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CONSTRUCT VALIDITY AND CLINICAL UTILITY OF SEVERAL TESTS OF MEMORY IN NORMAL AND TRAUMATICALLY BRAIN INJURED YOUTH

by

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Abstract

This dissertation embodies five papers concerning memory functioning in "normal" and traumatically brain injured youth, aged 9-15 years. The purpose of the research was to provide information regarding the construct validity and clinical utility of several tests of memory in youth. The first paper explores the principal component structure of the Continuous Visual Memory Test (CVMT), the Selective Reminding Procedure (SRP), the Consonant Trigrams Test (CTT), and the Wechsler Memory Scale – Revised (WMS-R): Logical Memory (LM) and Visual Reproduction (VR) subtests in a group comprised of 471 "normal" children and a group of 239 "normal" adolescents. Results of this study revealed varied component structures between the children and adolescents and did not consistently support a distinction between verbal and visual memory. In the second paper, the clinical sensitivity of the SRP to verbal learning and memory deficits in adolescents with moderate to severe traumatic brain injury (TBI) was examined. The final three papers examined the clinical sensitivity of the WMS – R: LM and VR subtests, the CTT, and the CVMT to visual and verbal memory deficits in youth with moderate to severe TBI. Results of the experimental studies revealed that the TBI youth performed worse than controls on the majority of SRP variables. Performance of the TBI patients on the delayed trials of LM and VR was consistently worse than controls. TBI youth also performed lower than controls on the 3 and 9-second delays of the CTT but not on the 18-second delay, suggesting that this lengthy delay may be too difficult even for "normal" children. There was no significant difference in performance between the TBI patients and controls on the CVMT. Clinical implications of these results and future areas of potential research are discussed.

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Table of Contents

List of Tables

Table **Description** **Page**

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 1

Introduction

Introduction

As the leading cause of death and a major contributor to disability in North American youth, traumatic brain injury (TBI) is a major social and public health concern. Although estimates of incidence vary because of differences in hospital reporting practices and discrepancy in definitions for classification, it is apparent that TBI is a significant problem in contemporary society. Kraus (1995) analyzed published literature regarding the demographics of TBI and found an average incidence rate of 200 per 100,000 children per year. Although the majority of injuries are mild, approximately 10 to 15 percent of cases are more serious and may result in long-standing consequences for the injured youth, their families and society as a whole (Annegers, 1983; Kraus, 1995).

Survivors of TBI exhibit heterogeneous problems that can range from persistent vegetative states to milder degrees of physical, emotional, behavioral, and/or cognitive disabilities (Fletcher & Levin, 1988). While early researchers believed that young brains had better potential than mature brains to restore damaged tissue and regenerate axons (Lynch & Gall, 1979), views regarding this perspective have been shifting. Current research indicates that recovery from paediatric TBI is related to a plethora of variables, including the mechanism and severity of injury, premorbid characteristics, size and location of lesions, as well as age (Ewing-Cobbs, Fletcher, & Levin, 1985; Levin, Ewing-Cobbs, & Eisenberg, 1995). Although the severity of injury appears to be the most assiduous predictor of post-injury sequelae, there appears to be no simple linear formula for predicting outcome from TBI in the developing brain (Fletcher & Levin, 1988; Levin, Ewing-Cobbs, & Eisenberg, 1995). In fact, a further complicating variable in paediatric TBI is that difficulties with cognition may not be immediately apparent, but can emerge as the youth matures and demands for new learning or organizational adeptness increase (Guthrie, Mast, Richards, McQuaid, & Pavlakis, 1999). That is, the youth may grow into his/her disability. For example, potential problems in the development of reading skills may not be identifiable in a preschooler immediately after TBI, but may become evident later in the child's development.

Among cognitive deficits of TBI, researchers have demonstrated that memory impairments are among the most significant and pervasive (Dalby & Obrzut, 1991; Ewing-Cobbs et al., 1998; Telzrow, 1987). Understanding the nature and extent of these deficits is essential for the Psychologist whose objective is to provide direction to the injured individual, family members, rehabilitation teams, and educators.

Over the last several decades, a great deal of labor has been dedicated to developing instruments to assess various aspects of attention and memory in youth. As a logical continuation to this movement, this dissertation was proposed to examine the construct validity and the clinical utility of several measures of memory that have been recently normed for children and adolescents. These issues were addressed through five papers that are briefly summarized at the end of this chapter.

Memory

The purpose of this section is to introduce a basic framework for understanding human learning and memory. Although components of memory will be discussed individually, it is not to suggest that these components are conceptually or neuropsychologically independent of one another. Neither is this discussion intended to provide an exhaustive review of cognitive theory regarding memory. Rather, the intent is to set the stage for the five papers, which are concerned with the performance of normal and brain-injured youth on specific learning and memory measures.

Information processing theory.

Atkinson and Shiffrin (1968) proposed a model of memory that was very influential in the study of human learning and recall. Their model was the first to distinguish between two separate storage systems in memory, short-term (STM) and long-term (LTM). STM was believed to be a temporary storage system that could hold a finite amount of information, roughly seven chunks, as is illustrated in an individual's ability to briefly maintain a seven-digit telephone number in memory. In contrast, LTM was conceptualized as a more enduring record of information with infinite capacity.

Atkinson and Shiffrin (1968) proposed that information is transferred from STM to LTM through rehearsal. Basically, information enters STM from the environment through a sensory register. If this information is rehearsed, it may enter LTM, thereby creating space in STM for more information from the environment. However, according to their model, information decays if it is not rehearsed or if new information that exceeds the capacity of STM is presented. In essence, when new information enters STM, old information in STM either decays or is transferred to LTM.

Basic experiments initially provided support for Atkinson and Shiffrin's (1968) theory, but their model was later shown to be too simplistic and unable to account for the complex processes of memory. Studies began to suggest that factors beyond rehearsal contributed to the consolidation of information in LTM. For example, Glenberg, Smith, and Green (1977) instructed examinees in their study to consider a four-digit number for two seconds and then rehearse a word for two, six or 18 seconds. Subjects were then asked to recall the four-digit number. The participants were administered 64 trials and were led to believe that the examiner was interested in digit recall, not the words. However, at the end of the test period, study participants were asked to recall the words that they had rehearsed. The results of their study demonstrated no relationship between rehearsal and word retrieval. Recognition of the words had a weak relationship with rehearsal, suggesting that repetition alone does not ensure encoding into or retrieval from LTM.

Craik and Lockhart (1972) also felt that factors other than rehearsal were related to recall and argued that a rather abstract concept called "depth of processing" played a role in recall. They suggested that rehearsal only improves recall if the information is rehearsed in a meaningful way. That is, simple repetition of information is not enough to improve recall. However, if a word is rehearsed in a sentence, for example, it increases the likelihood of it being recalled because this provides semantic meaning to the word. According to Craik and Lockhart's theory, information processed with semantic meaning is more deeply processed than information processed based on, for example, phonetic sound.

Working memory.

In contemporary cognitive psychology, the term working memory replaces the term short-term memory. Baddeley and Hitch (1974) and Baddeley (1986) described a model of working memory that comprises three main components: (1) the central executive, (2) the phonological loop, and (3) the visuospatial sketchpad. The central executive's function is to coordinate information in working memory that is obtained through the phonological loop and the visuospatial sketchpad, the slave systems of the central executive. The central executive makes decisions regarding which information will be registered in working memory and later transferred to LTM, retrieves information from LTM, and is believed to be responsible for the operations of logical reasoning and mental arithmetic (Baddeley, 1986). The visuospatial sketchpad, as its name implies, briefly holds visual and spatial information. Baddeley proposed that individuals can rehearse mental images to maintain information. In everyday life, this system is believed to be involved in tasks such as navigation and architectural work. The second slave component to the central executive, referred to as the phonological loop, holds verbally based information. Similar to STM, the phonological loop has a limited capacity. However, its capacity is believed to relate to time and extends approximately two seconds. To illustrate, Hulme and MacKenzie (1992) reported that average digit span performance varies across languages. In English the average digit span is seven, which corresponds to the usual number of digits that can be articulated by English speakers in two seconds. In contrast, Chinese speakers have an average digit span of nine, because their digits can be articulated more efficiently. Decay of this phonological information, however, remains a problem without rehearsal.

In summary, although Baddeley and Hitch's (1986) model of working memory continues to evolve, at the present time neuropsychological data appears to support their model that memory is organized, to some extent, using various modalities. For example, researchers have found that deficits in visual memory may be more related to right than left-hemisphere damage and verbal memory problems may be related to damage in the left-hemisphere (Hanley, Young, & Pearson, 1991; Sass et al., 1990; Trahan, Larrabee, & Quintana, 1990). Although the results of research into lateralization of verbal and visual memories is by no means conclusive, research into this area underscores the importance of comprehensive assessment of an individual's functioning to determine strengths and weaknesses in ability.

Long-term memory.

LTM is the storage place for an individual's knowledge and its capacity continues to be conceptualized as unlimited. A belief that is widely accepted is that LTM holds two major types of information: implicit and explicit memory. Implicit memory is knowledge of how to do things, can be acquired through practice, and is stored unconsciously (Howard, 1995). It is also thought to be less vulnerable to forgetting than is explicit memory, even in traumatically brain injured children (Shum, Jamieson, Bahr, & Wallace, 1999). Explicit memory is more consciously available to individuals and refers to knowledge that can be reported and of which individuals are consciously aware (Cohen & Squire, 1980; Schacter, 1987). It is also believed to be more vulnerable to deterioration and does not necessarily need practice to be learned (Howard, 1995).

It is important in this discussion to also distinguish between three commonly proposed stages of LTM: (1) acquisition, (2) retention, and (3) retrieval. Acquisition refers to an individual taking in information and then storing it within LTM or adding information to stores already available in LTM. Retention refers to how well the information in storage is retained over time and the retrieval process refers to how well cues activate particular memory stores.

Traumatic Brain Injury Defined

TBI is a complex problem that provides unique challenges for children who are in the midst of development. It occurs when an external force produces a temporary or permanent reduction in the brain's ability to control physical, behavioral, emotional or cognitive functions (Savage & Wolcott, 1994). Within the category of TBI, a primary distinction is made between non-penetrating (blunt) injuries and penetrating injuries. In a penetrating injury, the dural lining of the brain is damaged by a projectile (e.g. a knife or a bullet) or by depression of the skull. Non-penetrating or blunt injuries are usually the result of falls, motor vehicle or bicycle accidents, sporting injuries or assaults, and do not result in penetration of the dural lining of the brain. Non-penetrating traumatic brain injuries are the focus of the current study.

Injuries related to TBI are usually categorized as primary or secondary. Primary injuries occur at the time of trauma and can include skull fractures, intracranial hematomas, contusions, lacerations, and diffuse axonal injury. Diffuse axonal injury is often the result of coup, contrecoup, and/or rotational inertia. This type of injury is very common subsequent to brain injuries in which individuals are thrust forward and then stopped by something (e.g. a windshield). Although the head stops, the brain often lags behind, leading to tearing and shearing of neurons. Secondary injuries develop indirectly from the injury and may include hypoxia and hypotension, elevated intracranial pressure, mass lesions, cerebral swelling and edema (Pang, 1985).

TBI Injury Severity

Injury severity is typically classified based on two rating systems: the Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) and length of post traumatic amnesia (PTA; Russell, 1932; Jennett & Teasdale, 1981).

Glasgow Coma Scale.

The GCS was originally developed with the goal of standardizing the assessment of depth and duration of impaired consciousness and coma. It incorporates three aspects of behavior in its measurement: (a) eye opening response, (b) verbal response, and (c) motor response. Scores range from 3-15 and are typically classified as mild (score of 13-15), moderate (9-12), and severe (3-8). Test items for eye-opening are on a four-point scale, with a score of four representing a spontaneous opening and one representing the absence of opening. Test items for the verbal response range from one to five, with five indicating normal speech and orientation, and one representing no verbal response. Finally, motor response scores range from one to six, with six indicating an ability to follow simple motor commands to one, indicating a flaccid patient. The sum of the scores from eye opening, verbal and motor responses can range from 3 to 15.

Post traumatic amnesia.

The term PTA, originally introduced by Russell (1932), corresponds to the length of time from injury to the time in which the injured individual is able to retain a memory of ongoing events. In a revision of Russell's (1932) classification system, Jennett and Teasdale (1981) developed a description for PTA that is commonly employed and which was regarded in this manuscript. Their PTA classification system is as follows:

Table 1

Post Traumatic Amnesia Classification System

Classification of injury	Length of PTA
Very mild	Less than five minutes
Mild	5 to 60 minutes
Moderate	1 to 24 hours
Severe	1 to 7 days
Very severe	1 to 4 weeks
Extremely severe	More than four weeks

Note. PTA: Post traumatic amnesia.

Purpose and Approach of the Present Research

The purpose of this research was twofold. First, an examination was conducted to explore the component structure of various verbal and visual memory tests in normal youth, aged 9-15 years, to further elucidate information regarding memory functioning at this age. Second, the clinical utility of various measures to memory difficulties in children and adolescents with significant TBI was examined. Specific hypotheses are presented in the individual papers, included in chapters two through six. The final section of this manuscript includes a general discussion that integrates the findings of the five papers. Below is list of the five papers:

Paper 1. Construct Validity of Several Tests of Memory: Comparison of Two Normal Paediatric Samples. This paper was exploratory in nature and examined the component structure of the Continuous Visual Memory Test (CVMT: Trahan & Larrabee, 1988), the Wechsler Memory Scale – Revised Logical Memory and Visual Reproduction subtests (WMS-R LM & VR: Wechsler, 1987), the Consonant Trigrams Test (CTT: Brown, 1958; Peterson & Peterson, 1959), and the Selective Reminding Procedure (SRP: Buschke, 1973) in groups of children aged, 9-12 and 13-15 years.

Paper 2. Clinical Utility of the Selective Reminding Procedure in Adolescents with Moderate to Severe Traumatic Brain Injury. This paper examined the verbal learning and memory performance of TBI adolescents (aged 13-15 years), relative to matched controls, using the Selective Reminding Procedure.

Paper 3. Wechsler Memory Scale – Revised: Clinical Utility of Logical Memory and Visual Reproduction in Youth with Moderate to Severe Traumatic Brain Injury. This paper examined the performance of TBI youth (aged 9-15 years), relative to matched controls, on the Logical Memory and Visual Reproduction subtests from the Wechsler Memory Scaled-Revised.

Paper 4. Clinical Utility of the Consonant Trigrams Test in Youth with Moderate to Severe Traumatic Brain Injury. This paper examined the performance of TBI youth (aged 9-15 years), relative to controls, on the Consonant Trigrams Test.

Paper 5. Clinical Utility of the Continuous Visual Memory Test in Youth with Moderate to Severe Traumatic Brain Injury. This paper examined the performance of TBI youth (aged 9-15 years), relative to controls, on the Continuous Visual Memory Test.

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Chapter 2

Construct Validity of Several Tests of Memory: Comparison of Two Normal Paediatric Samples

Construct Validity of Several Tests of Memory: Comparison of Two Normal Paediatric Samples

Memory functioning is among the most commonly investigated sequelae of traumatic brain injury (TBI; Dalby & Obrzut, 1991; Fletcher & Levin, 1988; Telzrow, 1987). Psychological tests are typically utilized to provide standard assessment of memory and they may involve examination of various modalities (e.g. verbal and visual) and dimensions of memory (e.g. working memory, immediate recall, delayed recall, and recognition). To evaluate memory, clinicians may utilize a standard scale, designed to assess multiple aspects of memory (e.g. Wide Range Assessment of Memory and Learning [WRAML], Shelsow & Adams, 1990; Wechsler Memory Scale- Revised [WMS-R], Wechsler, 1987). They may also employ combinations of specialized tests of memory to assess this construct.

Concomitant with growth in the area of paediatric neuropsychology, a battery of individual memory tests, originally designed for adults, has recently been normed in a large paediatric sample of youth from a major Canadian city. The tests were the Logical Memory (LM) and Visual Reproduction (VR) subtests from the WMS-R (Wechsler, 1987), the Continuous Visual Memory Test (CVMT; Trahan & Larrabee, 1988), Consonant Trigrams Test (CTT; Brown, 1958; Peterson & Peterson, 1959), and the Selective Reminding Procedure (SRP; Buschke, 1973). Normative data for each of these measures has been made easily accessible to clinicians in individually published manuscripts and books (Miller, Murphy, Paniak, LaBonte, & Spackman, 1996; Miller, Murphy, Paniak, Spackman, & LaBonte, 1998; Paniak, Miller, Murphy, Andrews, & Flynn, 1997; Paniak, Murphy, Miller, & Lee, 1998). However, although the construct validity of the CVMT, SRP, the CTT, LM and VR has been examined in adult samples (e.g., Boone, Ponton, Gorsuch, Gonzalez, & Miller, 1998; Elwood, 1993; Larrabee & Curtiss, 1995; Larrabee, Trahan, & Curtiss, 1992; Smith, Malec, & Ivnik, 1992), a review of the literature did not reveal any studies of the construct validity of these tests in youth. The absence of such information can impede a clinician's ability to interpret test results. Thus, the aim of the present study was to examine the construct validity of the CVMT, SRP, CTT, LM and VR using principal components analysis techniques in two large community samples of youth, aged 9-12 and 13-15 years.

