe the neuropsychological tests of interest in more detail.

Description of Neuropsychological Batteries

Hopkins Verbal Learning Test – Revised (HVLT–R; Brandt & Benedict, 2001)

The HVLT-R is a paper-and-pencil task that reflects verbal memory. Participants are read a list of words out loud and are given three trials to verbally recall as many words as possible. A fourth trial is then presented after a delay of about 20 minutes. According to the HVLT-R manual, this task has a test-retest reliability coefficient of 0.74 (Bailey et al., 2006).

The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) Test Battery (Lovell, Collins, Podell, Powell, and Maroon, 2000)

The ImPACT consists of demographic data, a series of neuropsychological tests, and a Post-Concussion Symptom Scale (PCSS). There are six different neuropsychological tests in 2.0 version of the ImPACT, which measure cognitive functioning domains that include reaction time, attention, memory, and information processing speed. Four composite scores are calculated from these tests—these include visual memory, verbal memory, visual-motor speed, and reaction time (2000).

The Brief Visuospatial Memory Test – Revised (BVMT – R; Benedict and Groninger, 1995)

The BVMT-R was created to assess changes in visuospatial memory (Benedict and Groninger, 1995). This test has six different forms and has been shown to be sensitive to cognitive changes in adults suffering from traumatic brain injury. During the test, participants are shown a sheet of paper with six figures on it, and are given 10 seconds to study the page. They then are given a blank sheet of paper and are asked to draw the images as accurately as they can remember, and this process is repeated two more times. A delayed recall trial is presented later. Evaluation data has suggested that the BVMT-R is a valuable asset to neuropsychological testing batteries in determining visuospatial memory ability (Benedict and Groninger, 1995). In a clinical study, the BVMT-R has shown excellent inter-form reliability and construct and criterion-related validity (Benedict, Schretlen, Groninger, Dobraski, and Shpritz, 1996).

The Symbol Digit Modalities Test (SDMT; Smith, 1982)

The Symbol Digit Modalities Test (SDMT) is used to screen for various types of cerebral dysfunction, and is often used to measure information processing speed. In the SDMT, the participant is shown a key that pairs different symbols with numbers 1-9. The participant is then given 90 seconds to correctly match the symbols and numbers in a random sequence, and the total number of correct matches within 90 seconds makes up the score (Landro, Celius, & Sletvold, 2003).

The Stroop Color-Word Test (Trenerry, Crosson, DeBoe, & Leber, 1989)

In the Stroop Color-Word Test, participants are shown a list of words in different color ink and are asked to read the words aloud as quickly as possible. Then, they are asked to name aloud the color of the ink in which the word was printed. The Stroop Test is a commonly-used neuropsychological test that measures attention, information processing speed, and visual tracking (Bailey, Echemendia, & Arnett, 2006).

The Wechsler Test of Adult Reading (WTAR; The Psychological Corporation, 2001)

This test involves reading recognition, and may be used to calculate a full-scale IQ score. In this test, participants are given a sheet of paper with 50 words of increasing difficulty, and are asked to pronounce each word out loud. A point is awarded for each correctly-pronounced word, including having the emphasis on the correct syllables. The test is discontinued after 12 incorrect pronunciations in a row.

The Beck Depression Inventory—Fast Screen (BDI-FS; Beck, Steer, & Brown, 2000)

The BDI-FS is a questionnaire of seven items that determines dysphoria, anhedonia, and suicidal thoughts. In this task, participants rate sentences on a three-point scale. Scores range from 0-21, with a higher score being more indicative of depression (Benedict, Fishman, McClellan, Bakshi, & Weinstock-Guttman, 2003).

Description of RBMT

The RBMT has been found to be a good measure of verbal memory, and verbal memory deficits are quite sensitive to concussion (Bruce & Echemendia, 2003). As previously mentioned, the RBMT is a test that was developed by Wilson, Cockburn, and Baddeley (1985) to accompany previously-existing memory tests in order to provide more insight about common memory problems (Wilson et al., 1989). Many other memory tests include questionnaires, checklists, and rating scales, all of which have certain weaknesses in measuring memory deficits in a brain injured population. Completing a questionnaire about memory is itself a memory task, and asking relatives for information about their loved one's memory is not necessarily accurate (1989).