A number of studies have investigated the construct validity of the measures of interest in adults. For example, several studies examining the factor structure of the WMS-R in mixed clinical samples of males produced a single factor that included Logical Memory and Visual Reproduction (Elwood, 1991, 1993). However, separate verbal and visual memory factors were not supported, nor were differences between immediate/acquisition and delayed trials even when percent retention scores were substituted for delay scores (Elwood, 1991; Elwood, 1993). These findings are somewhat unexpected given that the WMS-R was designed to assess multiple aspects of memory and given that Wechsler's (1987) examination of the component structure of the WMS-R using the original standardization sample resulted in two factors: general memory and learning, and attention/concentration. Roth, Conboy, Reeder, and Boll (1990) examined the factor structure of the WMS-R in a TBI sample and found three factors: attention/concentration, immediate memory, and delayed memory. LM and VR acquisition trials (LM I & VR I) loaded on the immediate memory factor and LM and VR delayed trials (LM II & VR II) loaded on the delayed memory factor. Separate verbal and visual memory factors were not found.

Several recent studies have also examined the factor structure of the WMS-R acquisition and delayed trials in combination with other cognitive tests. Leonberger, Nicks, Goldfader, and Munz (1991) reported the results of a principal component factor analysis derived from a mixed clinical sample of patients referred for neurological reasons. In their study, LM I and LM II both loaded on a verbal memory factor that was relatively independent of attention and verbal reasoning skills. In contrast, VR I and VR II were more closely associated with a spatial/nonverbal reasoning factor than a memory factor, suggesting that VR taps spatial reasoning and not simply visual memory.

Although all of the above factor analytic studies combined the WMS-R LM and VR immediate and delayed trials in their analyses, some authors advise against this procedure (Larrabee, Kane, Schuck, & Francis, 1985; Smith et al., 1992). These authors contend that due to the intercorrelations between immediate and delayed trials, secondary to analogous testing procedures that use the same stimulus, spurious factors that are related more to method variance than true constructs may be found when immediate and delayed trials are included in the same factor analyses. Several studies have adhered to this recommendation and examined immediate and delayed trials in separate analyses. One of these studies examined the factor structure of the WMS-R with other measures in a mixed brain injured sample and found that LM I and LM II loaded on general memory factors that were separate from the Weschler Adult Intelligence Scale – Revised (Leonberger, Nicks, Larrabee, and Goldfader, 1992; Wechsler, 1981). In contrast, VR I was more closely associated with a nonverbal/spatial reasoning factor than memory, and

VR II contributed to a general memory factor as well as a nonverbal/spatial reasoning factor. Interestingly, separate verbal and nonverbal memory factors did not emerge. In a study examining the construct validity of the CVMT in normal adults, researchers found that the CVMT d' (acquisition) score and VR I both had modest associations with attentional and verbal intellectual factors, but did not load strongly on a memory factor (Larrabee et al., 1992). In contrast, the delayed score from the CVMT and VR II loaded on a separate visual memory factor, apart from nonverbal/spatial tasks and verbal memory tests. Consistent long-term recall (CLTR), an acquisition score from the SRP, loaded on a verbal learning and memory factor that was separate from vocabulary/verbal intellectual functioning and visual/nonverbal cognitive factors.

Smith et al. (1992) examined the construct validity of nonverbal memory in a normal elderly sample using a variety of tests. They combined immediate and delayed scores in the same analysis but not if they were from the same subtest. That is, LM II and VR I were included in one analysis; however, VR I and VR II were analyzed in separate procedures. This approach avoids the problem of intercorrelations between immediate and delayed trials from the same subtest creating spurious factors. Their results failed to find separate verbal and nonverbal memory factors or a distinction between immediate and delayed memory factors. Similar to the Leonberger et al. (1992) findings, VR I loaded with visual perceptual tests and VR II loaded on perceptual organization and general memory factors. LM II loaded on a general memory factor that was distinct from a factor comprised of the Vocabulary and Information scores from the WAIS-R.

Larrabee and Curtiss (1995) examined the factor structure of several tests including the SRP, CVMT and the VR subtest from the WMS (Wechsler, 1945) in a mixed clinical sample. In their analyses of immediate scores, they found that CLTR from the SRP and CVMT Total (acquisition) score loaded on a general memory factor that was separate from verbal and spatial intelligence. Consistent with results of previous studies (Leonberger et al., 1992; Smith et al., 1992), VR I was more closely related to a visual spatial intelligence factor than memory. The SRP delay score, VR II, and CVMT delay scores all loaded on a general memory factor.

Boone et al. (1998) conducted a factor analytic study using a mixed clinical and normal sample to examine the construct validity of several tests thought to be related to prefrontal lobe functioning. The CTT and the Wisconsin Card Sorting Test (WCST: Heaton, 1981) were among these tests and LM and VR were included as marker variables, purportedly representing nonfrontal lobe abilities. The WCST was used as a marker variable of cognitive flexibility in the present study and thus the results of the Boone et al. (1998) study are pertinent to this report. Boone et al. found a three-factor solution in which WCST variables loaded on a cognitive flexibility factor, separate from the CTT scores, which loaded on a factor of divided attention and short-term memory. A Verbal Intelligence Quotient loaded highly on the same factor as the CTT variables. However, LM and VR did not appear to be strongly associated with any of the factors.

In summary, a number of construct validity studies provide support for the LM immediate and delayed trials (Leonberger et al., 1991; Leonberger et al., 1992; Smith et al., 1992), while most factor analytic studies suggest that VR immediate is more strongly related to spatial than memory abilities (Larrabee & Curtiss, 1995; Leonberger et al., 1992; Smith et al., 1992). The delayed trial of VR and the CVMT acquisition scores have produced varied results, with some studies relating performance on these measures to visual spatial skills and others to memory ability (Larrabee & Curtiss, 1995; Larrabee et al., 1992; Leonberger, 1992; Smith et al., 1992). SRP acquisition and delayed scores have typically loaded on verbal learning and memory or general memory factors (Larrabee & Curtiss, 1995; Larrabee et al., 1992). In the only factor analytic study known to have examined the construct validity of the CTT, results indicated that the CTT variables loaded on a short-term memory/attentional factor that was separate from a cognitive flexibility factor but related to verbal intelligence (Boone et al., 1998). Finally, the presence of separate verbal versus nonverbal constructs of memory has varied across studies (e.g., Elwood, 1991, 1993; Larrabee et al., 1992; Leonberger et al., 1991; Roth et al., 1990).

In the present study, the component structure and construct validity of the CVMT, CTT, SRP, and LM and VR from the WMS-R was examined in two samples of children, aged 9-12 and 13-15 years. The groups were divided and analyzed by age because the SRP employs separate forms in these two age groups. In addition, it was of interest whether the component structure of these tests would vary with age. Variations in the factor structure of the WMS-R by age have been documented with adults (Bornstein & Chelune, 1989). Also, the effect of age on performance of youth on the measures of interest has been documented (Miller et al., 1996; Miller et al., 1998; Paniak et al., 1997; Paniak et al., 1998). However, in youth, the effect of age on the constructs measured by memory tests has not been well examined.

Method

Participants

Participants were 716 children aged 9 to 15 years who were recruited from Edmonton Public Schools as part of a larger normative data study. Consent was first obtained from Edmonton Public Schools and then was followed by a request for parental consent. Children for whom parental consent was obtained were selected to participate if they passed a screening. To be eligible for participation in the study the children must have met the following criteria: (a) English must have been the main language used at home, (b) regular education placement with no history of learning difficulties and/or special education services due to a major psychiatric disorder or a documented brain injury, and (c) no history of hospitalization due to behavior difficulties or brain injury. Children were not excluded from the study if diagnosed with attention deficit hyperactivity disorder unless they had been hospitalized for treatment of this disorder.

Participants ranged in age from 9 to 15 years. 710 participants were included out of the 716 included in the initial database. Six participants were excluded due to missing data or to outlying scores that might skew the data. In total, there were 385 females and 325 males. The number of participants in age contingents were: 9 yrs, $n = 79$; 10 yrs, $n = 140$; 11 yrs, $n = 130$; 12 yrs, $n = 122$; 13 yrs, $n = 96$; 14 yrs, $n = 115$; 15 yrs, $n = 28$.

Measures

Continuous Visual Memory Test.

The CVMT is a neuropsychological test that measures both acquisition and delayed recognition of abstract visual designs (Trahan & Larrabee, 1988). The CVMT involves three tasks: (a) acquisition, (b) delayed recognition, and (c) visual discrimination. The first task, acquisition, involves presentation of 112 complex designs from which the examinee is required to identify "new" versus "old" designs. With the presentation of each design, the examinee is required to identity the design as "new" (first time presented) or "old" (presented previously).

The second task involves a delayed recognition component. Following a thirty minute delay, the examinee is presented with seven designs that he/she has seen previously during the acquisition phase. Six of the designs were presented once previously while one design was presented seven times during the acquisition phase. The examinee is asked to identify which design has been seen more than once. There are seven trials for the delayed recognition task. The third task involves a visual discrimination examination. The examinee is presented with a card with a single design and with a card with seven small designs, one being the design on the card with the single design. The examinee is asked to identify which design on the card with multiple designs matches the single design. This task involves seven trials and is administered to assist in discriminating visual memory problems from visual discrimination problems (Trahan & Larrabee, 1991; Trahan & Larrabee, 1988). Measures used from this test were: (a) delayed recognition (the number of correct responses on this task), and (b) total (the number of correctly identified old and new designs).

Wechsler Memory Scale - Revised (Logical Memory and Visual Reproduction).

The WMS-R (Wechsler, 1987) is a test developed for examining various dimensions of memory functioning. The test has subtests that purport to evaluate verbal and visual memory and employs both immediate and delayed recall measures. Although the WMS-R has 12 subtests, in the present study only the two most commonly used subsets, LM and VR, were utilized (Butler, Retzlaff, & Vanderploeg, 1991). For LM I, the examinee is required to recall as much information as possible from two brief stories immediately following their oral presentation. For LM II, the examinee is required to recall as much as possible from each of the two stories, 30 minutes later. Essentially, LM I purports to measure immediate verbal recall, while LM II measures delayed recall of verbal information. Scores from LM I, LM II and a savings score (LM I/LM II) were calculated for use in the analyses.

Visual Reproduction I (VR I) involves the presentation of four cards containing designs. Following the presentation of each design for 10 seconds, the examinee is required to draw it. VR II requires the examinees to draw each of the designs again but 30 minutes following their initial presentation. VR I purports to measure immediate visual recall while VR II strives to assess delayed recall of visual information (Wechsler, 1991). Scores for both VR I, VR II and a savings score (VR I/VR II) were used in the analyses.

Brown-Peterson Auditory Short Term Memory Task.

The Brown-Peterson Auditory Short Term Memory Task (Consonant Trigrams Test – CTT) is proposed as a test of auditory short term memory (Brown, 1958; Peterson & Peterson, 1959). Administration of the CTT involves the presentation of three consonants followed by a number. In the adult version, examinees are required to count backwards by threes from a three-digit number for a specified time period, and then they are requested to recall the consonants. Time period delays for adults usually range from 0 to 36 seconds. In the children's version (Paniak et al., 1997), children count backwards by ones and the delay periods are 3, 9, and 18 seconds. To accommodate for their young age, the examinees are also only presented with two digit numbers as start points for counting backwards. Five trials at each delay interval are administered for a total of 15 trials. Scores for each delay interval (i.e. 0", 3"," 9", & 18") may range from 0 to 15 and represent the number of consonants recalled. A total score ranging from 0 to 45 is also calculated. The 0" delays are administered as practice items and are not included in the total score. In this study, the total score across all delay intervals for each participant was used in the analyses.

Selective Reminding Procedure.

The Selective Reminding Procedure (SRP) is a test of verbal learning and memory originally developed by Buschke (1973). It involves the oral presentation of a list of 12 words to the examinee. Immediately following this presentation, the examinee is required to recall as many of the words on the list as possible. Following the first trial, the examiner repeats only the words that the examinee did not recall. The examinee then is requested to verbally recall as many words as possible from the entire list. This process continues for eight consecutive trials (with children) or until the examinee recalls all of the words on the list for two consecutive trials. Several scores can be derived. The scores utilized in this study were: (a) Consistent Long Term Retrieval (CLTR) which refers to retrieval of a word on every trial once it has entered Long Term Storage (LTS), which refers to recall of a word on at least one trial without a reminder and (b) Total recall (refers to the number of words the examinee recalls from the list 30 minutes following the eighth trial). "Savings" scores based on the examinees recall on the last trial/recall after the 30 minute delay were also calculated. For the purposes of the current study two different age forms were used (Form A: 9 – 12 years) and (Form 1: 13-15 years).

Wisconsin Card Sorting Test.

The WCST is proposed to be a test of abstract abilities, mental flexibility and executive function (Heaton, 1981). The test stimuli consist of two identical decks of 64 cards each. Each card displays one to four shapes. The shapes on each card are presented in one of four colors. Four stimulus cards that vary along the same dimensions are also presented. The test is administered by placing the four stimulus cards in front of the examinee. The examinee is then asked to match each of the 128 cards to one of the four stimulus cards. The examinee is not instructed as to how to match the card. The examiner only informs the examinee whether her/his responses are correct or incorrect. Once the examinee has made ten consecutive sorts correctly, the sorting principle changes. The procedure continues for five shifts in the three possible sorting strategies or until all cards have been sorted. Perseverative response scores (the number of perseverative sorts to an incorrect principle) were used in this study as markers of cognitive flexibility or a measure of non-memory. Larrabee and Curtiss (1995) advised that learning and memory variables should load separately from marker variables to demonstrate construct validity.

Wechsler Intelligence Scale for Children – III: Vocabulary subtest.

The WISC-III (Wechsler, 1991) Vocabulary subtest requires examinees to define orally presented words. A maximum of thirty words are presented, in increasing order of difficulty. Start points vary according to age and the discontinuation criterion is four consecutive, zero point responses. Scoring criteria range from 0-2 for each word and are outlined in the WISC-III manual (Wechsler, 1991). Of all the WISC-III subtests, Vocabulary has the highest test-retest reliability coefficient, $r = .89$ (Wechsler, 1991). Vocabulary also correlates more highly with Verbal IQ, $r = .87$ and Full scale IQ $r = .79$, than does any other subtest on the WISC-III. This score was included as a marker variable of estimated intellectual ability.

Procedure

Each participant was administered six tests over a one hour period, in the following order: WMS-R LM I, WMS-R VR I, CTT, WISC-III Vocabulary, WMS-R LM II, WMS-R VR II, SRP, CVMT, WCST, SRP-delayed trial, and the CVMT delayed trial. Time of day was variable but test administration order was stable across subjects. The mean delay times between tests in minutes for LM II, VR II, SRP delay, and CVMT delayed recognition were respectively, $M = 24.63$, $SD = 4.33$; $M = 24.34$, $SD = 4.53$; $M = 29.0$, $SD = 16.46$; $M = 23.99$, $SD = 14.25$.

Principal components analysis was used to examine the component structure of the CVMT, CTT, SRP, and WMS-R LM and VR subtests. Due to the separate age forms used for the SRP and to examine the relationship of age to structure, separate analyses were conducted across two age groups 9-12 years ($n = 471$) and 13-15 years ($n = 239$). In addition, within each age group, analyses were conducted separately on the immediate, delayed and savings scores to avoid the problem of clustering due to "method variance" (Larrabee et al., 1985; Smith et al., 1992). The WISC – III Vocabulary raw scores and WCST PR scores were used, respectively, as marker variables of intelligence and cognitive flexibility. In addition, age and gender were projected into the analysis as extension loadings in order to examine which components, if any, these variables relate to without biasing the factors defined by the test scores (O'Connor, 2001). The number of factors extracted was determined by inspection of the Scree Plot (Cattell, 1966) and when possible, the best simple component solution. A loading criteria of .40 was used based on the minimum average partial correlational method (Verlicer, 1977).

Results

Table 1 presents means and standard deviations for the two samples (9-12 and 13-15 years of age). Table 2 presents correlations of each of the test variables included in the analyses along with their correlations with age and gender. Bivariate correlations were calculated for gender and the test variables.

Table 3 presents the component solutions for the younger sample (9-12 years) on the three variable sets: immediate, delayed and delayed/savings. For immediate scores, a two-component solution was suggested by the Scree plot and accounted for 52.44% of the variance in the set. Component I accounted for 38.22% of the total variance and can most parsimoniously be interpreted as a verbal acquisition/verbal intellectual dimension. Component II accounted for 14.22 % of the variance and appears to represent a visual acquisition/cognitive flexibility dimension. The CTT total score represents a complex variable and split its loadings across both components, indicating modest associations with both factors. The extension loadings of gender were below the previously stipulated cutoff of .40, indicating negligible association with the components. The relationship of age with the components was stronger than gender.

For the delayed scores, a two-component solution was suggested by the Scree Plot. This solution accounted for 49.41% of the variance in the set. Component I appears to represent a verbal memory/verbal intellectual dimension, accounting for

37.51% of the variance. Component II, accounting for 11.90 % of the variance, appears to represent a visual memory/cognitive flexibility dimension. SRP delay had a modest association with component II. Again, the relationship of gender with the components was negligible but age showed a modest association with both components.

For the savings scores, a two-component solution was suggested by the Scree Plot. This solution accounted for 44.12 % of the variance in the set. Component I accounted for 28.50% of the total variance and appears to represent a heterogeneous cognitive ability dimension. Component II, which accounted for 15.62% of the variance was primarily identified by two measures, suggesting a verbal memory component. VR savings score split its loadings between the general ability and verbal memory components, suggesting that it is a more complex variable. Gender had a weak relationship with the components. In contrast, age was found to be associated with component I but not with component II.

Table 4 presents the varimax rotated component solutions for the older sample (13-15 years) on the three variable sets: immediate, delayed, and delayed/savings. For immediate scores, a two-component solution was suggested by the Scree Plot. This solution accounted for 48.45% of the variance in the set. Component I accounted for 33.98% of the variance and may be interpreted as an acquisition/attentional dimension. Component II accounted for 14.47 % of the variance and appears to represent a heterogeneous ability dimension. Imposing the previously stipulated .40 cutoff, gender and age were not found to be strongly associated with either component.

For the delayed scores, a two-component solution was suggested by the Scree Plot. This solution accounted for 51.69 % of the variance in the set. Component I appears to represent a general memory dimension, accounting for 37.51% of the total variance. Component II, accounting for 14.18 % of the variance, appears to primarily represent a verbal intellectual/cognitive flexibility dimension. LM II had modest associations with both components. Again, the relationship of age and gender with the components was weak.

For the delayed/savings scores, a three-component solution was suggested by the Scree Plot. This solution accounted for 58.90 % of the variance in the set. Component I accounted for 27.64% of the total variance and appears to represent a visual memory/auditory attentional component. Component II, accounting for 16.92 % of the variance, appears to represent a verbal memory component while Component III, accounting for 14.34 % of the variance, appears to represent a verbal intellectual/cognitive flexibility dimension. As with the previous analyses with this age group, age and gender were not strongly associated with any of the components.

Discussion

This investigation was conducted to examine the component structure of the SRP, CVMT, CTT, and the LM and VR subtests from the WMS-R in two samples of "normal" youth, aged 9-12 and 13-15 years. Consistent with the findings of Bornstein and Chelune's (1989) study with adults, the data suggest that the component structure of these measures varied between the children and adolescents. The general findings of each of the component analyses in terms of the individual tests and their interpretations based on age groups are discussed below.

With respect to the verbal memory tests in the younger group, the acquisition trials of LM and the SRP were closely tied with estimated verbal intelligence, suggesting that clinicians should consider a child's verbal intellectual abilities in interpreting his/her performance on the acquisition trials of LM and the SRP. These findings are inconsistent with previous studies with adults, which have generally supported the independence of LM and SRP acquisition scores from verbal intellectual functioning (Larrabee et al., 1992; Larrabee & Curtiss, 1995; Leonberger et al., 1991; Leonberger et al., 1992). In the older group, the acquisition trial of LM was also associated with estimated verbal intelligence. However, in contrast, the SRP acquisition score loaded on a component that had only modest association with estimated verbal intelligence, suggesting that for young adolescents, the SRP may be a more "pure" measure of verbal acquisition than is LM I. In fact, examination of the bivariate correlations between Vocabulary on the WISC – III and performance on these measures (Table 2) indicates that in both the young and old age groups, Vocabulary has a stronger relationship with LM I than the SRP CLTR acquisition score. This finding affirms that performance on CLTR may be more independent of verbal or general intelligence than is performance on LM I.

The SRP delay and LM II (both delay scores) varied in their loadings across age groups. In the younger group, LM II loaded with verbal intellectual and verbal memory measures while the SRP delay loaded more highly with visual memory and cognitive flexibility tests. Within the older group, SRP delay loaded with measures of both verbal and visual memory (or as part of a general memory factor) while LM II loaded with measures of intellectual ability and cognitive flexibility. In contrast to the delay scores, the SRP and LM savings scores loaded separately from attentional/working memory, intellectual/cognitive flexibility and visual memory measures across both age groups, suggesting that they may be of more clinical use than the delay scores as they appear to be more "pure" measures of verbal memory. Furthermore, savings scores offer other benefits in that they can provide comparison of the examinees' scores proportionate to their initial performance. This information is useful in clinical populations to help determine what percentage of information initially learned is being recalled after a period of time. On the other hand, when utilizing savings scores, clinicians should also bear in mind that ratio scores typically have lower reliability than single scores due to the increased chance for error because these scores are calculated based on two scores, whose reliability in youth is unknown at the present time.

With respect to the visual memory tasks, the pattern of loadings also varied between age groups. In the young group, VR I and the CVMT acquisition score loaded separately from verbal acquisition and estimated verbal intellectual reasoning, but were associated with a cognitive flexibility factor. They shared modest associations with the CTT, a measure of short-term/working verbal memory/divided attention. In the older group, the CVMT acquisition score and VR I loaded together with the CTT and the SRP acquisition score, suggesting that neither the CVMT or VR acquisition trials appear to be pure measures of visual acquisition/immediate memory. These results are consistent with the Larrabee et al. (1992) study with adults, in which their findings suggested that VR I and CVMT acquisition trials were associated with spatial reasoning and attention skills. However, the results of the current study contrast the findings of Larrabee and Curtiss (1995). In Larrabee and Curtiss' study, the CVMT acquisition score was relatively independent of spatial/attentional abilities while VR I showed a stronger relationship with these skills.

The CVMT delay and VR II loaded together with a measure of cognitive flexibility and had modest associations with the SRP delay, suggesting that within the young age group performance on these visual tasks may be confounded by other abilities. In the older group, consistent with adult findings, the CVMT and VR II loaded on a general memory factor, suggesting that these tasks were more "pure" measures of memory with the young adolescents as compared to the children in this study (Larrabee & Curtiss, 1995).

VR savings in the younger group showed only modest associations with the two components that emerged: general cognitive ability and verbal memory. In the older group, VR savings loaded with the CVMT delay score and an attentional/working memory measure, supporting its construct validity.

The CTT has been conceptualized as a prefrontal lobe task, a measure of divided auditory attention, and as a measure of auditory working memory/short-term memory. In previous adult work its scores loaded separately from the WCST test, which is thought to examine cognitive flexibility, suggesting that it measures something distinct from the WCST (Boone et al., 1998). In the current study, the CTT is likely most appropriate to consider in light of the immediate score analyses because it does not involve a lengthy delay component. As such, the results indicate for the younger group that the CTT seemed to split its loadings across factors, suggesting that this test may measure something distinct from visual or verbal acquisition and reasoning. In the older group, the CTT appeared more strongly associated with a general acquisition component.

In keeping with the adult literature, the results of this study do not consistently support a distinction between verbal and nonverbal memory abilities (Elwood, 1991, 1993; Larabee & Curtiss, 1995; Leonberger, 1992). However, it is also possible that this finding may be related to the limited number of marker variables included in the analyses. This research would have been enhanced if marker variables of visuospatial reasoning and information processing speed had been included to determine whether the verbal and visual memory tests demonstrated distinct loadings from these measures.

The present study also demonstrates that the association of gender has a negligible relationship with the component structure. In contrast, the associations of age with the components were generally higher. The highest association was found with age and a general ability component and the weakest relationship was with age and a verbal memory component that was defined by savings scores, suggesting that as acquisition improves with age, so does delayed recall of information.

In closing, it is important to note that the results of this study were obtained in a group of normals. In the future it will be important to examine the construct validity of these same tests in clinical groups because the construct structure of different samples can vary (Tabachnick & Fidell, 1983).

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Table 1

Descriptive Statistics for the Test Variables in the Principal Components Analyses

	Age 9 to 12 (*n* = 471)		Age 13 to 15 (*n* = 239)	
Measure	*M*	*SD*	*M*	*SD*
LM I	22.60	7.43	26.93	6.78
LM II	19.88	7.37	23.76	7.04
LM Savings	87.56 %	14.91 %	87.57 %	12.00 %
VR I	31.00	4.51	35.04	2.93
VR II	27.23	5.88	32.75	4.51
VR Savings	87.94 %	15.61 %	93.28 %	10.35 %
SRP CLTR	56.53	18.25	61.69	17.15
SRP Delay	10.30	1.62	10.25	1.80
SRP Savings	94.83 %	13.70 %	92.22 %	14.38 %
CVMT Total	68.92	9.95	78.72	6.28
CVMT Delay	4.18	1.65	5.38	1.25
CTT Total	39.80	6.31	46.28	5.97
WCST PR	22.09	14.22	14.18	9.81
Vocabulary	30.10	7.33	40.38	6.39

Note. Measure refers to the raw score unless otherwise noted. LM I = Logical Memory immediate; LM II = Logical Memory delay; LM Savings = Logical Memory savings; VR I = Visual Reproduction immediate; VR II = Visual Reproduction delay; VR Savings = Visual Reproduction savings; SRP CLTR = Selective Reminding Procedure consistent long-term recall; SRP Delay = Selective Reminding Procedure 30 minute delayed recall; SRP Savings = Selective Reminding Procedure savings; CVMT Total = Continuous Visual Memory Test Total score; CVMT Delay = CVMT 30 minute delayed recognition; CTT Total = Consonant Trigrams Test total score; WCST PR = Wisconsin Card Sorting Test perseverative responses; Vocabulary = WISC – III Vocabulary score.

Table 2

Correlation Matrix

	LM I	LM II	LM %	VR I	VR II	VR %	CLTR	SRP Delay	SRP %	CVMT Total	CVMT Delay	CTT Total	WCST PR	Vocab	Age	Gender
LM I		.92**	.08	.22**	.23**	.09	.28**	.16**	.02	.19**	.22**	.25**	-.12**	.52**	.24**	-.01
LM II	.92**		.43**	.23**	.24**	.10*	.32**	.21**	.03	.20**	.20**	.26**	-.11*	.50**	.22**	.01
LM %	.20**	.55**		.04	.07	.06	.17**	.18**	.06	.05	.01	.06	.00	.06	.03	.03
VR I	.09	.14*	.13		.64**	-.05	.12*	.19**	.13**	.32**	.38**	.32**	-.25**	.39**	.363**	-.01
VR II	.18**	.20**	.09	.61**		.72**	.26**	.31**	.19**	.33**	.37**	.32**	-.25**	.38**	.37**	.09
VR %	.17**	.16*	.05	.02	.79**		.22**	.24**	.13**	.13**	.13**	.14**	-.12*	.15	.18**	.12**
CLTR	.38**	.43**	.27**	.15*	.26**	.21**		.64**	.01	.29**	.22**	.23**	-.13**	.28**	.12*	.10*
SRP Delay	.28**	.39**	.39**	.15*	.30**	.27**	.70**		.64**	.24**	.21**	.19**	-.12**	.20**	.15**	.10*
SRP %	.18**	.27**	.32**	.09	.20**	.20**	.27**	.78**		.04	.09	.08	-.02	-.03	.07	.06
CVMT Total	.25**	.29**	.21**	.29**	.29**	.14*	.22**	.24**	.16*		.53**	.31**	-.25**	.36**	.38**	-.08
CVMT Delay	.13*	.17*	.13*	.22**	.32**	.23**	.26**	.25**	.12	.56**		.31**	-.24**	.36**	.34**	-.09*
CTT Total	.17*	.17**	.05	.20**	.29**	.20**	.29**	.21**	.09	.16*	.14*		-.15**	.42**	.34**	-.05
WCST PR	-.17**	-.16*	-.00	-.13*	-.10	-.02	-.06	-.06	-.07	-.05	-.09	-.11		-.26**	-.25**	-.04
Vocab	.49**	.47**	.12	.21*	.29**	.20**	.23**	.22**	.16	.36**	.25**	.32**	-.27*		.50	-.07
Age	.15*	.13*	.01	.19**	.23**	.14*	.10	.15*	.12	.07	.03	.16*	-.12	.29**		.02
Gender	-.01	.01	.08	-.01	-.02	-.03	.16*	.16*	.13*	-.05	.01	-.07	.17**	-.09	-.09	

Note. Correlations for ages 9 to 12 (*n* = 471) appear above and correlations for ages 13-15 (*n* = 239) appear below the diagonal. LM I = Logical Memory immediate; LM II = Logical Memory delay; LM % = Logical Memory savings; VR I = Visual Reproduction immediate; VR II = Visual Reproduction delay; VR % = Visual Reproduction savings; SRP CLTR = Selective Reminding Procedure consistent long-term recall; SRP Delay = Selective Reminding Procedure 30 minute delayed recall; SRP Savings = Selective Reminding Procedure savings; CVMT Total = Continuous Visual Memory Test Total score; CVMT Delay = CVMT 30 minute delayed recognition; CTT Total = Consonant Trigrams Test total score; WCST PR = Wisconsin Card Sorting Test perseverative responses; Vocabulary = WISC – III Vocabulary score.

**p* < .05; ** *p* < .01.

Table 3

Principal Components Loadings for the Immediate, Delayed and Savings Scores for Children Age 9-12 years (*n* =471)

Variable	Component I	Component II
	Immediate	
LM I	**.79**	.05
Vocabulary	**.67**	.44
CLTR	**.66**	.03
CTT Total	**.49**	.41
WCST PR	.07	**-.75**
VR I	.19	**.69**
CVMT Total	.31	**.59**
[a]Age	.30	.44
[a]*Gender*	.00	-.04
	Delayed	
LM II	**.84**	.09
Vocabulary	**.75**	.32
CTT Total	**.57**	.32
WCST PR	.08	**-.74**
VR II	.33	**.65**
CVMT Delay	.27	**.64**
SRP Delay	.26	**.43**
[a]Age	.37	.37
[a]Gender	-.04	.04
	Savings	
Vocabulary	**.75**	-.17
CTT Total	**.69**	-.05
CVMT Delay	**.68**	-.14
WCST PR	**-.52**	.25
SRP %	.21	**.68**
LM %	.13	**.56**
VR %	.40	.44
[a]Age	.53	.10
[a]Gender	-.06	.10

Note. LM I = Logical Memory immediate; LM II = Logical Memory delay; LM Savings = Logical Memory savings; VR I = Visual Reproduction immediate; VR II = Visual Reproduction delay; VR Savings = Visual Reproduction savings; SRP CLTR = Selective Reminding Procedure consistent long-term recall; SRP Delay = Selective Reminding Procedure 30 minute delayed recall; SRP Savings = Selective Reminding Procedure savings; CVMT Total = Continuous Visual Memory Test Total score; CVMT Delay = CVMT 30 minute delayed recognition; CTT Total = Consonant Trigrams Test total score; WCST PR = Wisconsin Card Sorting Test perseverative responses; Vocabulary = WISC – III Vocabulary score.

[a] Loadings for age and gender are extension loadings.

Table 4

Principal Components Loadings for the Immediate, Delayed and Savings Scores for Adolescents Age 13-15 years ($n = 239$)

	Component I	Component II	Component III
Variable	Immediate		
VR I	**.71**	-.09	
CVMT Total	**.70**	.11	
CTT Total	**.53**	.23	
CLTR	**.49**	.34	
LM I	.25	**.73**	
WCST PR	.12	**-.68**	
Vocabulary	.41	**.68**	
[a]Age	.18	.20	
[a]Gender	.03	-.11	
	Delayed		
VR II	**.71**	.09	
SRP Delay	**.67**	.15	
CVMT Delay	**.65**	.02	
CTT Total	**.46**	.30	
WCST PR	.16	**-.79**	
Vocabulary	.37	**.70**	
LM II	.39	**.43**	
[a]Age	.18	.22	
[a]Gender	.09	-.17	
	Savings		
VR %	**.77**	.08	-.15
CVMT Delay	**.59**	.16	.08
CTT Total	**.58**	-.07	.33
LM %	-.004	**.83**	.02
SRP %	.18	**.76**	.06
WCST PR	.07	-.02	**-.87**
Vocabulary	.46	.13	**.61**
[a]Age	.18	.04	.20
[a]Gender	-.03	.14	-.18

Note. LM I = Logical Memory immediate; LM II = Logical Memory delay; LM Savings = Logical Memory savings; VR I = Visual Reproduction immediate; VR II = Visual Reproduction delay; VR Savings = Visual Reproduction savings; SRP CLTR = Selective Reminding Procedure consistent long-term recall; SRP Delay = Selective Reminding Procedure 30 minute delayed recall; SRP Savings = Selective Reminding Procedure savings; CVMT Total = Continuous Visual Memory Test Total score; CVMT Delay = CVMT 30 minute delayed recognition; CTT Total = Consonant Trigrams Test total score; WCST PR = Wisconsin Card Sorting Test perseverative responses; Vocabulary = WISC – III Vocabulary score.

[a] Loadings for age and gender are extension loadings.

Chapter 3

Clinical Utility of the Selective Reminding Procedure in Adolescents with Moderate to Severe Traumatic Brain Injury

Clinical Utility of the Selective Reminding Procedure in Adolescents with Moderate to Severe Traumatic Brain Injury

Impairments in memory are among the most commonly reported cognitive sequelae following traumatic brain injury (TBI; Dalby & Obrzut, 1991; Ewing-Cobbs, Fletcher & Levin, 1985; Levin et al., 1988; Reeder & Logue, 1994; Telzrow, 1987). A considerable body of research has been dedicated to understanding memory functioning and developing tools to test this construct in adults. Recent efforts also have been focused on the development and validation of tools to assess memory in children and adolescents. A major impetus for study into this area has been that it has become increasingly clear that the effects of TBI on a brain that is still developing differ from the effects on an adult brain (Baron, Fennell, & Voeller, 1995; Barth et al., 1983). For example, Levin et al. (1992) found differential outcomes as a result of brain injury in infants, children, adolescents and adults. Some studies have also suggested that youth is protective across certain cognitive functions but when brain injury occurs during the developmental process, problems in function may also be elucidated as the child ages (Brazzelli, Columbo, Della Sala, & Spinnier, 1994; Levin, 1991).