The RBMT differs from these other memory tests. This task was constructed by first questioning and observing patients with a wide range of memory deficits and then by developing 12 subtests that screen for each deficit. These 12 subtests were developed so that normal patients would pass them easily but that patients with memory deficits would fail them (de Wall et al., 1994). The subtests were validated in four different ways: (1) the scores were correlated with performance on previously-established memory tasks, (2) the scores were found to be consistently lower for patients who had been diagnosed with memory deficits; (3) the scores were correlated with memory lapses for a large number of patients over many hours' time, and (4) there was found to be a strong correlation between patients' RBMT scores and their ability to live independently five to ten years post-assessment (1994). However, Wall et al. also acknowledged that a limitation of the RBMT was that it may not be an appropriate memory screening for patients experiencing milder memory deficits (1994).

Although the entire RBMT is composed of 12 subtests, the particular subtest that includes the prose passage does not have the ceiling effect characteristic of some of the other RBMT subtests. In this subtest, the patient is read a short passage, and then is tested for both immediate recall and delayed recall after about 20 minutes. Each passage contains 21 “ideas”, and a point is awarded for each idea that is correctly recalled (Wilson et al., 1989). There are four different forms of this subtest, and it is the validation of this subtest that is of interest for the current study.

Description of Statistical Analyses

Descriptive statistics regarding the participant pool were calculated (Appendix A, Table 1). The participants were divided into four groups, based upon which form (A, B, C, D) of the RBMT that they were administered, and descriptive statistics regarding performance on each form was compiled for both immediate and delayed recall (Tables 2 and 3). One-way ANOVAs were performed to determine differences between the different RBMT forms.

Correlational analyses were performed between the convergent and discriminant validity tests. The analyses were two-tailed, and correlations below 0.05 were considered significant. One important point to note is that the ImPACT Reaction Time Composite and the Stroop 1 Total Time variables were reverse coded, as higher reaction time scores should indicate slower information processing speed. Because of this, the signs of the resulting correlations were switched, so that it matched the same direction as the other discriminant validity correlations.

Results

The Statistical Package for the Social Sciences (SPSS) version 17.0 was used to perform all of the following data analyses for this study. A table of descriptive statistics pertaining to the athletes involved in the study is listed in Appendix A (see Table 1). A one-way ANOVA was performed both between-groups and within groups for the athletes' ages, baseline WTAR estimated FSIQ scores, and the baseline BDI Fastscreen total scores. No significant differences were found.

The mean baseline scores for the athletes on the four forms (A, B, C, and D) of the RBMT for both the Immediate and Delayed Recall were compared (see Tables 2 and 3). The athletes were almost evenly split between the four forms. For both the Immediate and Delayed Recall, athletes achieved the highest mean scores on form B, followed by form A, then form D, and then form C. The forms were significantly different from one another, $F(3, 158) = 12.12$, $p < .001$. Post-hoc Tukey HSD tests revealed that forms A and B were both significantly ($p < .05$) higher than both forms C and D (see Table 2). Likewise, similar results were found in the RBMT delayed recall: the forms were significantly different from one another, $F(3, 158) = 15.84$, $p < .001$. Post-hoc Tukey HSD tests revealed that forms A and B were both significantly ($p < .05$) higher than forms C and D (see Table 3).

Descriptive statistics on the convergent and discriminant validity measures are displayed in Tables 4 and 5 in Appendix A. For the four tasks from the ImPACT testing battery that were included in the analyses, only 161 participants are included, as those data for one participant were lost. The other convergent and discriminant validity measures have data from all 162 participants.

Correlational analyses were performed to compare the convergent and discriminant validity measures with both Immediate and Delayed Recall RBMT scores. All four convergent validity measures were significantly correlated with the RBMT Immediate and Delayed Recall measures (Table 6). The HVLT-R Total Recall was the most strongly correlated with the RBMT Immediate and Delay scores. For the discriminant validity analyses, the Stroop 1 Total Time scores and the ImPACT Visual Motor Speed Composite scores were not significantly correlated with the RBMT Immediate and Delay scores. The SDMT Total Correct scores and the ImPACT Reaction Time Composite scores were significantly correlated with the RBMT Immediate and Delayed Recall scores; however, these correlations were weaker than most of the convergent validity correlations (Table 7).

Discussion

The purpose of this study was to perform a validity analysis of the RBMT, a measure of everyday memory problems, which is one of the neuropsychological tests comprising the concussion testing battery of the Penn State Sports Concussion Program. The equivalence of the four forms of the RBMT was measured. Convergent and discriminant validity analyses were also performed to see whether the RBMT is correlated with other measures of verbal memory and uncorrelated with measures that do not seek to measure verbal memory, such as information processing speed.

The first hypothesis, which stated that the four RBMT forms are not all equivalent, was supported. It was found that athletes' performance on forms A and B of the RBMT was significantly better than performance on forms C and D.

The second hypothesis, which stated that the RBMT would be highly correlated with other tests measuring memory in the testing battery, was generally supported. The RBMT was significantly correlated with the four tests in the convergent validity analysis, the HVLT-R Total Recall Score, the ImPACT Memory Composite Verbal Score, the ImPACT Memory Composite Visual Score, and the BVMT-R Total Recall Score. However, there is only some evidence for correlation, for although the correlations were significant, they were mostly small in magnitude. The strongest correlations were found between the RBMT and two of the tests that most closely measured verbal memory, the HVLT-R and the ImPACT Verbal Memory Composite. The correlations were slightly weaker for the tests that more closely measured visual memory, the ImPACT Visual Motor Speed Composite and the BVMT-R. Thus, these results indicate that the RBMT is more closely correlated with other verbal memory tasks, rather than visual memory tasks.

The third hypothesis, which stated that the RBMT would be weakly correlated with measures in the Penn State University concussion battery that are thought to be least associated with memory, was generally supported. The RBMT was not significantly correlated with the Stroop 1 Total Time Score or the ImPACT Visual Motor Speed Composite Score, demonstrating that these tasks are better indicators of information processing speed and not of verbal memory. The RBMT was significantly correlated with the SDMT Total Correct score and the ImPACT Visual Motor Speed Composite score, but these correlations were slightly weaker than the convergent validity correlations. One possible explanation for the significant correlations could be that there may be some working memory functioning involved in both the SDMT and ImPACT Visual Motor Speed tasks, whereas the Stroop 1 and the ImPACT Reaction Time Composite rely more on information processing than working memory.

Limitations and Future Research

There are several limitations in the present study, some of which may serve as areas for future research. This study only analyzed athletes' baseline RBMT scores, and not their post-concussion scores. In the future, it might be worthwhile to analyze any differences between RBMT performance scores post-concussion compared to baseline. If the RBMT is truly sensitive to concussion, then athletes should score lower after having experienced a concussion than at baseline.

Also, it could be further hypothesized that athletes who are only administered the RBMT post-concussion and not at baseline may have lower scores compared with athlete controls tested at baseline. Practice effects were not taken into consideration for the current study, but they might cause athletes to perform better on the RBMT during post-concussion assessment if they had also taken the RBMT during baseline assessment.

Finally, this study did not consider whether intelligence is related to performance on the RBMT. As a larger vocabulary is often associated with higher intelligence, those with higher intelligence may find it easier to remember the specific verbal details of the RBMT stories and may score higher on the task. In future studies, it might be useful to see if there is a correlation between performance on intelligence tests and performance on the RBMT. Future implications may also include controlling for intelligence when analyzing RBMT performance in a clinical setting.