One verbal memory task that has been commonly employed with brain-injured adults is the Selective Reminding Procedure (SRP; Buschke, 1973; Butler, Retzlaff, & Vanderploeg, 1991). The purpose of the current study was to examine its sensitivity in identifying memory deficits in an adolescent sample, aged 13-15 years, with moderate to severe TBI. The SRP is a task that was originally developed for use in adult populations to assess verbal acquisition, learning, and memory. The test involves a multi-trial presentation of a list of words in which the examinee is reminded only of the words that were not recalled on the previous trial, but the examinee is asked to recall all of the words on the list on each trial. Buschke's (1973) scoring procedures involve the calculation of scores based on short-term recall (STR), long-term storage (LTS), a total recall score (TR), long-term retrieval (LTR), and a delayed recall score. LTR is divided into both consistent (CLTR) and random long-term retrieval (RLTR). CLTR indicates that once a word has been transferred to LTS, it is recalled consistently, without reminders. RLTR represents inconsistent recall once information has been placed in LTS. Buschke and Fuld (1974) suggested that CLTR and RLTR scores represent differences in learning, with RLTR suggesting poorer learning. In light of this, some researchers have also examined the ratio score of CLTR/LTR, suggesting that it could provide an explanation for persons with memory complaints but normal total recall scores on testing (Levin & Grossman, 1976; Paniak, Shore, & Rourke, 1989). For details regarding the calculation of these scores, please refer to the Method section of this manuscript.

SRP indices are sensitive to a variety of conditions known to be associated with memory deficits (e.g., left temporal lobe lesions, Alzheimer's dementia, and seizure disorder; Lee, Loring, & Thompson, 1989; Martin, Loring, Meador, & Lee, 1988; Masur et al., 1989; Snow, English, & Lange, 1992). Several studies have also examined performance on the SRP of patients with traumatic brain injury. Using a modified version of the SRP, Paniak et al. (1989) found that CLTR and the ratio of CLTR/ LTR were the best scores to discriminate between controls and adults with severe closed head injury. Levin, Grossman, Rose, and Teasdale (1979) examined memory performance on the SRP of 27 patients between 16 and 50 years who had initial Glasgow Coma Scale (GCS) scores of less than 8. In follow-up, the researchers classified patients into groups according to the Glasgow Outcome Scale. Patients were classified as having a "good recovery, moderate disability or severe disability". The researchers found that that the gain in CLTR across trials was significant for patients classified as having a "good recovery" and those with "moderate disability". The "severely disabled" patients did not demonstrate a significant increment in learning. Total scores on the SRP between the "moderately disabled" and "severely disabled" patients did not significantly differ from one another, but both groups were worse than the "good recovery" patients in their total recall.

In terms of younger persons, Bassett and Slater (1990) found that adolescents with severe TBI scored worse than controls across all twelve trials on the SRP. Levin, Eisenberg, Wigg, and Kobayashi (1982) found that adolescents who suffered severe TBI demonstrated residual deficits in CLTR both at baseline and follow-up (median length = 12.5 months) when compared to age-matched controls with mild to moderate injuries. Levin et al. (1988) found that severely brain injured adolescents were impaired relative to controls and patients with mild to moderate brain injuries in their total recall of words on the SRP at both baseline and one year follow-up. Ewing-Cobbs, Levin, Fletcher, Miner and Eisenberg (1990) found that CLTR was significantly related to length of post-traumatic amnesia, as indicated by the Child's Orientation and Amnesia Test.

Although some researchers have examined the SRP in studies with adolescents, to my knowledge previous work has not provided a comprehensive analysis of SRP indices with this group. Several obstacles have made clinical usage and research into the SRP with adolescents a challenging task. First, only a small normative base for adolescents, aged 13-18, was available (Levin, Benton, & Grossman, 1982; Levin & Grossman, 1976). This normative data provided information for males ($n = 23$) and females ($n = 27$) for the measures LTS and CLTR on the adult SRP form 1 (Hannay and Levin, 1985). Second, there has been no universally utilized form of the SRP for adolescents and this limits comparison across studies. Consequently, studies utilizing the SRP have been based on different word lists and standardization of the SRP has been lacking. Recently, however, Miller, Murphy, Paniak, Spackman, and Labonte's study (as cited in Spreen & Strauss, 1998) provided a large set of normative data for adolescents aged 13-15 years using a modified version of the adult SRP, Form 1. The publication of this data provides opportunity for further study into memory functioning in adolescents and into the clinical sensitivity of the SRP with this population.

Specifically, the aim of the current study was to evaluate whether adolescents who have sustained moderate to severe TBI would demonstrate impaired performance on the SRP. The a priori hypotheses were that TBI patients would perform worse than matched controls on the SRP learning and memory indices. In concordance with previous research in the adult literature (Paniak et al. 1989), CLTR and the ratio of CLTR/LTR were expected to best distinguish the performance of TBI patients from that of normal controls. In addition, optimal classification of the patients and controls was studied through an examination of the sensitivity (true positives) and specificity (true negatives) of SRP indices at various cutoff scores.

Method

Participants and Procedure

Participants were 16 patients who suffered moderate to severe blunt brain injuries and 32 non-injured controls, comprising 2 groups of 16 student volunteers.

The TBI participants included both inpatients and outpatients at the Glenrose Rehabilitation Hospital. Specific inclusion criteria were as follows: (a) brain injury producing either a moderate TBI score [Glasgow coma scale (GCS) of 9-12] upon hospital admission or a severe TBI [GCS of 3-8 upon hospital admission], (b) Post traumatic amnesia (PTA) over 24 hours, (c) English must have been the main language used in the home, (d) no history of hospitalization due to behavior difficulties or previous documented brain injury, and (e) no history of diagnosed learning disability or Attention Deficit Hyperactivity Disorder. CT scan and MRI reports were inconsistently available and therefore were not considered in the analysis. All TBI patients were tested within 1.5 years of injury with 12/16 being tested within 6 months of their injury and 15/16 being tested within one year of injury. The mechanism of injury involved motor vehicle accidents for 14/16 patients; one patient was injured on a bicycle and another in a sporting accident. No participant had aphasia that significantly affected SRP performance.

To be eligible for participation in the study, the controls must have met the following criteria: (a) English must have been the main language used at home, and (b) no history of hospitalization due to behavioral concerns or documented brain injury. Children were not excluded from the group if diagnosed with Attention Deficit Hyperactivity Disorder or learning disability unless they had been hospitalized for treatment of this disorder.

Control group ASV was matched with the TBI patients based on age, sex and scaled Vocabulary score on the Wechsler Intelligence Scale for Children – Third Edition (WISC-III: Wechsler, 1991). Control group AS was matched according to age and sex.

Two control groups were utilized to explore whether verbal memory deficits were independent of basic vocabulary skills. Controls were obtained from the SRP normative data (Miller, Murphy, Paniak, Spackman, & LaBonte, 1996). They were selected in sequential order from the database and matched individually with the patients. The range for age matching between patients and control group ASV was plus or minus seven months. Eleven of the sixteen patients were matched exactly with individuals in control group ASV based on their WISC-III Vocabulary scaled scores. Three patients were matched within one point, one within two points and one patient had a three point difference from his/her control. The range for age matching between the patients and control group AS was plus or minus eight months.

The mean WISC-III scaled Vocabulary scores, gender, and test ages for the TBI group and control groups A and B are listed in Table 1. There was no significant difference in average Vocabulary scores between control group ASV and the TBI patients. Control group AS had an average Vocabulary score that was significantly better than both control group ASV and the TBI group. There was no significant difference in mean test ages between the groups.

All of the participants were seen individually and the SRP was administered as part of a larger neuropsychological test battery.

Material

Selective Reminding Procedure.

The Selective Reminding Procedure (SRP) is a test of verbal learning and memory originally developed by Buschke (1973). It involves the verbal presentation of a list of 12 words to the examinee. Immediately following the presentation, the examinee is required to recall as many of the words on the list as possible. After the first trial, the examiner repeats only the words that the examinee did not recall. The examinee then is requested to verbally recall as many words as possible from the entire list. A modified version of Hannay and Levin's (1985) form 1 was utilized in this study. Administration involved eight consecutive trials (instead of 12) or until the examinee recalled all of the words on the list for three consecutive trials (in the latter case, scores were pro-rated). Several scores can be derived from this procedure: (a) long-term storage (LTS) refers to recall of a word on at least one trial without a reminder, (b) consistent long term retrieval (CLTR) refers to retrieval of a word on every trial once it has entered LTS, (c) random long term retrieval (RLTR) refers to inconsistent retrieval of a word once it has entered LTS, (d) short term recall (STR) refers to recall of an item on the trial on which the examiner has presented it, (e) long term retrieval (LTR) refers to both random and consistent retrieval of items after they have entered storage, (f) total recall (TR) on a trial refers to the number of words retrieved from both STR and LTR, (g) the ratio of CLTR/LTR, and (h) Delay refers to the number of words the examinee recalls from the list following a 30-minute delay.

Wechsler Intelligence Scale for Children – III (WISC-III): Vocabulary subtest.

The WISC-III (Wechsler, 1991) Vocabulary subtest requires examinees to define aurally presented words. A maximum of thirty words are presented, in increasing order of difficulty. Start points vary according to age and the discontinuation criterion is four consecutive, zero point responses. Scoring criteria range from 0-2 for each word and are outlined in the WISC-III manual (Wechsler, 1991). Of all the WISC-III subsets, Vocabulary has the highest test-retest reliability coefficient, $r = .89$ (Wechsler, 1991).

Vocabulary also correlates more highly with Verbal IQ, $r = .87$ and Full scale IQ $r = .79$, than any other subtest on the WISC-III.

Results

Table 2 lists the average raw scores for each group (control ASV, control AS, and the patients) on the SRP indices (dependent variables), the *F* ratio values and effect sizes. The following formula was used to calculate effect sizes for each SRP index: (*M* of patient group – *M* of control group ASV or AS/ *SD* of control group ASV or AS). A MANOVA with an alpha level of .05 demonstrated a significant main effect of group, Wilks' lambda, $F(12, 80) = 2.9, p = .002$. Univariate ANOVAs revealed significant results for CLTR, LTS, STR, TR, delay, and the ratio of CLTR/LTR. LTR was not included in the MANOVA due to its high correlation (.99) with LTS, suggesting that LTS and LTR are redundant variables (Tabachnick & Fidell, 1983). The effect of group for RLTR did not reach statistical significance.

Bonferroni comparisons for the dependent measures revealed that the patient group performed significantly worse than both control groups on the same variables that differed in the ANOVA. There were no significant differences noted on any of the SRP variables between control groups ASV and AS. Therefore the effect sizes presented in Table 2 represent aggregate scores. That is, the effect sizes for each dependent measure were calculated individually for control ASV versus the patients, and control AS versus the patients. Subsequently, the two effect sizes obtained for each SRP index were added together and then divided by two. Cohen's (1992) classification system was used to define effect sizes. That is, small, medium and large effect sizes are defined respectively as .20, .50, and .80.

Two direct discriminant function analyses (dfa) were performed using STR, LTS, TR, CLTR, delay and the ratio of CLTR/LTR as predictors of group membership. The first analysis examined control group ASV versus the patients and the second, control group AS versus the patients. Results of the first discriminant function contained in Table 3, indicated a combined X^2 (6) = 16.75, $p = .01$. The loading matrix of correlations between predictors and the discriminant function is also presented in Table 3. The results indicated that LTS was the best discriminator among the variables, but was not more strongly associated with the discriminant function than STR, which was the next best discriminator, T^2 (29) = 1.18, $p > .05$, ns. Essentially, analyses testing the relationship of each SRP variable with the discriminant function indicated that no particular variable was more strongly correlated with the discriminant function than all other variables. However, CLTR/LTR had a weaker relationship with the discriminant function than did the top four variables, LTS, STR, TR, and CLTR. Differences were significant for LTS versus CLTR/LTR, T^2 (29) = 3.87, $p < .001$, STR versus CLTR/LTR, T^2 (29) = 2.53, $p < .02$, TR versus CLTR/LTR, T^2 (29) = 2.49, $p < .02$, and CLTR versus CLTR/LTR, T^2 (29) = 3.05, $p < .01$. In terms of classification, using the total sample of 32 participants, 25 (78%) were correctly classified.

Since pooled within-group correlations among the six predictors (Table 3) were quite high, a stepwise discriminant function analysis was conducted to determine which variable would contribute to discriminant power once variance associated with the other variables was partialled out. LTS was the only variable that was retained in the stepwise analysis, F (1, 30) = 17.40, $p = .000$

Results of the second dfa indicated a combined $X^2 = 19.14, p = .004$. The loading matrix of correlations (Table 4) between predictors and the discriminant function indicates that LTS has the highest relative correlation with the dfa. Again, LTS was the best discriminator between the TBI patients and controls. However, LTS was no more strongly related to the dfa than was TR, which was the next best discriminator, T^2 (30) = 2.05, $p > .05$, ns. Again, the analysis of the correlations does not clearly support any particular index correlation with the dfa as being significantly stronger than the remaining indices. However, CLTR/LTR was the worst discriminator between patients and controls, and was more weakly related to the dfa than were LTS, T^2 (29) = 3.36, $p < .01$, CLTR, T^2 (29) = 2.63, $p < .02$, and TR, T^2 (29) = 2.40, $p < .05$. In terms of classification, using the total sample of 32 participants, 25 (78%) were correctly classified.

Pooled within-group correlations (Table 4) among predictor variables were again, quite high. Therefore, the variables in this analysis were also entered into a stepwise dfa. Consistent with the results of the stepwise dfa for control ASV and the patients, LTS was the only variable retained, F (1, 30) = 18.33.

Sensitivity and specificity values (see Table 5) of the SRP indices, based on various z-score cutoff values, were also examined. That is, the performance of each participant on each of the SRP indices, except RLTR was converted to z-scores based on normative data (Miller et al., 1996). For example, 13 year old participants were compared to the 13 year old normative data mean(s), based on the same sex, while 14 year olds were compared to the 14 year old data, based on the same sex , and so on. Miller et al. (as cited in Spreen and Strauss, 1998) stratified the original normative data based on Verbal IQ scores (low = 110 or less and high = 111 and above) obtained from the Canadian Cognitive Ability Test (CCAT). In the present study, *z*-scores were calculated without stratification based on the CCAT scores. Sensitivity referred to whether a TBI patient received a score that fell below a particular cutoff. Specificity referred to whether a control received a score above the established cutoff. Sensitivity and specificity rates were examined at 0.5, 1.0 and 1.5 *z*-scores below the normative mean(s). Consequently, sensitivity (true positives) referred to the percentage of TBI patients who received a score below whichever cutoff was used and specificity (true negatives) referred to the percentage of controls whose scores fell above the cutoff.

Results revealed generally higher sensitivity when a *z*-score cutoff closer to zero was used. When 0.5 *z*-score(s) below the mean was used as a cutoff, sensitivity values ranged from 63% to 88%; specificity rates remained above chance and ranged from 56% to 88% across indices for both control groups. The highest specificity rates were of course, found with lower *z*-score cutoffs. For example when 1.5 *z*-score(s) below the mean was used, 81% of controls were correctly identified across all seven scores. However, using this cutoff, reduced sensitivity substantially.

Table 6 reveals diagnostic accuracy using the same *z*-score cutoffs as used for sensitivity and specificity values. For the purposes of this study, diagnostic accuracy reflects both sensitivity and specificity of each of the SRP test scores by revealing how accurately the test scores predicted group membership. In other words, diagnostic accuracy represents the percentage of TBI patients and controls that were correctly classified. Results indicate that correct classification of subjects was obtained approximately two thirds to three fourths of the time when using 1.0 *z*-score below the mean as a cutoff. However, maximum diagnostic accuracy was encountered at varying *z*-

score cutoffs. That is, the highest diagnostic accuracy was reached for different scores at different cutoffs.

Discussion

In keeping with the hypotheses, significant differences and large effect sizes between the performance of TBI patients and controls emerged for seven of eight SRP indices (i.e., STR, LTS, CLTR, Delay, TR, and CLTR/LTR, but not RLTR). These findings provide support for the clinical utility of the adolescent version of the SRP with moderate to severe traumatically brain-injured individuals, aged 13-15 years, tested within 18 months of injury. The results are also consistent with previous child and adult research, supporting the utility of various SRP scores with TBI patients (e.g., Bassett and Slater, 1990; Paniak, et al., 1989).

The prediction that CLTR and the ratio of CLTR/LTR would best distinguish the performance of TBI patients and controls was not supported. In fact, all SRP indices entered into the discriminant functions were found to be reasonable discriminators; no one variable stood out as being significantly better than all the rest, likely secondary to their high correlations with each other. Of all the SRP indices entered into the dfa, CLTR/LTR appeared to be the worst discriminator. There has been some inconsistency in previous work with regard to the discriminatory strength of the various SRP indices. For example, Spreen and Strauss (1988) suggested that using the TR score from the SRP may be sufficient since SRP indices are intercorrelated (Larabee, Trahan, Curtiss, & Levin, 1988; Paniak et al., 1989; Smith, Goode, la March, & Boll, 1995). However, Paniak et al. (1989) suggested that TR was a less useful measure of the severity of memory impairment after severe TBI than CLTR and the ratio of CLTR/LTR. Snow et al. (1992) found that CLTR and TR were the most effective SRP indices in discriminating between children with learning disabilities, seizure disorders and normal controls. The disparity of findings between studies may be explained by several factors. First, no study to date has examined the SRP variables as comprehensively as in the present work. Researchers in the past have included only some of the indices from the SRP in their analyses. Consequently, they have identified the best discriminators among those included, not necessarily the best discriminators among the SRP indices that are available. Second, the SR procedures utilized and the clinical populations examined by Paniak et al. (1989), Snow et al., (1992) and the present study were varied. Paniak et al. (1989) used a modified version of the SRP that included six abstract words and six words that were considered more concrete. Nine trials were administered with a yes/no recognition trial after trial five. Snow et al. (1992) used a children's version that includes a list of twelve concrete nouns and a maximum of eight trials. In the present work, the Miller et al. (1998) version for adolescents, aged 13-15 years was utilized. This version includes twelve words (six more abstract and six more concrete) and a maximum of eight trials. In light of the issue regarding differences in administration of the SRP, future researchers may wish to focus on using a standard format and word list to allow for more specific comparison of clinical findings. The recent collection by Miller et al. (1998) of a large set of SRP normative data provides an opportunity for psychologists to improve standardization in administration of the SRP to enhance both clinical application and research with adolescents.

Diagnostic hit rates were better than chance for the SRP indices, although the accuracy varied depending on which cutoff score was used. Consistent with results of the discriminant functions, no particular score was significantly better in terms of diagnostic prediction relative to the others. Concerning application, discrimination using particular SRP indices is presumably of most pertinent use if the aim of testing is to detect relatively mild verbal learning or memory problems. Data from the present paper do not strongly support a fine discrimination between SRP indices with the exception of RLTR, which did not appear to be at all sensitive to memory deficits in the TBI sample. However, additional study into the reliability of the various SRP scores in youth is needed to provide clinician's with further information regarding the diagnostic utility of the SRP scores.

Consistent with adult findings (Larrabee et al., 1988; Paniak et al., 1989; Smith et al., 1995), SRP indices (except RLTR) were highly intercorrelated in the current study. However, in view of the fact that the SRP is based on an information processing model, high correlations among variables are to be expected.

Controls were matched by age and sex (AS) or age, sex, and WISC-III Vocabulary standard score (ASV), to help delineate whether the memory deficits were specific or related to impaired verbal skills in general. Previous researchers have documented a relationship between some SRP indices and psychometric intelligence (Bishop, Dickson, & Allen, 1990; Miller et al., 1998). Others (Parsons, 1984), found no relationship between SRP indices and intelligence. The results of this study supported the memory deficits in our patients as being over and above any basic vocabulary deficits. The patient group performed significantly worse than both control groups on most SRP indices, despite the fact that the patient group was matched to control group A on the WISC-III Vocabulary subtest.

A potential limitation of this study is that although adolescents with a pre-morbid history of Attention Deficit Hyperactivity Disorder or learning disability were excluded from the clinical group, participants were not excluded from the control groups, unless they had been hospitalized due to their attention concerns. Thus, the impact of pre-morbid attention concerns on SRP performance in the control groups in this study cannot be determined. Future researchers may wish to address this issue by excluding all study participants with a history of impairment in attention when studying performance on the SRP. Prospective work using larger samples and more stringent standardization of the interval from time of injury to testing may also allow for increased generalization of the findings. However, notwithstanding the limitations in research design, the results of this preliminary investigation do support the SRP as a clinically sensitive tool in identifying deficits in verbal learning and memory in adolescents who have sustained moderate to severe TBI.

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Table 1

Descriptive Statistics and Performance of Participants on WISC-III Vocabulary Test

Variable	Patients *(M/SD)*	Control ASV *(M/SD)*	Control AS *(M/SD)*
Vocabulary	8.88 (2.39)	9.25 (1.81)	11.69 (1.67)
Test Age (years)	14.37 (0.99)	14.22 (0.81)	14.28 (0.86)
Gender	9 females	9 females	9 females

Note. Vocabulary refers to the scaled score from the Wechsler Intelligence Scale for Children – Third Edition (WISC-III). Control ASV = control group matched based on age, sex and WISC-III Vocabulary scaled score; Control AS = control group matched based on age and sex.

n = 16 in each patient and control group.

Table 2

Means, Standard Deviations, F Values, and Effect Sizes for the Sample on SRP Variables

Variable	Patients M(*SD*)	Control A *M*(*SD*)	Control B *M*(*SD*)	F (*df*)	Effect Size[a]
CLTR	34.25(23.24)	61.31(19.20)	60.94(18.52)	9.23** (2, 45)	-1.43
Delay	7.69(3.22)	10.38(1.71)	10.75(1.39)	8.80** (2, 45)	-1.86
LTS	50.56(21.41)	76.62(12.89)	76.06(10.44)	14.50** (2, 45)	-2.21
TR	62.88(13.98)	78.44(9.74)	78.13(7.87)	10.78** (2, 45)	-1.75
RLTR	12.50(8.84)	11.56(8.27)	11.06(9.22)	0.11 (2, 45)	-0.14
STR	16.13(9.69)	5.56(4.94)	6.13(4.19)	12.48** (2, 45)	-2.25
CLTR/LTR	0.64(.26)	0.83(0.13)	0.83(0.15)	5.23** (2, 45)	-1.36

Note. CLTR: consistent long-term recall; Delay: # of words recalled after a thirty minute delay; LTS: long-term storage; TR: Total # of words recalled across eight trials; RLTR: random long-term retrieval; STR: short-term recall; CLTR/LTR: CLTR divided by the # of words in LTR. All scores represent raw scores unless otherwise noted. Control ASV = control group matched based on age, sex and WISC-III Vocabulary scaled score; Control AS = control group matched based on age and sex.

n = 16 for each patient and control group.

[a] Represents an average score based on effect sizes for control A versus the patients and control B versus the patients for each SRP index.

***p*. < .001

Table 3

Direct Discrimimant Function of SRP Variables for Control ASV and the Patients

Predictor variable	Correlations of predictor variables with dfa	Univariate *F* (1, 30)
STR	-.77	15.10
LTS	.82	17.40
CLTR/LTR	.50	6.41
Delay	.58	8.70
CLTR	.71	12.89
TR	.72	13.35
Canonical *R*	.68	

Pooled within-group correlations among predictors

Predictor Variable	STR	LTS	CLTR/LTR	Delay	CLTR	TR
STR	1.00	-.92	-.59	-.77	-.76	-.75
LTS		1.00	.69	.79	.86	.93
CLTR/LTR			1.00	.63	.85	.76
Delay				1.00	.80	.78
CLTR					1.00	.93
TR						1.00

Note. STR: short-term recall; LTS: long-term storage CLTR/LTR: CLTR divided by the # of words in LTR; Delay: # of words recalled after a thirty minute delay; CLTR: consistent long-term recall; TR: Total # of words recalled across eight trials. Control ASV = control group matched based on age, sex and WISC-III Vocabulary scaled score. *n* = 16 for each group.

Table 4

Direct Discriminant Function of SRP Variables for Control AS and the Patients

Predictor Variables	Corrleations of predictor variables with dfa	Univariate *F* (1, 30)
STR	-.68	14.36
LTS	.77	18.33
CLTR/LTR	.46	6.43
Delay	.63	12.20
CLTR	.65	12.90
TR	.68	14.45
Canonical *R*	.71	

Pooled within-group correlations among predictors

Predictor Variable	STR	LTS	CLTR/LTR	Delay	CLTR	TR
STR	1.00	-.92	-.58	-.72	-.74	-.73
LTS		1.00	.69	.72	.84	.93
CLTR/LTR			1.00	.53	.86	.77
Delay				1.00	.65	.67
CLTR					1.00	.92
TR						1.00

Note. STR: short-term recall; LTS: long-term storage CLTR/LTR: CLTR divided by the # of words in LTR; Delay: # of words recalled after a thirty minute delay; CLTR: consistent long-term recall; TR: Total # of words recall across eight trials. Control AS = control group matched based on age and sex.

n = 16 for each group.

Table 5

Sensitivity and Specificity Values for SRP Raw Scores

	z scores		
	-0.5	-1.0	-1.5
TBI & Control ASV			
CLTR	75/63	69/75	63/88
Delay	69/63	50/81	44/100
LTS	81/75	69/88	56/88
STR	63/81	63/88	56/94
CLTR/LTR	63/56	56/69	50/81
TR	88/81	63/81	56/81
TBI & Control AS			
CLTR	75/75	69/81	63/81
Delay	69/88	50/94	44/100
LTS	81/69	69/88	56/94
STR	63/69	63/81	56/100
CLTR/LTR	63/69	56/81	50/81
LTR	88/69	63/81	56/88

Note. Sensitivity and specificity values are listed respectively and rounded to the nearest whole number. Sensitivity refers to the percentage of correctly classified patients. Specificity refers to the percentage of correctly classified controls. CLTR: consistent long-term recall; Delay: # of words recalled after a thirty minute delay; LTS: long-term storage; STR: short-term recall; CLTR/LTR: CLTR divided by the # of words in LTR; TR: Total # of words recalled across eight trials. Control ASV = matched based on age, sex and WISC-III Vocabulary scaled score; Control AS = matched based on age and sex. *n* = 16 in each patient and control group.

Table 6

Diagnostic Accuracy of SRP Variables

	z scores		
	-0.5	-1.0	-1.5
TBI and control ASV			
CLTR	69	72	75
Delay	66	66	72
LTS	78	78	72
STR	72	75	75
CLTR/LTR	60	*66*	*66*
TR	84	72	69
TBI and control AS			
CLTR	75	75	72
Delay	78	72	72
LTS	75	78	75
STR	66	72	78
CLTR/LTR	66	69	66
TR	78	72	72

Note. The values represent the percentage of controls and patients who were correctly classified. Bold indicates best diagnostic accuracy rate. Control ASV = control group matched based on age, sex and WISC-III Vocabulary scaled score; Control AS = control group matched based on age and sex.

Chapter 4

Wechsler Memory Scale – Revised: Clinical Utility of Logical Memory and Visual Reproduction in Youth with Moderate to Severe Traumatic Brain Injury

Wechsler Memory Scale – Revised: Clinical Utility of Logical Memory and Visual Reproduction in Youth with Moderate to Severe Traumatic Brain Injury

The Wechsler Memory Scale – Revised (WMS-R) is a test originally designed to evaluate memory functioning in individuals aged 16-74 years (Wechsler, 1987). The scale, which is comprised of twelve subtests, each purportedly evaluating a different aspect of memory, was identified as the most frequently administered memory measure in a test usage survey of 500 psychologists (Butler, Retzlaff, & Vanderploeg, 1991). Among the WMS-R subtests, Logical Memory (LM) and Visual Reproduction (VR) were identified as the two most commonly employed (Butler et al., 1991). While the WMS-R subtests and indices have demonstrated utility with various adult populations (Reid & Kelly, 1993; Troster et al., 1993), examinations regarding their usefulness with children and adolescents has been sparse, likely because until recently, only limited normative data were available for these age groups. Curry, Logue, and Butler (1986) introduced initial norms for Russell's revision of the WMS for a sample of 247 individuals, aged 91/2 to 151/2 years. More recently, Paniak, Murphy, Miller, and Lee (1998) provided normative data on LM and VR based on a sample of 714 children, aged 9 to 15 years. The present study was undertaken to examine the sensitivity of the WMS-R LM and VR measures to memory deficits in children and adolescents with acquired moderate to severe traumatic brain injury (TBI).

Although identifying profound memory impairment after TBI may not require sensitive instruments, detecting more mild or moderate memory deficits and determining where the deficiencies in this complex cognitive process may be occurring can be a challenge. Memory assessment involves in depth evaluation that considers the distinct stages of memory (e.g. encoding and retrieval) and various modalities (e.g. visual, verbal, and tactile). On the WMS-R, LM is characterized by immediate and delayed story recall and VR involves immediate and delayed recall and construction of abstract designs. In addition, savings scores that indicate the percentage of information recalled on the delay trial as a function of the amount of information recalled initially for both LM and VR can be calculated, allowing for more specific analysis of memory performance. For example, if an individual obtained borderline scores on the immediate and delayed trials of LM, one may mistakenly assume that delayed retrieval of information is impaired/borderline. However, examination of the savings scores may indicate that the individual retained most of the information recalled on the immediate trial, suggesting that the difficulty at the delay may have been related to other factors, such as reduced attention or problems with acquisition, rather than retention or retrieval.

Logical Memory, Visual Reproduction and their savings scores (LMSAV & VRSAV) have demonstrated validity with various conditions with associated memory difficulties, such as Alzheimer's disease and adult amnesic disorders (Troster et al., 1993; Butters et al., 1988). Specific to TBI, Reid and Kelly (1993) reported that the savings scores for LM and VR differentiated between adult controls and a head injured sample (*n* = 20) whose post-traumatic amnesia ranged from 3-150 days. Bigler et al., (1996) tested individuals, more than 90 days post injury, who suffered moderate to severe TBIs and found a relationship between hippocampal volume and savings scores for LM and VR. In one of the only studies examining the usefulness of LM and VR with traumatic brain injury in adolescents, Bassett and Slater (1990) compared the performance of mild and severe head injury patients to controls. All patients were tested within two months of their injuries. Results indicated no difference between the performance of adolescents with mild head injury and controls on LM I and LM II. However, adolescents with severe TBIs differed significantly from both the control group and mild head injury group on LM I and LM II. Similarly, the mild TBI patients did not differ from controls in their performance on VR I and VR II. Controls differed significantly from the severe TBI patients on VR I and VR II. Performance among the three groups did not differ on LM savings. However, the mild TBI patients and controls obtained similar scores on the VR savings scores, while the severe TBI patients scored significantly worse than both groups on this measure. Paniak, Murphy, Lee, & Miller (1997) found that a mixed brain injury sample of children, comprised of stroke and TBI patients, performed significantly lower than age and sex matched controls on LM I, LM II, VRII, and LM and VR savings scores. There was no difference found between the groups on VR I. In the same study, Paniak et al. (1997) found that their mixed clinical sample performed lower than an age, sex, and WISC-III Vocabulary matched control group on VR II and the LM and VR savings scores. No significant differences were found between the latter groups on LM I, LM II, or VR I.

In accordance with previous research (Bassett & Slater, 1990; Paniak et al., 1997), patients in the current study were predicted to perform worse than controls on LM I, LM II, LM savings, VR I, VR II, and VR savings. Two control groups were utilized in this research, one matched by age, sex, and the Wechsler Intelligence Scale for Children – 3rd Edition (WISC-III) Vocabulary score, and the other by age and sex, to explore whether memory deficits would be independent of basic vocabulary skills. LM and VR savings scores were expected to produce significant differences between patients and controls, regardless of matching variables. It was postulated that the savings scores would best distinguish the performance of TBI patients from that of controls.

Method

Participants and Procedure

Participants were 28 patients who suffered moderate to severe blunt brain injuries and 56 non-injured controls, comprising 2 groups of 28 student volunteers.

The TBI participants included both inpatients and outpatients at the Glenrose Rehabilitation Hospital in Edmonton, Alberta, Canada. Specific inclusion criteria were as follows: (a) brain injury producing either a moderate TBI score [Glasgow coma scale (GCS) of 9-12] upon hospital admission or a severe TBI [GCS of 3-8 upon hospital admission], (b) Post traumatic amnesia (PTA) over 24 hours, (c) English must have been the main language used in the home, (d) no history of hospitalization due to behavior difficulties or previous documented brain injury, and (e) no premorbid diagnosis of learning disability or Attention Deficit Hyperactivity Disorder. CT scan and MRI reports were inconsistently available and therefore were not considered in the analysis. All TBI patients were tested within 13 months of injury. The mechanism of injury involved motor vehicle accidents for 25/28 patients; one patient was injured on a bicycle, and two in sporting accidents. No participant had aphasia that significantly affected performance.

To be eligible for participation in the study, the controls must have met the following criteria: (a) English must have been the main language used at home, and (b) no history of hospitalization due to psychiatric concerns or documented brain injury. Children were not excluded from the group if diagnosed with Attention Deficit

Hyperactivity Disorder or learning disability unless they had been hospitalized for treatment of this disorder.

One control group (ASV) was matched with the TBI patients based on age, sex and scaled Vocabulary score on the WISC-III. A second control group (AS) was matched according to age and sex, the two factors typically utilized for matching in research studies. Two control groups were used in this study to explore whether verbal memory deficits were independent of basic vocabulary level. Controls were obtained from the WMS-R Logical Memory and Visual Reproduction normative data (Paniak, Murphy, Miller, & Lee, 1998). They were selected in sequential order from the database and matched individually with the patients. The range for age matching between patients and control group ASV was plus or minus nine months. Twenty-two of the 28 patients were matched exactly with controls on their WISC-III Vocabulary scaled scores. Four patients were matched within one point, one within two points and one was matched within three scaled score points. The range for age matching between the patients and control group AS was plus or minus eight months.

The mean WISC-III scaled Vocabulary scores, mean test ages for the TBI group and control groups ASV and AS and the gender breakdown for the groups are listed in Table 1. There was no significant difference in Vocabulary scores for control group ASV and the TBI patients. Control group AS had an average Vocabulary score that was significantly higher than control group ASV and the TBI group. There was no significant difference in mean test ages between the groups.

All of the participants were seen individually and the Logical Memory and Visual Reproduction subtests were administered as part of a larger neuropsychological test battery.

Material

Wechsler Memory Scale –Revised: Logical Memory and Visual Reproduction.

The WMS-R is a standardized test used to examine various dimensions of memory functioning. It is comprised of 12 subtests, two of which (Logical Memory [LM] and Visual Reproduction [VR]), were administered for this study. LM and VR both involve immediate (I) and delayed (II) trials. LM I involves the presentation of two brief stories, after which the examinee is immediately requested to recall as much information from the stories as possible. LM II is the delayed recall portion of the subtest, in which the examinee is required to recall as much as possible from the two stories, thirty minutes after their initial presentation. Scores for both Logical Memory I and II represent the number of units of verbal information recalled by the examinee and range from 0-25 for each story. A savings score (LMSAV) was calculated by dividing the LM II score by the LM I score.

VR I involves the presentation of four abstract designs. Each design is presented for 10 seconds. Immediately after each presentation, the examinee is requested to reproduce the design. VR II requires the examinee to draw the designs thirty minutes after their initial presentation. Scores for VR I and II are represented by the number of parts of the designs that the examinee reproduces correctly. Scores for each of VR I and VR II range from 0-41. A savings score (VRSAV) was calculated by dividing the VR II score by the VR I score.