Conclusions

Overall, this validity study demonstrated that the RBMT is a valid measure of verbal memory in a population of concussed college athletes; however, not all forms of the RBMT were found to be equivalent. While the RBMT demonstrates some convergent validity and discriminant validity, the values of some of the correlations tended to be of similar magnitude between the convergent and discriminant tasks. As many aspects of cognitive functioning—including processing speed and working memory—tend to be correlated with each other (Luciano, Wright, Smith, Geffen, Geffen, & Martin, 2001), this is not surprising. Additionally, the magnitudes of the correlations of the RBMT with the convergent validity tasks indicates that the RBMT may measure an aspect of verbal memory not captured in the other verbal memory tasks of the concussion testing battery. The HVLT-R and the ImPACT Verbal Memory Composite measure list-learning verbal memory, whereas the RBMT may utilize story context and mental reorganization in order to aid in verbal memory. As a result, the BVMT-R appears to be a relatively unique measure of verbal memory.

The findings of this study have some implications for the future of the Penn State Sports Concussion Program and other sports concussion programs. Because the RBMT forms are not equivalent, athletes who receive different forms at baseline and at assessment post-concussion may have skewed results. If an athlete were to receive one of the more difficult forms at baseline and one of the easier forms at post-concussion assessment, higher performance on the post-concussion assessment compared to baseline may erroneously indicate that the athlete has shown recovery, when that may not be the case. A simple solution would be to calculate standard scores for the different forms of the RBMT. Alternatively, finding or developing another story memory test that has equivalent alternate forms would result in a more accurate assessment of verbal memory.

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Appendix A: Tables

Table 1

Data Set Information

Measure	N	Mean	Standard Deviation
Age in years	162	18.27	0.66
Sex	162	1.28	0.45

Table 2

Baseline RBMT Immediate Recall
Descriptive Statistics

RBMT Form	N	Mean	Standard Deviation	Minimum	Maximum
A	39	7.88_a	2.63	3.00	15.00
B	40	8.60_a	2.66	5.00	16.50
C	41	5.74_b	2.31	1.50	11.50
D	42	6.00_b	2.65	0.00	13.00
Total	162	7.03	2.82	0.00	16.50

Note: Means with subscripts having different letters are significantly different from one another using Tukey's HSD Post-Hoc Test.

Table 3

Baseline RBMT Delayed Recall
Descriptive Statistics

RBMT Form	N	Mean	Standard Deviation	Minimum	Maximum
A	39	7.12_a	2.71	2.50	14.00
B	40	8.01_a	2.42	4.00	13.00
C	41	4.87_b	2.13	0.50	8.50
D	42	5.05_b	2.63	0.00	13.00
Total	162	6.23	2.81	0.00	14.00

Note: Means with subscripts having different letters are significantly different from one another using Tukey's HSD Post-Hoc Test.

Table 4

Descriptive Statistics: RBMT and Convergent Validity Measures

Measure	N	Mean	Standard Deviation
Baseline RBMT Immediate	162	7.03	2.82
Baseline RBMT Delay	162	6.23	2.81
Baseline HVLT-R Total Recall	162	26.23	3.72
Baseline ImPACT Memory Composite: Verbal	161	86.04	11.01
Baseline ImPACT Memory Composite: Visual	161	76.79	12.58
Baseline BVMT-R Total Recall	162	28.16	5.28

Table 5

Descriptive Statistics: RBMT and Discriminant Validity Measures

Measure	N	Mean	Standard Deviation
Baseline RBMT Immediate	162	7.03	2.82
Baseline RBMT Delay	162	6.23	2.81
Baseline SDMT Total Correct	162	60.91	11.70
Baseline Stroop 1 Total Time	162	53.88	10.72
Baseline ImPACT Visual Motor Speed Composite	161	35.86	7.85
Baseline ImPACT Reaction Time Composite	161	0.59	0.08

Table 6

Correlational Analysis Between RBMT Immediate and Delayed Recall and Convergent Validity Measures

		Baseline HVLT-R Total Recall	**Baseline ImPACT MC Verbal**	**Baseline ImPACT MC Visual**	**Baseline BVMT-R Total Recall**
Baseline RBMT Immediate	**Pearson Correlation**	0.28**	0.19*	0.18*	0.20*
	Sig. (2-tailed)	0.00	0.02	.02	0.01
	N	162	161	161	162
Baseline RBMT Delay	**Pearson Correlation**	0.28**	0.28**	0.23**	0.27**
	Sig. (2-tailed)	0.00	0.00	0.00	0.00
	N	162	161	161	162