Wechsler Intelligence Scale for Children – III (WISC-III): Vocabulary subtest.

The WISC-III (Wechsler, 1991) Vocabulary subtest requires examinees to define aurally presented words. A maximum of thirty words is presented, in increasing order of difficulty. Start points vary according to age and the discontinuation criteria is four consecutive, zero point responses. Scoring criteria range from 0-2 for each word and are outlined in the WISC-III manual (Wechsler, 1991). Of all the WISC-III subsets, Vocabulary has the highest test-retest reliability coefficient, $r = .89$ (Wechsler, 1991). Vocabulary also correlates more highly with Verbal IQ, $r = .87$ and Full scale IQ $r = .79$, than any other subtest on the WISC-III.

Results

Table 2 lists the average raw scores for each group (control ASV, control AS and the patients) on the dependent variables (LM I, LM II, LMSAV, VR I, VR II, and VRSAV), the F ratio values and effect sizes. The following formula was used to calculate effect sizes for each index: (*M* of patient – *M* of control group ASV or AS/*SD* of control group ASV or AS). Cohen's (1992) classification system was used to define effect sizes. That is, small, medium and large effect sizes are defined respectively as .20, .50, and .80.

A MANOVA with an alpha level of .05 demonstrated significant differences among the groups on the WMS-R indices, Wilks' lambda, $F\,(12, 152) = 2.75, p = .002$. Examination of the univariate ANOVAs revealed significant group differences for LM II, LMSAV, VR I, VR II, and VRSAV at an alpha level of .05. Comparisons using the Bonferoni procedure indicated that the ASV control group performed significantly higher than the patients on LM II, LMSAV,VR II, and VRSAV. Group differences on VR I were approaching statistical significance, $p = .06$. The AS matched control group performed better than the patients on LM II, LMSAV, VR I and VR II. The ASV control group performed better than the AS control group on VRSAV.

Two direct discriminant function analyses (dfa) were performed using LM II, LMSAV, VR I, VR II, and VRSAV as predictors of group membership. LM I was not included in any of the analyses because it produced a non-significant univariate *F* ratio. The first dfa examined control ASV versus the patients and the second examined, control AS versus the patients. Results of the first discriminant function contained in Table 3, indicated a combined X^2 (5) = 15.82 $p = .007$. The loading matrix of correlations between predictors and the discriminant function is also presented in Table 3. Hotelling's (1940) t-test revealed that VR II was more highly correlated (.88) with the discriminant function than was the next best discriminator, VR savings (.78), $T^2(53) = 2.40, p < .05$. Pooled within-group correlations among the five predictors are also shown in Table 3. In terms of classification, using the total sample of 56 persons, 41 (73%) were correctly classified.

Results of the second dfa (Table 4) indicated a combined X^2 (4) = 12.67, $p < .05$. This analysis suggested that LM II was the best discriminator between the patients and control group AS. However, examination of the correlations between predictors and the discriminant function, using Hotelling's (1940) t-test, suggested that LM II was no more highly correlated with the discriminant function than was the next best discriminator, LMSAV, T^2 (53) = .28, ns. In fact, LM II did not show a stronger association with the discriminant function than did any of the other variables included in the analysis. Pooled within-group correlations among the four predictors are also shown in Table 4. In terms of classification, using the total sample of 56 people, 41 (73%) were correctly classified.

Discussion

In general, the results of this study support the hypothesis that youth with moderate to severe traumatic brain injury would perform worse on the WMS-R LM and VR subtests. Consistent with Bassett and Slater's (1990) findings with severe TBI adolescents, statistically significant differences were found between controls and patients on the same variables, with the exception of LM I for which the difference between the groups was only approaching significance. In addition, effect sizes for all variables included in the analyses (i.e. LM I, LM II, LMSAV, VR I, VR II, and VRSAV), exceeded .50, indicating at least a medium difference between the means of the control and patient groups.

In an effort to address the issue of whether performance on LM and VR is independent of WISC-III Vocabulary, the best predictor of verbal intelligence or IQ in general (Wechsler, 1991), two control groups were utilized in this study. Earlier work (Curry, Logue, & Butler, 1986) established a relationship between scores on LM I, LM II, VR I and performance on the Peabody Picture Vocabulary Test (Dunn, 1959) in male, but not female children and adolescents. Paniak et al. (1998) described a generally stronger relationship between LM performance and WISC-III Vocabulary scores than VR and WISC-III Vocabulary in normals, aged 9-15 years. In the same study, savings scores for both LM and VR were essentially unrelated to WISC-III Vocabulary performance (Paniak et al., 1998).

The results of the current investigation suggest that the scores from LM tap something more than verbal or general intelligence. The TBI patients performed worse than controls on LM II and LM savings, regardless of whether they were matched on Vocabulary. Furthermore, no differences in the LM II, or LM savings scores were identified between the two control groups in this study, although they differed significantly on Vocabulary. The relationship of impaired performance on the immediate trial of LM with Vocabulary was less definitive.

Patients in this study also performed worse than both control groups on the delayed trial of VR, supporting the presence of deficits in delayed visual constructional memory in the TBI patients, irrespective of Vocabulary. VR savings scores produced rather unexpected results. The ASV group performed significantly better than both the patients and the AS control group on VRSAV. Although the difference in performance on the VR savings variable, at first glance, may appear somewhat confusing, in keeping with previous studies, it supports that, indeed, performance on VRSAV appears to be independent of Vocabulary (MacDonald, 2002; Paniak et al., 1998). That is, the ASV group performed better than brain injured individuals who obtained similar WISC-III Vocabulary scores, and better than control group AS who obtained statistically higher Vocabulary scaled scores. The relationship of VR I performance to predicted verbal or general intelligence requires further study.

Contrary to predictions, VR and LM savings scores were not the best discriminators between the control groups and the patients. Although savings scores have been shown to be particularly sensitive to Alzheimer's disease as compared to Huntington's (Troster et al., 1993), they do not appear to have the same utility with traumatically brain injured children and adolescents. Failure to find consistently better discrimination, using savings scores as compared to immediate or delayed scores on LM and VR, underscores the diffuse nature of traumatic brain injury. Unlike Alzheimer's disease, forgetting rates do not appear to be a particularly distinguishing feature of TBI over simple difficulties with delayed retrieval. However, it is also noteworthy that in the present investigation, information regarding specific neuroimaging results was not examined. Patients were selected based on initial GCS or PTA scores and neither the presence nor severity of lesions were identified. Future researchers may wish to examine the sensitivity of VR, LM, and their savings scores with lateralized brain injury samples.

Several points pertaining to the design of this study are important to mention. First, given the relatively small sample size utilized, the generalization of results may be limited. Second, although patients with a previous documented learning disability or Attention Deficit Hyperactivity Disorder (ADHD) were excluded from participation, controls were excluded only if they had been hospitalized for these difficulties. The possibility of children with ADHD and/or learning disabilities participating as controls, reduces the sensitivity of this study. However, despite this limitation, the results of this investigation do, in general, support the sensitivity of LM and VR to memory deficits subsequent to moderate to severe traumatic brain injury in children and adolescents.

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Table 1

Descriptive Statistics and Performance of Participants on WISC-III Vocabulary

Variable	Patients	ASV	AS
	M(*SD*)	*M*(*SD*)	*M*(*SD*)
Vocabulary	8.68 (2.41)	9.00 (1.98)	11.36 (1.87)
Age (years)	12.95 (2.01)	12.54 (3.04)	12.89 (1.96)
Gender	13 females	13 females	13 females

Note. Vocabulary: Wechsler Intelligence Scale for Children – Third Edition (WISC-III) Vocabulary scaled score; Age: listed in years; ASV: age/sex/WISC-III Vocabulary score matched control group; AS: age/sex matched control group.

n = 28 for each patient and control group.

Table 2

Means, Standard Deviations, F Values and Effect Sizes for Logical Memory and Visual Reproduction for Patients and Controls

Variable	Patients *M(SD)*	ASV *M(SD)*	AS *M(SD)*	*F* (df)	Effect Size ASV/AS
LM I	21.14 (7.58)	25.00 (7.20)	24.82 (7.09)	2.49 (2, 80)	- .54/-.52
LM II	16.64 (8.72)	21.64 (7.15)	22.68 (7.33)	4.83* (2, 80)	- .70/-.82
LMSAV	77.18 (22.45)	85.98 (11.19)	90.39 (11.81)	4.94* (2, 80)	-.79/-.1.12
VR I	30.61 (5.41)	32.89 (3.80)	33.96 (4.01)	4.13* (2,80)	-.60/-.84
VR II	24.50 (7.74)	31.29 (5.15)	29.46 (5.82)	8.61* (2,80)	-1.32/-.85
VRSAV	79.25 (20.61)	94.67 (11.55)	85.92 (9.67)	7.71* (2,80)	-1.33/-.69

Note. ASV: age/sex/Vocabulary matched control group; AS: age/sex matched control group; LM I: Logical Memory immediate recall raw score; LM II: Logical Memory delayed recall raw score; LMSAV: % of information recalled from LM I to LM II; VR I: Visual Reproduction immediate recall raw score; VR II: Visual Reproduction delayed recall raw score; VRSAV: % of information recalled from VR I to VR II.

$n = 28$ for each patient and control group

$^{*}p < .05$

Table 3

Direct Discriminant Function for Control Group ASV and the Patients on Logical Memory and Visual Reproduction

Predictor variable	Correlations of predictor variables with dfa	Univariate *F* (1, 54)
LM II	.53	5.50
LMSAV	.42	3.44
VR I	.42	3.34
VR II	.88	14.92
VRSAV	.78	11.93
Canonical *R*	.51	

Pooled within-group correlations among predictors

Predictor Variable	LM II	LMSAV	VR I	VR II	VRSAV
LM II	1.00	.60	.17	.25	.25
LMSAV		1.00	-.12	.16	.36
VR I			1.00	.68	.09
VR II				1.00	.77
VRSAV					1.00

Note. LM II: Logical Memory thirty minute delay trial; LMSAV: % of raw score units recalled from Logical Memory immediate to delayed trial; VR I: Visual Reproduction immediate delay; VR II: Visual Reproduction thirty minute delay trial; VRSAV: % of raw score units recalled from Visual Reproduction immediate to delayed trial; AS: age/sex/WISC – III Vocabulary matched control group.

n = 28 for each patient and control group.

Table 4

Direct Discriminant Function for Control Group AS and the Patients on Logical Memory and Visual Reproduction

Predictor Variables	Correlation's of predictor variables with dfa	Univariate F (1, 54)
LM II	.65	7.85
LM SAV	.64	7.59
VR I	.61	6.96
VR II	.63	7.36
Canonical R	.51	

Pooled within-group correlations among predictors

Predictor Variable	LM II	LM SAV	VR I	VR II
LM II	1.00	.63	.36	.49
LM SAV		1.00	-.02	.20
VR I			1.00	.76
VR II				1.00

Note. LM II: Logical Memory thirty minute delay trial; LMSAV: % of raw score units retained from Logical Memory immediate to delayed trial; VR I: Visual Reproduction immediate delay; VR II: Visual Reproduction thirty minute delay trial; VRSAV: % of raw score units retained from Visual Reproduction immediate to delayed trial; AS: age/sex matched control group.

n = 28 for each group.

Chapter 5

Clinical Utility of the Consonant Trigrams Test in Youth with Moderate to Severe Traumatic Brain Injury

Clinical Utility of the Consonant Trigrams Test in Youth with Moderate to Severe Traumatic Brain Injury

Following traumatic brain injury (TBI), deficiencies in attention are frequently reported (Gronwall, 1987; Pennington, Bennetto, McAleer, & Roberts, 1996; Van Zomeren & Van Den Burg, 1985). Indicators of these difficulties may be observed during simple tasks, focused and sustained activities, and situations in which divided attention, the ability to concentrate on two stimuli at the same time, is necessary. However, deficits in one aspect of attention do not warrant an assumption that exhaustive deficits in this domain exist. For instance, Anderson, Fenwick, Manly, and Robertson (1998) offered that children, aged 8 to 14 years, with moderate to severe TBI, tested a minimum of two years post-injury, demonstrated generally preserved focused attention abilities, despite exhibiting deficiencies in sustained and divided attention. Anderson et al. (1998) posited that focused attention may have remained intact in their TBI group because these skills are better developed in middle-childhood, and therefore are less vulnerable to cerebral disruption than are sustained and divided attention skills. Even in adult survivors of TBI, studies examining various types of attention have been somewhat inconclusive, particularly regarding the concept of divided attention (Park, Mosscovitch, & Robertson, 1999). Recently, Park et al. (1999) conducted a meta-analysis of studies examining divided attention and found that adult TBI survivors are impaired on such tasks, if the tasks place demands on working memory. That is, if the tasks require the person to use and remember previously stored information. However, TBI patients were not impaired on tasks of divided attention that involved perceptual or motor demands, if the tasks did not place demands on working memory; that is, when the task could be completed more or less automatically.

The Brown-Peterson Auditory Short-Term Memory Task (Consonant Trigrams Test: CTT) is a commonly employed measure for assessing divided auditory attention and working memory capacity in adults (Brown, 1958; Butler, Retzlaff, & Vanderploeg, 1991; Peterson, & Peterson, 1959). The intent of the present study was to examine its sensitivity to divided attention/working memory difficulties in a paediatric sample. The CTT is a relatively efficient test to administer and has established sensitivity to working memory difficulties associated with various conditions. In work conducted by Stuss et al. (1985), the CTT total score discriminated between adult TBI patients diagnosed with varying degrees of initial injury severity, who were later identified as having good recoveries, and normal controls. The patients were classified as having good recoveries based on the Glasgow Outcome Scale, and the mean interval between injury and testing was 2.6 years (Stuss et al, 1985). Likewise, Stuss, Stethem, Hugenholtz, and Richard (1989) found that patients classified as having “more severe chronic” TBIs, tested within three years of injury, performed significantly worse than normal controls and “mildly concussed” patients on the CTT. Length of post-traumatic amnesia was inversely related to performance on the CTT and among three tests of attention, working memory and information processing, the CTT was the only one that distinguished between controls and “mildly concussed” patients (Stuss et al., 1989). Deficits on the CTT have also been identified in adults with Alzheimer’s disease, Korsakoffs, and anterior communicating artery aneurysms (Cermak & Butters, 1972; Dannenbaum, Parkinson, & Inman, 1988; Parkin, Leng, Stanhope, & Smith, 1988).

In keeping with the effort to develop clinically useful tools to assess cognitive functioning in children, a child version of the CTT was recently developed (Paniak, Miller, Murphy, Andrews, & Flynn, 1997). To date, no empirical studies have been published that examine the sensitivity of this version to attentional/working memory deficits frequently associated with children and adolescents subsequent to TBI. The purpose of the present study was to investigate the CTT's sensitivity to divided auditory attention/working memory deficits in a paediatric sample, aged 9-15 years, with moderate to severe TBI. A goal of the study was to examine whether children and adolescents with moderate to severe TBI perform like or unlike adults with similar injury severity. The following a priori hypothesis was addressed: TBI patients were expected to perform worse than matched controls on the 3", 9", and 18" delays.

Method

Sample and Procedure

Participants were 29 patients who suffered moderate to severe blunt brain injuries and 58 non-injured controls, comprising 2 groups of 29 student volunteers each.

The TBI participants included both inpatients and outpatients at the Glenrose Rehabilitation Hospital in Edmonton, Alberta, Canada. Specific inclusion criteria for the patients were as follows: (a) brain injury producing either a moderate TBI score [Glasgow coma scale (GCS) of 9-12] upon hospital admission or a severe TBI [GCS of 3-8 upon hospital admission], (b) Post traumatic amnesia (PTA) over 24 hours, (c) English must have been the main language used in the home, (d) no history of hospitalization due to behavior difficulties or previous documented brain injury, and (e) no history of diagnosed learning disorder or Attention Deficit Hyperactivity Disorder

(ADHD). CT scan and MRI reports were inconsistently available and therefore were not considered in the analysis. All TBI patients were tested within one year of their injuries. The mechanism of injury involved motor vehicle accidents for 22/25 patients; one patient was injured on a bicycle and two in sporting accidents. No participant had aphasia that significantly affected CTT performance.

To be eligible for participation in the study, the controls must have met the following criteria: (a) English must have been the main language used at home, and (b) no history of hospitalization due to psychiatric concerns or documented brain injury. Children were not excluded from the group if diagnosed with Attention Deficit Hyperactivity Disorder or learning disability unless they had been hospitalized for treatment of this disorder.

Control group ASV was matched with the TBI patients based on age, sex and scaled Vocabulary score on the Wechsler Intelligence Scale for Children – Third Edition (WISC-III). Control group AS was matched according to age and sex, the two factors typically utilized for matching in research studies. Two control groups were used in this study to explore whether auditory attention/working memory deficits were independent of basic Vocabulary deficits. Controls were obtained from the CTT normative data (Paniak et al., 1996). They were selected in sequential order from the database and matched individually with the patients. Vocabulary score differences between the patients and control group ASV were from plus or minus zero to three scaled score points. Test age differences between control group ASV and the patients were from plus or minus zero to nine months. Test age differences between patients and control group AS were from plus or minus zero to eight months. The mean WISC-III Vocabulary scaled scores, test ages and a gender breakdown for the sample are presented in Table 1. Overall, there was no significant difference in the mean Vocabulary score between control group ASV and the TBI patients. Control group AS had an average Vocabulary score that differed from control group ASV and the TBI group. There was no significant difference in mean test ages between the groups.

All of the participants were seen individually and the CTT was administered as part of a larger neuropsychological test battery.

Measures

Brown-Peterson Auditory Short-Term Memory Task.

The Brown-Peterson Auditory Short Term Memory Task (Consonant Trigrams Test – CTT) was proposed as a test of auditory short term memory (Brown, 1958; Peterson & Peterson, 1959). Administration of the CTT involves the presentation of three consonants followed by a number. In the adult version, examinees are required to count backwards by three's for a specified time period and then they are requested to recall the consonants. Time period delays for adults usually range from 0 to 36 seconds. In the children's version, children count backwards by one's and the delay periods are 0, 3, 9, and 18 seconds. To accommodate for their young age, the examinees are also only presented with two digit numbers as start points for counting backwards. Five trials at each delay interval are administered for a total of 15 trials. Scores for each delay interval (i.e. 0", 3"," 9", & 18") may range from 0 to 15 and represent the number of consonants recalled. A total score ranging from 0 to 45 is also calculated. The 0" delays are administered as practice items and are not included in the total score.

Wechsler Intelligence Scale for Children – III (WISC-III): Vocabulary subtest.

The WISC-III (Wechsler, 1991) Vocabulary subtest requires examinees to define aurally presented words. A maximum of thirty words are presented, in increasing order of difficulty. Start points vary according to age and the discontinuation criteria is four consecutive, zero point responses. Scoring criteria range from 0-2 for each word and are outlined in the WISC-III manual (Wechsler, 1991). Of all the WISC-III subsets, Vocabulary has the highest test-retest reliability coefficient, $r = .89$ (Wechsler, 1991). Vocabulary also correlates more highly with Verbal IQ, $r = .87$ and Full scale IQ $r = .79$, than any other subtest on the WISC-III.

Results

Table 2 lists the average raw scores for each group on the CTT indices, F ratios, and effect sizes. A multivariate analysis of variance was used to compare group performances on the CTT variables. Group had three levels: control group ASV, control group AS and the TBI patients. Results indicated a significant main effect of group (TBI/controls) for the CTT variables, Wilks' Lambda, $F\,(6, 140) = 2.29$ $p < .05$. Using the Hummel and Sligo (1971) two-stage significance-testing procedure, inspection of the univariate statistics revealed that the effect of group was significant for the 3" and 9" delays but not for the 18" delay, using $p < .05$. Post-hoc Bonferroni comparisons indicated a significant difference in performance on the 3" and 9" delays for control group ASV versus the TBI patients and control group AS versus the TBI patients. No significant differences were found between the control groups on the CTT delays. Therefore, the effect sizes presented in Table 2 reflect the average effect sizes for the ASV group versus the TBI patients and the AS group versus the TBI patients for each

CTT delay. Cohen's (1992) classification system was used to define effect sizes. That is, small, medium and large effect sizes are defined respectively as .20, .50, and .80.

Discussion

Consistent with the adult literature (Stuss et al., 1985; Stuss et al., 1989) and predictions of this study, children and adolescents with sustained moderate to severe TBI generally exhibited divided auditory attention/working memory deficits on the CTT, compared to controls. Examination of individual delay scores suggests that the shorter CTT delays (i.e. 3" and 9") were sensitive to these deficits but the 18" delay was not. One possible explanation for this finding is that the lengthiest delay on the child version of the CTT was simply too difficult for even the normal controls, resulting in a floor effect.

Two control groups were utilized in effort to isolate divided auditory attention/working memory deficits from basic vocabulary deficits. The results revealed impaired performance on the 3" and 9" delays for the TBI patients, compared to controls matched for age, sex, and WISC-III Vocabulary scaled score and compared to controls matched by only age and sex. These findings suggest that deficits in divided auditory attention/working memory exist following moderate to severe TBI in youth, and they appear to be independent of basic vocabulary deficits.

In summary, the results of this study suggest that the CTT appears to be generally sensitive to divided attention/working memory deficits in youth with moderate to severe TBI. However, performance of youth on the 18-second delay of the CTT should be interpreted with caution until further investigations, utilizing larger samples, are undertaken regarding the sensitivity and validity of this delay. Additionally, future research should examine whether young survivors of TBI are also impaired during divided attention tasks that rely more or less on automatic responses, with few working memory demands.

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Table 1

Demographic Features of the Patient and Control Groups

Variable	TBI patients ($n = 25$)	Control ASV ($n = 25$)	Control AS ($n = 25$)
Vocabulary	8.52	8.92	11.12
Test age	13 years	12.91 years	12.94 years
Number of females	12	12	12

Note. Vocabulary refers to the WISC – III Vocabulary scaled score.

Table 2

Means, Standard Deviations, F Values, and Effect Sizes for CTT Delay Scores

CTT	TBI *M(SD)*	ASV *M(SD)*	Control AS *M(SD)*	*F* (*df*)	Effect Size[a]
3" Delay	9.56 (3.03)	11.48 (2.28)	11.76 (2.20)	5.60** (2, 72)	-.92
9" Delay	7.12 (2.82)	9.00 (3.00)	9.40 (3.14)	4.15* (2, 72)	-.68
18" Delay	7.04 (2.69)	7.96 (2.95)	7.88 (3.26)	.73 (2, 72)	-.29

Note. TBI = traumatic brain injury group; ASV = matched control group based on age, sex and Wechsler Intelligence Scale for Children Vocabulary scaled score; AS = matched control group based on age and sex.

n = 25 for each group.

[a] Represents an average score based on effect sizes for control ASV versus the patients and control AS versus the patients for each CTT delay.

**p* < .05. ***p* < .01.

Chapter 6

Clinical Utility of the Continuous Visual Memory Test in Youth with Moderate to Severe Traumatic Brain Injury

Clinical Utility of the Continuous Visual Memory Test in Children and Adolescents with Moderate to Severe Traumatic Brain Injury

Over the last several decades there has been rapid growth within the field of child neuropsychology, likely stimulated in part by the realization that children, like adults, may exhibit significant cognitive and longstanding impairments subsequent to traumatic brain injury (TBI). Impairments in memory are a frequent concern and while deficits on tasks of verbal memory have been reported (Levin, Eisenberg, Wigg, & Kobayashi, 1982; Shum, Jamieson, Bahr, & Wallace, 1999), relatively few studies have been dedicated to examining visual memory performance after paediatric TBI.

A number of measures have recently been developed to assess visual memory. Among these instruments is the Continuous Visual Memory Test (CVMT; Trahan & Larrabee, 1988) which is a measure that was originally designed for adults and later normed for children and adolescents (Miller, Murphy, Paniak, LaBonte, & Spackman, 1996a; Ullman, Mckee, Campbell, Larrabee, & Trahan, 1991). The CVMT is proposed as a measure of visual acquisition (learning) and delayed visual recognition memory. Its design avoids some limitations of other visual memory measures by including abstract visual designs rather than pictures that can be verbally encoded. It also utilizes a delayed recognition trial, rather than delayed reproduction, avoiding constructional confounds. Finally, a visual discrimination task completed after the delayed recognition trial evaluates whether the examinee's discrimination abilities are adequate for testing.

As noted above, the CVMT employs a delayed visual recognition trial. Results on this trial are relatively independent of intellectual ability in normals (Larrabee, Trahan, & Curtiss, 1992). The acquisition trials of the CVMT showed modest associations with both verbal intellectual and attentional factors (Larrabee, Trahan, & Curtiss, 1992). In a mixed patient group, Larrabee and Curtiss (1995) demonstrated that the CVMT acquisition and delayed scores loaded separately in a factor analytic study from basic vocabulary, suggesting independence of these abilities.

The CVMT has demonstrated sensitivity to memory deficits associated with various conditions in adults. Trahan (as cited in Trahan & Larrabee, 1988) reported that the CVMT Total Score and d' (both measures of learning), and the delayed recognition score distinguished normal adults from those with closed head injuries, Alzheimers, and amnestic disorders. Stein and Sullivan (1992) reported that a TBI sample performed significantly different than the CVMT normative sample on the Total score, Hits, False Alarms and the Delay score. Trahan, Larrabee, and Quintana (1990) hypothesized that patients with right-hemisphere cerebral vascular accidents (RCVA) would perform more poorly on the CVMT than those with left-hemisphere cerebral vascular accidents (LCVA). Their results showed that the RCVA group performed worse than the LCVA group on the Total score, d', and Delay score; differences in their performance on Hits and False Alarms did not reach statistical significance. Trahan, Larrabee, & Quintana (1990) also found that their RCVA group performed worse than controls on Hits, Total score, d', and the Delay score. The RCVA group also made significantly more false alarms than did controls.

At the current time, there are no published studies examining the sensitivity of the CVMT to memory deficits in children and adolescents. The purpose of the current study was to examine its sensitivity to visual recognition learning and memory deficits with youth, aged 9-15 years subsequent to moderate to severe TBI. Two control groups were utilized in the study, one matched by age, sex and Vocabulary score (ASV) on the Wechsler Intelligence Scale for Children – Third Edition (WISC-III: Wechsler, 1991) and the other based on age and sex (AS), to explore whether visual memory deficits would be independent of basic vocabulary skills. The following a priori hypothesis was addressed: Based on previous research (Stein & Sullivan, 1992), TBI patients were expected to perform worse than controls on the Delay score, Hits, False Alarms, Total, and d' scores.

Method

Participants and Procedure

Clinical study sample.

Participants were 27 patients who suffered moderate to severe blunt brain injuries and 54 non-injured controls, comprising 2 groups of 27 student volunteers each.

The TBI participants included both inpatients and outpatients at the Glenrose Rehabilitation Hospital in Edmonton, Alberta, Canada. Specific inclusion criteria were as follows: (a) brain injury producing either a moderate TBI score [Glasgow coma scale (GCS) of 9-12] upon hospital admission or a severe TBI [GCS of 3-8 upon hospital admission], (b) Post traumatic amnesia (PTA) over 24 hours, (c) English must have been the main language used in the home, (d) no history of hospitalization due to behavior difficulties or previous documented brain injury, and (e) no history of diagnosed learning disorder or Attention Deficit Hyperactivity Disorder (ADHD). CT scan and MRI reports were inconsistently available and therefore were not considered in the analysis. All TBI patients were tested within thirteen months of injury. The mechanism of injury involved motor vehicle accidents for 24/27 patients; one patient was injured on a bicycle and two in sporting accidents.

To be eligible for participation in the study, the controls must have met the following criteria: (a) English must have been the main language used at home, and (b) no history of hospitalization due to psychiatric concerns or documented brain injury. Children were not excluded from the group if diagnosed with Attention Deficit Hyperactivity Disorder or learning disability unless they had been hospitalized for treatment of this disorder.

Control group ASV was matched with the TBI patients based on age, sex and scaled Vocabulary score on the Wechsler Intelligence Scale for Children – Third Edition (WISC-III: Wechsler, 1991). Control group AS was matched according to age and sex, the two factors typically utilized for matching in research studies. Two control groups were used in this study to explore whether visual learning and memory deficits were independent of basic vocabulary deficits. Control participants were obtained from the CVMT normative data (Miller, Murphy, Paniak, Labonte, & Spackman, 1996b). They were selected in sequential order from the database and matched individually with the patients. Vocabulary score differences between the patients and control group ASV ranged from plus or minus zero to three scaled score points. Test age differences between control group ASV and the patients ranged from plus or minus zero to seven months. Test age differences between patients and control group AS ranged from plus or minus zero to eight months. The mean WISC-III scaled Vocabulary scores for the TBI patients and control groups ASV and AS were respectively, 8.48, 8.85, and 11.26. Overall, there was no significant difference in the mean Vocabulary score between control group ASV and the TBI patients. Control group AS had an average Vocabulary score that differed from control group ASV and the TBI group. There were 13 females and 14 males in each group.

All of the control participants were seen individually and the CVMT was administered as part of a larger neuropsychological test battery. All participants included in the study obtained full credit on the visual discrimination task on the CVMT.

Normative sample.

Participants were 716 children aged 9 to 15 years who were recruited from Edmonton Public Schools as part of a larger normative data study (Miller et al., 1996b). Consent was first obtained from Edmonton Public Schools, followed by a request for parental consent. Children for whom parental consent was obtained were selected to participate if they passed a screening. To be eligible for participation in the study the children must have met the following criteria: (a) English must have been the main language used at home, (b) regular education placement with no history of learning difficulties and/or special education services due to a major psychiatric disorder or a documented brain injury, and (c) no history of hospitalization due to behavior difficulties or brain injury. Children were not excluded from the study if diagnosed with Attention Deficit Hyperactivity disorder unless they had been hospitalized for treatment of this disorder.

Participants ranged in age from 9 to 15 years. 710 participants were included out of the 716 included in the initial database. Six participants were excluded due to missing data or to outlying scores that may skew the data. In total, there were 385 females and 325 males. The number of participants in age contingents were: 9 yrs, n = 79; 10 yrs, n = 140; 11 yrs, n = 130; 12 yrs, n = 122; 13 yrs, n = 96; 14 yrs, n = 115; 15 yrs, n = 28. The scores of these participants on the CVMT were examined in a post-hoc manner to determine the relationship of test age with CVMT performance.

Materials

Continuous Visual Memory Test.

The CVMT is a test that purports to measure both acquisition and delayed recognition of visual memory for abstract designs (Trahan & Larrabee, 1988). The test begins with the presentation of 112 complex designs. As each design is presented, the examinee is asked to identify whether it is "new" (first time seen), or "old" (seen before in the series). Following a thirty minute delay, a recognition task is administered in which the examinee is presented with seven designs. Six of the designs have been seen only once before and one of the designs was presented seven times during the acquisition phase. The task of the examinee is to identify which design was presented repeatedly. Seven trials are administered during the delayed recognition phase. The final task involves a visual discrimination test in which the examinee is presented with two cards, one with a single design on it and one with seven small designs. The task of the examinee is to identify which of the designs on the multiple card matches the card with the single design. Seven trials are administered during this component and the goal of this task is to help differentiate between visual discrimination versus visual memory difficulties (Trahan & Larrabee, 1988).

Six different scores can be derived from the CVMT: (1) Hits (the number of old items that the examinee identified correctly in the acquisition phase), (2) False alarms (the number of new designs misidentified as old), (3) d-Prime (d': Hits minus False Alarms in z-scores), (4) Total (the number of correctly identified old and new designs),

(5) Delayed Recognition (the number of correct responses on this task), and (6) Visual Discrimination (the number of correct response on this task). It is noteworthy that although 112 design cards are shown, only items 17-112 (total of 96) are used for computing the acquisition scores (i.e. Hits, False Alarms, d', & Total Score). Hits may range from 0-42 and False Alarms from 0-54. Possible scores for Delayed Recognition and visual Discrimination both range from 0-7. The Total score can range from 0-96 and d' is presented in *z*-scores.

Wechsler Intelligence Scale for Children – III (WISC-III): Vocabulary subtest.

The WISC-III (Wechsler, 1991) Vocabulary subtest requires examinees to define aurally presented words. A maximum of thirty words are presented, in increasing order of difficulty. Start points vary according to age and the discontinuation criteria is four consecutive, zero point responses. Scoring criteria range from 0-2 for each word and are outlined in the WISC-III manual (Wechsler, 1991). Of all the WISC-III subsets, Vocabulary has the highest test-retest reliability coefficient, $r = .89$ (Wechsler, 1991). Vocabulary also correlates more highly with Verbal IQ, $r = .87$ and Full scale IQ $r = .79$, than any other subtest on the WISC-III.

Results

Table 1 lists the average raw scores for each group on the CVMT indices, *F* ratios, and effect sizes. The following formula was used to calculate effect sizes for each CVMT score (*M* of patient group – *M* of control group AS or ASV/*SD* of control group AS or ASV). A multivariate analysis of variance was used to compare group performances on the CVMT variables. Group had three levels: control ASV, control AS and the TBI patients. The results indicated a non-significant main effect of group

(TBI/controls) for the CVMT variables, Wilks's lambda, F (10, 148) = 1.40 p = .19. Inspection of the univariate statistics reveals results consistent with the multivariate test. There were no significant differences between group performances on Hits, Total, d', and the Delay score. There was a significant difference in performance between the groups on False Alarms, although interpretation of this result is improper in light of the non-significant multivariate result. Bonferroni comparisons indicated a significant difference between control group ASV and the patients on False Alarms but no differences between control AS and the patients. Differences between the two control groups on False Alarms variable did not reach statistical significance. Consistent with the results of the univariate analyses, the effect sizes for d', Hits, and the Delay score were small for control group ASV versus the patients and control group AS versus the patients (Cohen, 1992). The effect size for the Total score for control group AS versus the patients was also small. Medium effect sizes were demonstrated for Total score for the ASV group versus the patients and for False Alarms for both control groups versus the patients.

Discussion

In general, the results of this study did not provide support for the hypothesis that youth with moderate to severe traumatic brain injury would perform worse than matched controls on the CVMT acquisition and delayed recognition variables. These findings may be related to several factors. First, given that TBI is a unique and heterogeneous condition, it is possible that the injured individuals in the clinical sample, legitimately, may not have had difficulties with visual learning and visual recognition memory. This is at odds with published research from adult samples, but no published research has examined this issue, using the CVMT, with youth. It is possible that TBI in youth is not generally associated with impaired performance on the CVMT, in contrast to what has been reported with adults. It is also possible that previous null research with children and/or adults on the CVMT has simply not been published, due to a potential bias against publishing null findings. In any case, the present findings underscore the need to not generalize findings from adult samples to paediatric samples without empirical study and validation.

Although previous research has suggested that youth with TBI present with deficiencies in visual memory (Bassett & Slater, 1990; MacDonald, 2002), the studies employed measures where the risk of constructional deficits impacting visual memory performance was high. Using the CVMT, a measure that includes variables thought to be relatively "pure" measures of visual memory (i.e. Delay score), the presence of visual recognition memory difficulties within a young TBI group was not supported in this study.