****Correlation is significant at the 0.01 level (2-tailed)**
***Correlation is significant at the 0.05 level (2-tailed)**

ImPaCT MC Verbal: ImPACT Memory Composite Verbal Score
ImPACT MC Visual: ImPACT Memory Composite Visual Score

Table 7

Correlational Analysis Between RBMT Immediate and Delayed Recall and Discriminant Validity Measures

		Baseline SDMT Total Correct	**Baseline Stroop 1 Total Time**	**Baseline ImPACT Visual Motor Speed Comp**	**Baseline ImPACT Reaction Time Comp**
Baseline RBMT Immediate	**Pearson Correlation**	0.20*	0.05	0.08	0.20*
	Sig. (2-tailed)	0.01	0.57	0.32	0.01
	N	162	162	161	161
Baseline RBMT Delay	**Pearson Correlation**	0.19*	0.078	0.08	0.18*
	Sig. (2-tailed)	0.02	0.32	0.31	0.03
	N	162	162	161	161

****Correlation is significant at the 0.01 level (2-tailed)**
***Correlation is significant at the 0.05 level (2-tailed)**

ImPaCT Visual Motor Speed Comp: ImPACT Visual Motor Speed Composite Score
Baseline ImPACT Reaction Time Comp: Baseline ImPACT Reaction Time Composite Score

Appendix B: Academic Vita

Kristina R. Krecko
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(717) 364-4402 (cell)

Permanent Address: 824 Plymouth Rd., Hershey, PA 17033
(717) 533-6944 (home)

Education

The Pennsylvania State University, University Park, PA
Bachelors of Science in Biology - Expected Graduation May 2010
Vertebrate Physiology Option
Minor: Psychology

Schreyer Honors College: Fall 2006 – Spring 2010
Honors in Psychology – Emphasis in Clinical Neuropsychology

Thesis – Examining the Equivalence of Story Memory Test Forms in Assessing Verbal Memory in Concussed College Athletes
Thesis Supervisor – Peter A. Arnett, Ph.D.
Honors Adviser—Kenneth N. Levy, Ph.D.

Research Experience

Penn State Concussion Program University Park, PA 1/2008-Present

Research Assistant
- Administer 2-hour neuropsychological concussion batteries to college athletes to analyze cognitive functioning
- Perform coding, reliability-checks, and data entry
- Train new research assistants

Penn State College of Medicine University Park, PA 5/2007-8/2007

Laboratory Intern
- Researched putative SNPs responsible for skin pigmentation in African and East Asian human populations, using zebrafish as a model organism
- Operated HapMap Online Database to search for known SNPs

- Assisted in various laboratory procedures, including DNA and protein purification, morpholino knockdown, gel electrophoresis, UV imaging techniques, and PCR

Other Experiences

Teaching Assistant at The Pennsylvania State University

- Mammalian Physiology, for Dr. James Strauss — Fall 2009
- Medical Embryology, for Dr. James Strauss — Spring 2010

Hershey Medical Center Clinical Preceptorship Program Hershey, PA 6/2008

Student Participant

- Shadowed internists and emergency medicine physicians full-time for 4 weeks
- Participated in problem-based learning activities, worked in a simulation laboratory, and attended presentations in order to gain exposure to a medical school setting

Shadowing (40+ hours) Hershey, Harrisburg, and York, PA 5/2007-5/2008

- Enhanced knowledge of various medical professions by shadowing different physicians:
  - Shadowed a pediatrician from Penn State Hershey Medical Center
  - Shadowed a psychiatrist in private practice
  - Shadowed a nephrologist from Pinnacle Health System—Harrisburg Hospital

Activities

Member of Phi Beta Kappa, Honors Society 3/2010-Present

Member of Alpha Epsilon Delta, Pre-med Honors Society 4/2008-Present

Penn State IFC/Pan-Hellenic Dance Marathon, Atlas Team 9/2006-4/2009