Another possibility for the non-significant results is that the sample size in this study was too small to observe differences in performance between the patients and controls, thereby resulting in Type II error. However, this interpretation is not generally supported if one considers the generally small effect sizes, as listed in Table 1. In addition, although TBI patients with a previously documented learning disability or a diagnosis of Attention Deficit Hyperactivity Disorder were excluded from participation, controls were excluded only if they had been hospitalized for these difficulties. Thus, the possibility of children with ADHD or learning disabilities participating as controls, reduces the overall sensitivity of this investigation. That is, because such children might have performed worse than other controls, the differences between their CVMT scores and those of the TBI patients may have been reduced.

Due to the generally non-significant findings in this study, it was queried, post-hoc, that the CVMT may have been too easy or too difficult for youth, leading to floor or ceiling effects. To explore this hypothesis, the data in the clinical study was examined to determine whether the controls and patients were performing at the very high or the very low end of the possible range of scores. However, examination of the average performance of the groups (Table 1), does not support this conclusion. For example, the minimum and maximum scores on two of the most commonly used variables (i.e. Total and Delayed Recognition) are 0-96 and 0-7, respectively. The youth in this study did not perform at the extreme ranges of these scores.

To further explore the hypothesis that children and/or adolescents reach a ceiling or floor effect on the CVMT, the relationship of the CVMT scores with test age was examined in the original CVMT normative data (Miller et al., 1996b). Results of the correlational analyses regarding test age and the CVMT variables are presented in Table 2. The results indicate statistically significant relationships with test age and the CVMT variables, thereby discounting the hypothesis of ceiling or floor effects causing the generally non-significant findings in the present study. That is, if there was no correlation of test scores with age, one might speculate that the test was too hard or too easy for children.

Despite the promising design of the CVMT, the current study does not provide much support for its sensitivity to visual memory deficits in a heterogeneous TBI sample of children with moderate to severe injuries. However, there is a need for further research that examines the sensitivity of the CVMT to memory deficits, using larger sample sizes and perhaps a more homogenous sample of TBI patients. False alarms may be a variable that deserves further examination. Consistent with previous work with TBI adults using, the Continuous Recognition Task (Hannay, Levin, & Grossman, 1979), TBI patient performance in this study was characterized by a relatively high number of false alarms, conceivably suggesting that TBI patients are somewhat more disinhibited than normal controls in their responses on visual recognition memory tests.

However, the “bottom line” is that children and adolescents with moderate to severe TBI did not generally perform worse than matched controls on the CVMT. Thus, the CVMT should be used with caution in young TBI survivors, lest one erroneously conclude that an individual does not have a visual memory deficit, whereas the reason for this might be that the CVMT is not sensitive to visual memory deficits in such children.

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Table 1

Means, Standard Deviations, F Values for CVMT Scores

Variable	Patients *M(SD)*	Control ASV *M(SD)*	Control AS *M(SD)*	*F* (df)	Effect Size ASV/AS
Hits	35.55 (4.11)	34.41 (5.09)	34.37 (4.82)	0.56 (2, 79)	.23/.25
False Alarms	18.70 (8.35)	13.70 (6.56)	15.55 (6.44)	3.36* (2, 79)	-.76/-.49
Total	70.85 (7.91)	74.85 (7.91)	72.81 (9.22)	1.46 (2, 79)	-.51/-.21
d'	1.57 (0.54)	1.74 (0.69)	1.61 (0.70)	0.51 (2, 79)	-.25/-.05
Delay	4.00 (1.64)	4.59 (1.57)	4.44 (1.57)	0.01 (2, 79)	-.38/-.28

Note. ASV: age/sex/Vocabulary matched control group; AS: age/sex matched control group: Hits: the number of old items identified correctly during the acquisition phase; False Alarms: the number of new items incorrectly identified as old; Total: the total number of correct responses during the acquisition phase; d': the difference between z-scores for False Alarms and Hits; Delay: the total designs correctly identified on the delayed recognition task.

$n = 27$ for each group.

$^*p < .05$

Table 2

Bivariate Correlations for CVMT Variables and Test age

Variable	Test age
Hits	.44**
False Alarms	-.42**
Total	.55**
d-Prime	.55**
Delay	.43**

Note. Correlations of the CVMT variables with test age in months for normative participants ($n = 710$). Hits: the number of old items identified correctly during the acquisition phase; FA: the number of new items incorrectly identified as old; Total: the total number of correct responses during the acquisition phase; d-Prime: the difference between z-scores for False Alarms and Hits; Delay: the total designs correctly identified on the delayed recognition task.

**$p < .01$

Chapter 7

General Discussion and Conclusions

General Discussion and Conclusions

The purpose of this dissertation was twofold. First, to examine the construct validity of several tests of memory administered to two large community samples of youth aged, 9-12 years and 13-15 years. Second, the sensitivity of the same tests to memory deficits in clinical samples of children and adolescents who were patients at a local rehabilitation hospital, and who had suffered moderate to severe traumatic brain injuries (TBI), was studied. Examination of the results of the five studies raised a host of clinical and conceptual issues. In the discussion to follow, the role of assessment of memory following TBI in youth is briefly presented, followed by a review of the major findings of the component analyses and their implications for clinical practice. Then, the major findings of the four clinical studies are discussed, along with theoretical considerations and recommendations for future directed study. The results are considered in light of the theories of memory presented in the initial chapter of this dissertation. Nevertheless, any one specific model of memory will not solely guide interpretation of the results. The purpose of this dissertation was not to develop a model of memory functioning following TBI nor was it proposed to test a specific model of memory. Rather, this study was conducted with the goal of extending knowledge regarding memory functioning in normal and traumatically brain injured youth.

Why Test?

Problems with cognition and behavior are recognized as the most prevalent and significant consequences of TBI, often impacting an injured individual's adjustment more than do physical sequelae (Ewing-Cobbs et al., 1998; Levin, Ewing-Cobbs, & Eisenberg, 1995). Cognitive deficits, which may not be as readily observable as physical problems, often persist and can provide ongoing problems for injured youth in their attempts to reintegrate into the community (Braga & DaPax, 2002; Johnson, 1992). Among cognitive deficits, memory is frequently described as a significant problem subsequent to TBI (Dalby & Obrzut, 1991; Ewing-Cobbs et al., 1998). However, until recently, paediatric cognitive assessments after TBI were often quite limited, perhaps including a test of intelligence, an achievement test, a visual-motor integration test and possibly a language screen, along with a few other measures (Baron, 2000). In the last few decades, as more information has been gained through clinical practice and research regarding the effects of injury on the developing brain, an emphasis has been placed on more comprehensive evaluation of children's functioning. Within rehabilitation settings, assessment of memory now plays an important role in determining treatment recommendations and future educational planning following TBI. Evaluation of memory is a crucial part of assessment since appropriate strategies to enhance learning following TBI can only be implemented if a child's capacity to learn and recall information is well understood by educators.

Construct Validity Study

The results of this study provide information regarding the construct validity of the CVMT, CTT, SRP, and the LM and VR subtests of the WMS-R in two samples of youth, aged 9-12 and 13-15 years. Overall, the analyses suggest that a number of abilities that we may conceptualize as distinct (e.g. verbal versus visual memory, attention, and intelligence), may not be so. That is, abilities measured by the aforementioned measures overlap and/or are interrelated with other cognitive abilities, particularly in the younger group (age 9-12 years) examined in this study. In fact, in the younger group in this study, LM and SRP savings scores were the only measures that appeared to be relatively "pure" measures of memory. This finding reinforces the importance of comprehensive examination of a child's abilities prior to making diagnostic statements or treatment recommendations. Simply stated, just because a child demonstrates impaired performance on a particular task, such as VR II, this does not necessarily imply that the problems with cognition lay exclusively with visual memory. Rather, clinicians would be well advised to also examine whether attention or spatial abilities impacted the child's performance on the task.

In the adolescent group, several of the test scores, including SRP CLTR, SRP Delay, CVMT Total, CVMT Delay, CTT Total, VR I, VR II, and the VR, LM, and SRP savings scores were more closely associated with other memory tasks, than with measures of estimated verbal intelligence or visual reasoning. However, even in this age group, the SRP and LM savings scores appeared to be the most "pure" measures of their proposed modality, verbal memory.

Overall, the results also suggested that the constructs measured by the tests varied across the age groups. This finding is not particularly surprising, given that children and young adolescents are still developing in terms of their capacity to think and that even in adults, age related changes in memory constructs have been documented (Bornstein & Chelune, 1989). However, it is a reminder of the importance of not generalizing cognitive memory constructs from one age group to another. That is, the term "memory" may not reflect the same combination of cognitive processes in different age groups, perhaps because children at various stages of development rely on different strategies to learn and remember information.

Clinical Studies

The results of the four clinical studies included in this dissertation provide preliminary information regarding the sensitivity of the SRP, CVMT, CTT and the WMS-R LM and VR subtests. The findings indicate that the SRP, WMS-R LM and VR subtests and the CTT can impart clinically useful information regarding memory functioning in young TBI survivors. However, the CVMT did not generally identify memory deficits in the young TBI survivors, relative to controls, and its usefulness with this clinical and age group requires further study.

Several pertinent findings that extend previous research with young TBI survivors were evident in examining the performance of the patients and controls on the various verbal and visual memory tests. First, examination of performance on the verbal memory tests indicates that the TBI patients did not perform statistically worse than controls in their immediate recall of stories, although the difference in performance between controls and patients did reflect a moderate effect size. Consequently, immediate story recall requires further study. In addition, the patients performed worse than matched controls on the learning indices on the SRP and the delayed memory components of both LM and the SRP. Consistent with findings with adult survivors of TBI and the few studies examining verbal memory in youth after TBI (Basset & Slater, 1990; Levin, Eisenberg, Wigg, & Kobayashi, 1982; Paniak, Shore, & Rourke, 1989), the results suggest that the TBI patients had problems with consolidation, storage and retrieval of verbal information.

Examination of performance of patients and controls on the SRP also permits an evaluation of the effects of repetition of information on learning and memory.

Accordingly, it is noteworthy that despite the fact that the SRP administration involves repetition of all words from the list that were not recalled on the previous trial, the TBI patients still recalled generally fewer words than did matched controls. Overall, the deficient performance of the patients compared to controls challenges Atkinson and Shiffrin's (1968) contention that information is transferred from STM to LTM through rehearsal. That is, despite repetition of the word list, the injured youth did not perform at the rate of the matched controls in transferring information from STM to longer-term storage and subsequent retrieval. It is possible that repetition of the words by the examiner did not automatically lead to rehearsal of the words in the TBI group. However, this issue was not directly examined in this study. Given that in "normal" children, automatic subvocal rehearsal is believed to emerge by age seven years (Gathercole & Hitch, 1993), examination of the presence or absence of this process in brain injured youth may be worthy of investigation. Regardless though, it is clear that factors beyond rehearsal must be taken into account in understanding human learning and memory.

It is also noteworthy that the effect sizes for LM I and LM II were generally smaller than effect sizes for the SRP indices. This finding suggests that patients were better at recalling the LM stories relative to controls than the SRP word list. Craik and Lockhart's (1972) "depth of processing" theory may provide partial explanation for this finding. According to this theory, information can be processed at different levels, and the more deeply the information is processed, the better the recall. For example, a word may be processed based simply on the way it sounds; it could also be processed based on its meaning. Information processed at a semantic level is believed to be more deeply encoded than information based on sound. As such, LM imposes semantic meaning on the verbal material simply by virtue of the fact that the information to be remembered is presented in a story format. In contrast, the SRP administration requires the examinee to learn and recall a list of unrelated words. Thus, effect sizes may have been larger for the SRP compared to LM because the TBI patients may have had more difficulty than controls in organizing the SRP word list into something meaningful, thereby processing the information at a more shallow level on the SRP than LM. That is, the SRP appears to place more demands for organization and depth of processing on the examinee, relative to the LM subtest.

It is also possible that the effect sizes between patients and controls were larger on the SRP than LM because the controls simply benefited more from repetition of the word list than did the patients, leading to a larger spread between patients and controls on the SRP. In contrast, the LM stories are only presented on one occasion and there is no opportunity to determine to what extent repetition of the story information assists with storage or retrieval. The issue of the effect of repetition on learning and memory is important beyond a theoretical level. From an educational perspective, if brain injured youth do not benefit significantly from repeated exposure of material or if they do not benefit as much as normals from rehearsal, other avenues need to be considered to promote and assess academic achievement. For instance, it would be unfair to assess children's achievement based on their recall of information, if despite good study habits, they simply could not retrieve or demonstrate their knowledge.

In comparison to verbal memory in young TBI survivors, visual memory functioning is less well understood. In fact, the majority of visual memory tests available for youth can be verbally encoded and/or are confounded by other factors. This issue is of particular relevance in studying visual memory because there is a great deal of evidence that by approximately age seven years, children begin using verbal strategies to encode visual information, if the information can be encoded in this manner (Gathercole, 1998). Prior to this age, children are believed to rely on visual strategies to recall visual or spatial information.

In the current work, examination of the visual memory tests indicates that the TBI patients demonstrated deficits on VR but generally not on the CVMT, suggesting that the TBI patients demonstrated visual constructional memory deficits but not deficits with visual recognition memory. Several points are important to discuss in light of these findings. First, it is possible that TBI youth generally do not demonstrate problems with visual recognition memory, although this contradicts previous research with adult TBI survivors (Stein & Sullivan, 1990). It also contrasts previous research that has documented visual recognition memory problems in children with severe TBIs (Levin, Eisenberg, Wigg, and Kobayashi, 1982; Levin et al., 1988), albeit these studies used measures whose stimuli could be verbally encoded. Thus, it is difficult to confidently delineate whether the deficits on the visual recognition task were purely related to visual memory problems. Similarly, it is important to consider whether the deficient performance on the VR subtest of the TBI patients compared to controls, could be related to constructional problems or spatial deficits rather than problems with visual memory. Examination of savings scores may help sort out this issue. For example, if an examinee obtains a score of 22/41on VR I but 10 points were lost due to constructional problems, and then the examinee obtained 22/41 on VR II, he/she actually reproduced 100% of the material from the initial trial. Although, the score of 22/41 may fall in the impaired range, the savings score suggests intact visual memory abilities. Indeed, constructional problems may have produced the impaired scores on VR I and VR II. Likewise, it is also important to be aware of the risk of verbal encoding on VR complicating interpretation of the results. Finally, it is also conceivable that the CVMT simply is not a sensitive test to the type of visual recognition memory deficits exhibited in youth with moderate to severe TBI. The bottom line, though, is that normal performance on the CVMT should not automatically be considered to support the absence of visual recognition difficulties. Nor, should the presence of impaired performance on VR absolutely imply visual memory difficulties, unless constructional and spatial problems have first been considered.

Consistent with adult TBI research (Stuss et al., 1985; Stuss, Stethem, Hugenholtz, & Richard, 1989), the results of this study also suggest that young TBI survivors have difficulty with divided attention when the task places demands on working memory, as is indicated by their performance on the CTT. Future researchers may wish to determine why the controls performed better than the TBI patients on the 3 and 9, but not the 18-second delay. Are the demands on working memory for the 18-second delay at a developmental level that was too high for the age groups in this study? Were the controls able to rehearse the trigrams on the shorter delays whilst engaging in the distracter task or what other strategies did they use that made them more successful than the patients at these tasks?

In terms of implications for treatment, educators should be aware that divided attention activities that place demands on working memory, may be very difficult for a brain injured child. Further study is needed to determine what kinds of activities, when paired together, may negatively impact the brain injured child or adolescent's learning opportunities. Some tasks that may be perceived as automatic or simple for young people without brain injuries, may be very challenging for the traumatically brain injured youth.

As a final consideration, it is possible that observed differences in effect sizes in this study could be related, to some extent, to the minor variations in samples selected for study. Although the patient groups were relatively stable across studies, there were some minor variations in the samples. The TBI patients were seen primarily because of their need for clinical evaluation. All tests of interest in this study, therefore, were not necessarily administered. In addition, the SRP was administered only to adolescents while the other measures were administered to children as well as adolescents. This variation in administering the SRP limits comparisons between the SRP study and the findings of the other studies.

Concluding Remarks and Future Study

Overall, the results of this dissertation submit preliminary data regarding memory constructs assessed in normal children and adolescents using four well standardized and normed measures of various aspects of memory functioning. In addition, this is one of the first studies to consider the memory performance of young TBI survivors in comparison to controls matched for age, sex, and WISC-III Vocabulary ability (i.e., estimated intelligence). It also leads study into divided attention abilities after childhood TBI, using a task that places high demands on working memory, and is the first known study of visual recognition memory following TBI in youth, using the CVMT.

Future research should focus on obtaining more information, utilizing larger sample sizes, regarding the neurobehavioral effects of TBI in youth and the specific impact of deficits in memory on the development of academic and social abilities with this population. In addition, further information is required regarding the validity and reliability of the CVMT, SRP, CTT, and WMS-R LM and VR subtests in normal and brain injured youth. The reliability and validity of tests in different populations can vary, and clinicians should be particularly cautious about generalizing adult findings to younger samples. Clinicians should always bear in mind that knowing "how" to administer a test does not mean that they know "what" they are assessing. Knowledge regarding the validity and reliability of test measures in various populations is an essential part of assessment. In providing information to rehabilitation team members, injured youth and their families, it is an essential responsibility of Psychologists to provide detailed information that can be utilized to enhance the injured child's social and educational experiences. Conscientious testing and assessment of memory can provide information regarding capacities that may significantly impact daily life, but which, otherwise, may be difficult to pinpoint.

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